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UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
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P.O. Box 1450
Alexandria, Virginia 22313-1450
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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
14/518,868	10/20/2014	Martin Alles	AND01 083 CONT

CONFIRMATION NO. 6799

POWER OF ATTORNEY NOTICE

79172
Duane Morris LLP
505 9th Street, N.W.
Suite 1000
Washington, DC 20004

OC000000121344919

Date Mailed: 11/17/2020

NOTICE REGARDING CHANGE OF POWER OF ATTORNEY

This is in response to the Power of Attorney filed 11/09/2020.

- The Power of Attorney to you in this application has been revoked by the assignee who has intervened as provided by 37 CFR 3.71. Future correspondence will be mailed to the new address of record(37 CFR 1.33).

Questions about the contents of this notice and the requirements it sets forth should be directed to the Office of Data Management, Application Assistance Unit, at **(571) 272-4000** or **(571) 272-4200** or **1-888-786-0101**.

/dgela/

GOOGLE EXHIBIT 1002
Google v. Geoscope

UNITED STATES PATENT AND TRADEMARK OFFICE

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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
14/518,868	10/20/2014	Martin Alles	AND01 083 CONT

CONFIRMATION NO. 6799

135878
Fogg & Powers LLC/Commscope
4600 W 77th St
Suite 305
Minneapolis, MN 55435

POA ACCEPTANCE LETTER

OC000000121344931

Date Mailed: 11/17/2020

NOTICE OF ACCEPTANCE OF POWER OF ATTORNEY

This is in response to the Power of Attorney filed 11/09/2020.

The Power of Attorney in this application is accepted. Correspondence in this application will be mailed to the above address as provided by 37 CFR 1.33.

Questions about the contents of this notice and the requirements it sets forth should be directed to the Office of Data Management, Application Assistance Unit, at **(571) 272-4000** or **(571) 272-4200** or **1-888-786-0101**.

/dgela/

PTO/AIA/80 (07-12)
Approved for use through 11/30/2014. OMB 0651-0035
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

POWER OF ATTORNEY TO PROSECUTE APPLICATIONS BEFORE THE USPTO

I hereby revoke all previous powers of attorney given in the application identified in the attached statement under 37 CFR 3.73(c).

I hereby appoint:

[X] Practitioners associated with the Customer Number: 135878

OR

[ ] Practitioner(s) named below (if more than ten patent practitioners are to be named, then a customer number must be used):

Name Registration	Number		Name Registration	Number

As attorney(s) or agent(s) to represent the undersigned before the United States Patent and Trademark Office (USPTO) in connection with and all patent applications assigned only to the undersigned according to the USPTO assignment records or assignment documents attached to this form in accordance with 37 CFR 3.73©.

Please change the correspondence address for the application identified in the attached statement under 37 CFR 3.73© to:

[X] The address associated with Customer Number: 135878

OR

[ ] Firm or Individual Name			
Address			
City		State	Zip
Country			
Telephone		Email	

Assignee Name and Address:

CommScope Inc. of North Carolina
1100 CommScope Place SE
Hickory, NC 28602

A copy of this form, together with a statement under 37 CFR 3.73(c) (Form PTO/SB/96 or equivalent) is required to be filed in each application in which this form is used. The statement under 37 CFR 3.73(c) may be completed by one of the practitioners appointed in this form, and must identify the application in which this Power of Attorney is to be filed.

SIGNATURE of Assignee of Record
The individual whose signature and title is supplied below is authorized to act on the behalf of the assignee

Signature	Laura Thomas	Date	5/18/2016
Name	Laura Thomas	Telephone	
Title	Assistant Secretary		

This collection of information is required by 37 CFR 1.31, 1.32 and 1.33. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CRF 1.11 and 1.14. This collection is estimated to take 3 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

PTO/AIA/96 (08-12)
Approved for use through 01/31/2013. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

STATEMENT UNDER 37 CFR 3.73(c)

Applicant/Patent Owner: CommScope Inc. of North Carolina

Application No./Patent No.: 9,097,784 Filed/Issue Date: 2015-08-04

Titled: SYSTEM AND METHOD TO COLLECT AND MODIFY CALIBRATION DATA

CommScope Inc. of North Carolina, a Corporation

(Name of Assignee) (Type of Assignee, e.g., corporation, partnership, university, government agency, etc.)

states that, for the patent application/patent identified above, it is (choose **one** of options 1, 2, 3 or 4 below):

1. [x] The assignee of the entire right, title, and interest.

2. [ ] An assignee of less than the entire right, title, and interest (check applicable box):

   [ ] The extent (by percentage) of its ownership interest is _____%. Additional Statement(s) by the owners holding the balance of the interest must be submitted to account for 100% of the ownership interest.

   [ ] There are unspecified percentages of ownership. The other parties, including inventors, who together own the entire right, title and interest are:

   Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

3. [ ] The assignee of an undivided interest in the entirety (a complete assignment from one of the joint inventors was made). The other parties, including inventors, who together own the entire right, title, and interest are:

   Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

4. [ ] The recipient, via a court proceeding or the like (*e.g.*, bankruptcy, probate), of an undivided interest in the entirety (a complete transfer of ownership interest was made). The certified document(s) showing the transfer is attached.

The interest identified in option 1, 2 or 3 above (not option 4) is evidenced by either (choose **one** of options A or B below):

A. [ ] An assignment from the inventor(s) of the patent application/patent identified above. The assignment was recorded in the United States Patent and Trademark Office at Reel _____, Frame _____, or for which a copy thereof is attached.

B. [✓] A chain of title from the inventor(s), of the patent application/patent identified above, to the current assignee as follows:

1. From: Martin Alles, John Carlson, George Maher, Selcuk Mazlum To: CommScope, Inc. of North Carolina

   The document was recorded in the United States Patent and Trademark Office at

   Reel _____, Frame _____, or for which a copy thereof is attached.

2. From: _____ To: _____

   The document was recorded in the United States Patent and Trademark Office at

   Reel _____, Frame _____, or for which a copy thereof is attached.

This collection of information is required by 37 CFR 3.73(b). The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

STATEMENT UNDER 37 CFR 3.73(c)

3. From: _____ To: _____

The document was recorded in the United States Patent and Trademark Office at

Reel _____, Frame _____, or for which a copy thereof is attached.

4. From: _____ To: _____

The document was recorded in the United States Patent and Trademark Office at

Reel _____, Frame _____, or for which a copy thereof is attached.

5. From: _____ To: _____

The document was recorded in the United States Patent and Trademark Office at

Reel _____, Frame _____, or for which a copy thereof is attached.

6. From: _____ To: _____

The document was recorded in the United States Patent and Trademark Office at

Reel _____, Frame _____, or for which a copy thereof is attached.

☐ Additional documents in the chain of title are listed on a supplemental sheet(s).

☑ As required by 37 CFR 3.73(c)(1)(i), the documentary evidence of the chain of title from the original owner to the assignee was, or concurrently is being, submitted for recordation pursuant to 37 CFR 3.11.

[NOTE: A separate copy (i.e., a true copy of the original assignment document(s)) must be submitted to Assignment Division in accordance with 37 CFR Part 3, to record the assignment in the records of the USPTO. See MPEP 302.08]

The undersigned (whose title is supplied below) is authorized to act on behalf of the assignee.

/David N Fogg/	November 7, 2020
Signature	Date
David N. Fogg	35138
Printed or Typed Name	Title or Registration Number

[Page 2 of 2]

Privacy Act Statement

The **Privacy Act of 1974 (P.L. 93-579)** requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether disclosure of these records is required by the Freedom of Information Act.
2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.
3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.
4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).
5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.
6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (*i.e.*, GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspection or an issued patent.
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

ASSIGNMENT

Insert Name(s) of Inventor(s)

Martin ALLES
John CARLSON
George MAHER
Selcuk MAZLUM

In consideration for good and valuable considerations, the receipt of which is acknowledged by each of the undersigned, the undersigned agree(s) to assign, and hereby do(es) assign, transfer and set over to

Insert name of Assignee: CommScope, Inc. of North Carolina
Insert address of Assignee: 1100 CommScope Place SE
Hickory, North Carolina 28602

and its successors, legal representatives and assigns (hereinafter designated as the Assignee) the entire right, title and interest in the invention disclosed and/or claimed in the United States application identified below, as well as all applications for patent and any Letters Patent which may be granted therefore in the United States of America and all foreign countries, and in and to any and all divisions, continuations, continuations-in-part of said applications, or re-issues or extensions of said patents or Letters Patent, and all rights under the International Convention for the Protection of Industrial Property:

Insert Identification of: SYSTEM AND METHOD TO COLLECT AND MODIFY CALIBRATION DATA

Docket Number, or Foreign Application Number: Docket No. (AND01 083)

Insert date of signing of application: _____

Alternative identification for filed applications: Application Number: 60/899,379
Filed: February 05, 2007

PATENT
REEL: 020791 FRAME: 0691

The undersigned further agree(s) to cooperate with the Assignee in every way possible and to do all affirmative acts, and to execute all papers which counsel for Assignee shall advise are necessary and/or desirable without charge to Assignee in connection with said applications including, without limitation, the execution of separate assignments in connection with such applications, claims or provisions of the International Convention for Protection of Industrial Property or similar agreements.

The undersigned hereby authorize(s) and request(s) the Commissioner of Patents to issue any and all Letters Patent of the United States resulting from said application or any division or divisions or continuing applications thereof to said Assignee, as Assignee of the entire interest, and hereby covenants that he/she has (they have) full right to convey the entire interest herein assigned, and that he/she has (they have) not executed and will not execute, any agreement in conflict herewith.

The undersigned hereby grant(s) to Mark C. Comtois, Reg. No. 46,285; D. Joseph English, Reg. No. 42,514; and Patrick D. McPherson, Reg. No. 46,255 the power to insert on this assignment any further identification which may be necessary or desirable in order to comply with the rules of the United States Patent Office for recordation of this document.

In witness whereof, executed by the undersigned on the date(s) opposite the undersigned name(s).

Date 04/01/08 Signature of Inventor _____
MARTIN ALLES

Date 4/4/08 Signature of Inventor _____
JOHN CARLSON

Date 3/31/2008 Signature of Inventor _____
GEORGE MAHER

Date 3/31/2008 Signature of Inventor _____
SELCUK MAZLUM

RECORDED: 04/11/2008
PATENT
REEL: 020791 FRAME: 0692

Electronic Acknowledgement Receipt

EFS ID:	41071273
Application Number:	14518868
International Application Number:	
Confirmation Number:	6799
Title of Invention:	SYSTEM AND METHOD TO COLLECT AND MODIFY CALIBRATION DATA
First Named Inventor/Applicant Name:	Martin Alles
Customer Number:	79172
Filer:	David Fogg/Judy Fan
Filer Authorized By:	David Fogg
Attorney Docket Number:	AND01 083 CONT
Receipt Date:	09-NOV-2020
Filing Date:	20-OCT-2014
Time Stamp:	17:51:46
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Power of Attorney	00939461.pdf	395345 600bd2e284d758cbe059d1acb6d7d05df8677953	no	2

Warnings:

Information:					
2	Assignee showing of ownership per 37 CFR 3.73	00939464.pdf	208442 7271c5cf46d3531051465974b6a34c1267e41be6	no	5
Warnings:					
Information:					
			Total Files Size (in bytes):	603787	

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
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Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NO.	ISSUE DATE	PATENT NO.	ATTORNEY DOCKET NO.	CONFIRMATION NO.
14/518,868	08/04/2015	9097784	AND01 083 CONT	6799

79172 7590 07/15/2015

Duane Morris LLP
505 9th Street, N.W.
Suite 1000
Washington, DC 20004

ISSUE NOTIFICATION

The projected patent number and issue date are specified above.

Determination of Patent Term Adjustment under 35 U.S.C. 154 (b)
(application filed on or after May 29, 2000)

The Patent Term Adjustment is 0 day(s). Any patent to issue from the above-identified application will include an indication of the adjustment on the front page.

If a Continued Prosecution Application (CPA) was filed in the above-identified application, the filing date that determines Patent Term Adjustment is the filing date of the most recent CPA.

Applicant will be able to obtain more detailed information by accessing the Patent Application Information Retrieval (PAIR) WEB site (http://pair.uspto.gov).

Any questions regarding the Patent Term Extension or Adjustment determination should be directed to the Office of Patent Legal Administration at (571)-272-7702. Questions relating to issue and publication fee payments should be directed to the Application Assistance Unit (AAU) of the Office of Data Management (ODM) at (571)-272-4200.

APPLICANT(s) (Please see PAIR WEB site http://pair.uspto.gov for additional applicants):

Martin Alles, Vienna, VA;
Andrew LLC, Hickory, NC
John Carlson, Dulles, VA;
George Maher, Herndon, VA;
Selcuk Mazlum, Leesburg, VA;

The United States represents the largest, most dynamic marketplace in the world and is an unparalleled location for business investment, innovation, and commercialization of new technologies. The USA offers tremendous resources and advantages for those who invest and manufacture goods here. Through SelectUSA, our nation works to encourage and facilitate business investment. To learn more about why the USA is the best country in the world to develop technology, manufacture products, and grow your business, visit SelectUSA.gov.

PART B - FEE(S) TRANSMITTAL

Complete and send this form, together with applicable fee(s), to: Mail **Mail Stop ISSUE FEE**
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450
or Fax (571)-273-2885

INSTRUCTIONS: This form should be used for transmitting the ISSUE FEE and PUBLICATION FEE (if required). Blocks 1 through 5 should be completed where appropriate. All further correspondence including the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address as indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" for maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Note: Use Block 1 for any change of address)

79172 7590 06/19/2015
Duane Morris LLP
505 9th Street, N.W.
Suite 1000
Washington, DC 20004

Note: A certificate of mailing can only be used for domestic mailings of the Fee(s) Transmittal. This certificate cannot be used for any other accompanying papers. Each additional paper, such as an assignment or formal drawing, must have its own certificate of mailing or transmission.

Certificate of Mailing or Transmission
I hereby certify that this Fee(s) Transmittal is being deposited with the United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Mail Stop ISSUE FEE address above, or being facsimile transmitted to the USPTO (571) 273-2885, on the date indicated below.

(Depositor's name)
(Signature)
(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
14/518,868	10/20/2014	Martin Alles	AND01 083 CONT	6799

TITLE OF INVENTION: SYSTEM AND METHOD TO COLLECT AND MODIFY CALIBRATION DATA

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	UNDISCOUNTED	$960	$0	$0	$960	09/21/2015

EXAMINER	ART UNIT	CLASS-SUBCLASS
SABOURI, MAZDA	2641	455-456100

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).
- ☐ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.
- ☐ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47; Rev 03-02 or more recent) attached. **Use of a Customer Number is required.**

2. For printing on the patent front page, list
(1) The names of up to 3 registered patent attorneys or agents OR, alternatively,
(2) The name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.

1 Duane Morris LLP
2
3

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. If an assignee is identified below, the document has been filed for recordation as set forth in 37 CFR 3.11. Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE: CommScope Technologies LLC

(B) RESIDENCE: (CITY and STATE OR COUNTRY): Hickory, North Carolina

Please check the appropriate assignee category or categories (will not be printed on the patent) : ☐ Individual ☒ Corporation or other private group entity ☐ Government

4a. The following fee(s) are submitted:
- ☒ Issue Fee
- ☐ Publication Fee (No small entity discount permitted)
- ☐ Advance Order - # of Copies _____

4b. Payment of Fee(s): **(Please first reapply any previously paid issue fee shown above)**
- ☐ A check is enclosed.
- ☐ Payment by credit card. Form PTO-2038 is attached.
- ☒ The director is hereby authorized to charge the required fee(s), any deficiency, or credits any overpayment, to Deposit Account Number 04-1679 (enclose an extra copy of this form).

5. **Change in Entity Status** (from status indicated above)
- ☐ Applicant certifying micro entity status. See 37 CFR 1.29 — NOTE: Absent a valid certification of Micro Entity Status (see forms PTO/SB/15A and 15B), issue fee payment in the micro entity amount will not be accepted at the risk of application abandonment.
- ☐ Applicant asserting small entity status. See 37 CFR 1.27 — NOTE: If the application was previously under micro entity status, checking this box will be taken to be a notification of loss of entitlement to micro entity status.
- ☐ Applicant changing to regular undiscounted fee status. — NOTE: Checking this box will be taken to be a notification of loss of entitlement to small or micro entity status, as applicable.

NOTE: This form must be signed in accordance with 37 CFR 1.31 and 1.33. See 37 CFR 1.4 for signature requirements and certifications.

Authorized Signature /Mark C. Comtois/ Date 30 June 2015

Typed or printed name Mark C. Comtois Registration No. 46,285

Electronic Patent Application Fee Transmittal

Application Number:	14518868
Filing Date:	20-Oct-2014
Title of Invention:	SYSTEM AND METHOD TO COLLECT AND MODIFY CALIBRATION DATA
First Named Inventor/Applicant Name:	Martin Alles
Filer:	Mark Charles Comtois/laureen ponder
Attorney Docket Number:	AND01 083 CONT

Filed as Large Entity

Filing Fees for Utility under 35 USC 111(a)

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Utility Appl Issue Fee	1501	1	960	960

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension-of-Time:				
Miscellaneous:				
			Total in USD ($)	**960**

Electronic Acknowledgement Receipt

EFS ID:	22783537
Application Number:	14518868
International Application Number:	
Confirmation Number:	6799
Title of Invention:	SYSTEM AND METHOD TO COLLECT AND MODIFY CALIBRATION DATA
First Named Inventor/Applicant Name:	Martin Alles
Customer Number:	79172
Filer:	Mark Charles Comtois/laureen ponder
Filer Authorized By:	Mark Charles Comtois
Attorney Docket Number:	AND01 083 CONT
Receipt Date:	30-JUN-2015
Filing Date:	20-OCT-2014
Time Stamp:	12:11:18
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Deposit Account
Payment was successfully received in RAM	$960
RAM confirmation Number	11501
Deposit Account	041679
Authorized User	COMTOIS, MARK C

The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:

Charge any Additional Fees required under 37 C.F.R. Section 1.16 (National application filing, search, and examination fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.17 (Patent application and reexamination processing fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.19 (Document supply fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.20 (Post Issuance fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.21 (Miscellaneous fees and charges)

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Issue Fee Payment (PTO-85B)	14518868IF.pdf	88149 b7778afcc78c5614f43c47f3f392b4c7229d61d1	no	1
Warnings:					
Information:					
2	Fee Worksheet (SB06)	fee-info.pdf	30540 26b0a8190a9ce9ad5b9d2fe4829fa5d8605e6ef9	no	2
Warnings:					
Information:					
		Total Files Size (in bytes):	118689		

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

NOTICE OF ALLOWANCE AND FEE(S) DUE

79172 7590 06/19/2015

Duane Morris LLP
505 9th Street, N.W.
Suite 1000
Washington, DC 20004

EXAMINER
SABOURI, MAZDA

ART UNIT	PAPER NUMBER
2641	

DATE MAILED: 06/19/2015

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
14/518,868	10/20/2014	Martin Alles	AND01 083 CONT	6799

TITLE OF INVENTION: SYSTEM AND METHOD TO COLLECT AND MODIFY CALIBRATION DATA

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	UNDISCOUNTED	$960	$0	$0	$960	09/21/2015

THE APPLICATION IDENTIFIED ABOVE HAS BEEN EXAMINED AND IS ALLOWED FOR ISSUANCE AS A PATENT. PROSECUTION ON THE MERITS IS CLOSED. THIS NOTICE OF ALLOWANCE IS NOT A GRANT OF PATENT RIGHTS. THIS APPLICATION IS SUBJECT TO WITHDRAWAL FROM ISSUE AT THE INITIATIVE OF THE OFFICE OR UPON PETITION BY THE APPLICANT. SEE 37 CFR 1.313 AND MPEP 1308.

THE ISSUE FEE AND PUBLICATION FEE (IF REQUIRED) MUST BE PAID WITHIN THREE MONTHS FROM THE MAILING DATE OF THIS NOTICE OR THIS APPLICATION SHALL BE REGARDED AS ABANDONED. THIS STATUTORY PERIOD CANNOT BE EXTENDED. SEE 35 U.S.C. 151. THE ISSUE FEE DUE INDICATED ABOVE DOES NOT REFLECT A CREDIT FOR ANY PREVIOUSLY PAID ISSUE FEE IN THIS APPLICATION. IF AN ISSUE FEE HAS PREVIOUSLY BEEN PAID IN THIS APPLICATION (AS SHOWN ABOVE), THE RETURN OF PART B OF THIS FORM WILL BE CONSIDERED A REQUEST TO REAPPLY THE PREVIOUSLY PAID ISSUE FEE TOWARD THE ISSUE FEE NOW DUE.

HOW TO REPLY TO THIS NOTICE:

I. Review the ENTITY STATUS shown above. If the ENTITY STATUS is shown as SMALL or MICRO, verify whether entitlement to that entity status still applies.

If the ENTITY STATUS is the same as shown above, pay the TOTAL FEE(S) DUE shown above.

If the ENTITY STATUS is changed from that shown above, on PART B - FEE(S) TRANSMITTAL, complete section number 5 titled "Change in Entity Status (from status indicated above)".

For purposes of this notice, small entity fees are 1/2 the amount of undiscounted fees, and micro entity fees are 1/2 the amount of small entity fees.

II. PART B - FEE(S) TRANSMITTAL, or its equivalent, must be completed and returned to the United States Patent and Trademark Office (USPTO) with your ISSUE FEE and PUBLICATION FEE (if required). If you are charging the fee(s) to your deposit account, section "4b" of Part B - Fee(s) Transmittal should be completed and an extra copy of the form should be submitted. If an equivalent of Part B is filed, a request to reapply a previously paid issue fee must be clearly made, and delays in processing may occur due to the difficulty in recognizing the paper as an equivalent of Part B.

III. All communications regarding this application must give the application number. Please direct all communications prior to issuance to Mail Stop ISSUE FEE unless advised to the contrary.

IMPORTANT REMINDER: Utility patents issuing on applications filed on or after Dec. 12, 1980 may require payment of maintenance fees. It is patentee's responsibility to ensure timely payment of maintenance fees when due.

PART B - FEE(S) TRANSMITTAL

Complete and send this form, together with applicable fee(s), to: Mail **Mail Stop ISSUE FEE**
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450
or Fax (571)-273-2885

INSTRUCTIONS: This form should be used for transmitting the ISSUE FEE and PUBLICATION FEE (if required). Blocks 1 through 5 should be completed where appropriate. All further correspondence including the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address as indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" for maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Note: Use Block 1 for any change of address)

79172 7590 06/19/2015
Duane Morris LLP
505 9th Street, N.W.
Suite 1000
Washington, DC 20004

Note: A certificate of mailing can only be used for domestic mailings of the Fee(s) Transmittal. This certificate cannot be used for any other accompanying papers. Each additional paper, such as an assignment or formal drawing, must have its own certificate of mailing or transmission.

Certificate of Mailing or Transmission
I hereby certify that this Fee(s) Transmittal is being deposited with the United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Mail Stop ISSUE FEE address above, or being facsimile transmitted to the USPTO (571) 273-2885, on the date indicated below.

(Depositor's name)
(Signature)
(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
14/518,868	10/20/2014	Martin Alles	AND01 083 CONT	6799

TITLE OF INVENTION: SYSTEM AND METHOD TO COLLECT AND MODIFY CALIBRATION DATA

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	UNDISCOUNTED	$960	$0	$0	$960	09/21/2015

EXAMINER	ART UNIT	CLASS-SUBCLASS
SABOURI, MAZDA	2641	455-456100

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).
- ❑ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.
- ❑ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47; Rev 03-02 or more recent) attached. **Use of a Customer Number is required.**

2. For printing on the patent front page, list
(1) The names of up to 3 registered patent attorneys or agents OR, alternatively,
(2) The name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.
1 _____
2 _____
3 _____

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. If an assignee is identified below, the document has been filed for recordation as set forth in 37 CFR 3.11. Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE (B) RESIDENCE: (CITY and STATE OR COUNTRY)

Please check the appropriate assignee category or categories (will not be printed on the patent) : ❑ Individual ❑ Corporation or other private group entity ❑ Government

4a. The following fee(s) are submitted:
- ❑ Issue Fee
- ❑ Publication Fee (No small entity discount permitted)
- ❑ Advance Order - # of Copies _____

4b. Payment of Fee(s): **(Please first reapply any previously paid issue fee shown above)**
- ❑ A check is enclosed.
- ❑ Payment by credit card. Form PTO-2038 is attached.
- ❑ The director is hereby authorized to charge the required fee(s), any deficiency, or credits any overpayment, to Deposit Account Number _____ (enclose an extra copy of this form).

5. **Change in Entity Status** (from status indicated above)
- ❑ Applicant certifying micro entity status. See 37 CFR 1.29 — NOTE: Absent a valid certification of Micro Entity Status (see forms PTO/SB/15A and 15B), issue fee payment in the micro entity amount will not be accepted at the risk of application abandonment.
- ❑ Applicant asserting small entity status. See 37 CFR 1.27 — NOTE: If the application was previously under micro entity status, checking this box will be taken to be a notification of loss of entitlement to micro entity status.
- ❑ Applicant changing to regular undiscounted fee status. — NOTE: Checking this box will be taken to be a notification of loss of entitlement to small or micro entity status, as applicable.

NOTE: This form must be signed in accordance with 37 CFR 1.31 and 1.33. See 37 CFR 1.4 for signature requirements and certifications.

Authorized Signature _____ Date _____

Typed or printed name _____ Registration No. _____

UNITED STATES PATENT AND TRADEMARK OFFICE

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
14/518,868	10/20/2014	Martin Alles	AND01 083 CONT	6799

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Suite 1000
Washington, DC 20004

EXAMINER	
SABOURI, MAZDA	
ART UNIT	**PAPER NUMBER**
2641	

DATE MAILED: 06/19/2015

Determination of Patent Term Adjustment under 35 U.S.C. 154 (b)
(Applications filed on or after May 29, 2000)

The Office has discontinued providing a Patent Term Adjustment (PTA) calculation with the Notice of Allowance.

Section 1(h)(2) of the AIA Technical Corrections Act amended 35 U.S.C. 154(b)(3)(B)(i) to eliminate the requirement that the Office provide a patent term adjustment determination with the notice of allowance. See Revisions to Patent Term Adjustment, 78 Fed. Reg. 19416, 19417 (Apr. 1, 2013). Therefore, the Office is no longer providing an initial patent term adjustment determination with the notice of allowance. The Office will continue to provide a patent term adjustment determination with the Issue Notification Letter that is mailed to applicant approximately three weeks prior to the issue date of the patent, and will include the patent term adjustment on the patent. Any request for reconsideration of the patent term adjustment determination (or reinstatement of patent term adjustment) should follow the process outlined in 37 CFR 1.705.

Any questions regarding the Patent Term Extension or Adjustment determination should be directed to the Office of Patent Legal Administration at (571)-272-7702. Questions relating to issue and publication fee payments should be directed to the Customer Service Center of the Office of Patent Publication at 1-(888)-786-0101 or (571)-272-4200.

OMB Clearance and PRA Burden Statement for PTOL-85 Part B

The Paperwork Reduction Act (PRA) of 1995 requires Federal agencies to obtain Office of Management and Budget approval before requesting most types of information from the public. When OMB approves an agency request to collect information from the public, OMB (i) provides a valid OMB Control Number and expiration date for the agency to display on the instrument that will be used to collect the information and (ii) requires the agency to inform the public about the OMB Control Number's legal significance in accordance with 5 CFR 1320.5(b).

The information collected by PTOL-85 Part B is required by 37 CFR 1.311. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, Virginia 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, Virginia 22313-1450. Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether disclosure of these records is required by the Freedom of Information Act.
2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.
3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.
4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).
5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.
6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspection or an issued patent.
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

Examiner-Initiated Interview Summary	Application No.	Applicant(s)	
	14/518,868	ALLES ET AL.	
	Examiner	Art Unit	
	MAZDA SABOURI	2641	

All participants (applicant, applicant's representative, PTO personnel):

(1) *MAZDA SABOURI*. (3)_____.

(2) *Mark Comtois*. (4)_____.

Date of Interview: *04 June 2015*.

Type: ☒ Telephonic ☐ Video Conference
☐ Personal [copy given to: ☐ applicant ☐ applicant's representative]

Exhibit shown or demonstration conducted: ☐ Yes ☐ No.
If Yes, brief description: _____.

Issues Discussed ☐101 ☐112 ☐102 ☐103 ☒Others
(For each of the checked box(es) above, please describe below the issue and detailed description of the discussion)

Claim(s) discussed: *1 and 12*.

Identification of prior art discussed: *Shkedi*.

Substance of Interview
(For each issue discussed, provide a detailed description and indicate if agreement was reached. Some topics may include: identification or clarification of a reference or a portion thereof, claim interpretation, proposed amendments, arguments of any applied references etc...)

Discussed proposed examiner amendments to put case in condition for allowance. Applicant agreed to proposed amendments on 6/10/2015.

Applicant recordation instructions: It is not necessary for applicant to provide a separate record of the substance of interview.

Examiner recordation instructions: Examiners must summarize the substance of any interview of record. A complete and proper recordation of the substance of an interview should include the items listed in MPEP 713.04 for complete and proper recordation including the identification of the general thrust of each argument or issue discussed, a general indication of any other pertinent matters discussed regarding patentability and the general results or outcome of the interview, to include an indication as to whether or not agreement was reached on the issues raised.

☐ Attachment

/MAZDA SABOURI/ Primary Examiner, Art Unit 2641	

Notice of Allowability	Application No. 14/518,868	Applicant(s) ALLES ET AL.	
	Examiner MAZDA SABOURI	Art Unit 2641	AIA (First Inventor to File) Status No

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address--

All claims being allowable, PROSECUTION ON THE MERITS IS (OR REMAINS) CLOSED in this application. If not included herewith (or previously mailed), a Notice of Allowance (PTOL-85) or other appropriate communication will be mailed in due course. **THIS NOTICE OF ALLOWABILITY IS NOT A GRANT OF PATENT RIGHTS.** This application is subject to withdrawal from issue at the initiative of the Office or upon petition by the applicant. See 37 CFR 1.313 and MPEP 1308.

1. ☒ This communication is responsive to *See Continuation Sheet*.
   ☐ A declaration(s)/affidavit(s) under **37 CFR 1.130(b)** was/were filed on_____.
2. ☐ An election was made by the applicant in response to a restriction requirement set forth during the interview on _____; the restriction requirement and election have been incorporated into this action.
3. ☒ The allowed claim(s) is/are *1-22*. As a result of the allowed claim(s), you may be eligible to benefit from the **Patent Prosecution Highway** program at a participating intellectual property office for the corresponding application. For more information, please see http://www.uspto.gov/patents/init_events/pph/index.jsp or send an inquiry to PPHfeedback@uspto.gov .
4. ☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

   Certified copies:

   a) ☐ All b) ☐ Some *c) ☐ None of the:
   1. ☐ Certified copies of the priority documents have been received.
   2. ☐ Certified copies of the priority documents have been received in Application No. _____ .
   3. ☐ Copies of the certified copies of the priority documents have been received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

   * Certified copies not received: _____.

Applicant has THREE MONTHS FROM THE "MAILING DATE" of this communication to file a reply complying with the requirements noted below. Failure to timely comply will result in ABANDONMENT of this application.
THIS THREE-MONTH PERIOD IS NOT EXTENDABLE.

5. ☐ CORRECTED DRAWINGS (as "replacement sheets") must be submitted.
   ☐ including changes required by the attached Examiner's Amendment / Comment or in the Office action of Paper No./Mail Date _____.

   Identifying indicia such as the application number (see 37 CFR 1.84(c)) should be written on the drawings in the front (not the back) of each sheet. Replacement sheet(s) should be labeled as such in the header according to 37 CFR 1.121(d).
6. ☐ DEPOSIT OF and/or INFORMATION about the deposit of BIOLOGICAL MATERIAL must be submitted. Note the attached Examiner's comment regarding REQUIREMENT FOR THE DEPOSIT OF BIOLOGICAL MATERIAL.

Attachment(s)

1. ☒ Notice of References Cited (PTO-892)
2. ☒ Information Disclosure Statements (PTO/SB/08), Paper No./Mail Date 5/19/2015
3. ☐ Examiner's Comment Regarding Requirement for Deposit of Biological Material
4. ☒ Interview Summary (PTO-413), Paper No./Mail Date _____ .
5. ☒ Examiner's Amendment/Comment
6. ☒ Examiner's Statement of Reasons for Allowance
7. ☐ Other _____.

/MAZDA SABOURI/
Primary Examiner, Art Unit 2641

Continuation of Item 1. This communication is responsive to : amendments filed on 10/20/2015 and examiner amendments made on 6/102/104.

1. The present application is being examined under the pre-AIA first to invent provisions.

EXAMINER'S AMENDMENT

2. An examiner's amendment to the record appears below. Should the changes and/or additions be unacceptable to applicant, an amendment may be filed as provided by 37 CFR 1.312. To ensure consideration of such an amendment, it MUST be submitted no later than the payment of the issue fee.

Authorization for this examiner's amendment was given in a telephone interview with Mark Comtois (46285) on 6/10/2015.

The application has been amended as follows:

1. (currently amended) A method for generating a calibration database, comprising;

receiving at a wireless device an attribute of a signal transmitted by a wireless transmitter to a mobile station in a region;

wirelessly transmitting from said wireless device said attribute to a controller unit;

obtaining location data of a plurality of geographic locations situated within said region, wherein said location data is determined using said wireless device, and wherein said region contains plural streets and intersections of said plural streets;

providing a location information database wherein said location database includes latitude and longitude information for each of a plurality of points within said region;

determining a status of said wireless device;

determining from said status a most likely one of said plural streets upon which said wireless device is ~~sited for a first one of said plural geographic locations~~ located;

determining said most likely street as a first one of said plural geographic locations;

determining a first point of said plural points that is in proximity to said first geographic location; and

entering said first point in said calibration database and associating the location data for the first one of said plural geographic locations determined by said wireless device with the first point.

12. (currently amended) 12. A system for generating a calibration database, comprising:

a wireless device for determining location data at a plurality of geographic locations situated within a region, wherein said region contains plural streets and intersections of said plural streets, said wireless device receiving an attribute of a signal transmitted by a wireless transmitter to a mobile station in said region;

a wireless device transmitter for transmitting from said wireless device said attribute to a controller unit;

a location information database wherein said location database includes latitude and longitude information for each of a plurality of points within said region;

circuitry for determining a status of said wireless device;

circuitry for determining from said status a most likely one of said plural streets upon which said wireless device is ~~sited for a first one of said plural geographic locations~~ located;

circuitry for determining said most likely street as a first one of said plural geographic locations;

circuitry for determining a first point of said plural points that is in proximity to said first geographic location; and

circuitry for entering said first point in said calibration database; and associating the location data for the first one of said plural geographic locations determined by said wireless device with the first point.

Allowable Subject Matter

3. The following is an examiner's statement of reasons for allowance: Claims 1 and 12 are directed towards a method and system for calibrating location data for a wireless device.

4. In a prior art search prior art was found teaching the inventive concept of collecting location fingerprints (*~claimed location data*) and GPS coordinates both corresponding to the same location and associating them in a database for calibration purposes (*see US 2008/0070572 [Shkedi], paragraph 54*).

5. Howevert Shkedi is silent with respect to the particular steps/functions recited in claims 1 and 12. For instance Shkedi fails to teach the following steps recited in claim 1, similar subject matter of which is recited in claim 12:

- **determining a status of said wireless device;**
- **determining from said status a most likely one of said plural streets upon which said wireless device is located;**
- **determining said most likely street as a first one of said plural geographic locations;**
- **determining a first point of said plural points that is in proximity to said first geographic location; and**
- and entering said first point in said calibration database and associating the location data for the first one of said plural geographic locations determined by said wireless device **with the first point**.

6. Prior art of record fails to render the differences between claims 1 and 12 and what is taught in Shkedi as obvious to one of ordinary skill in the arts. Therefore, claims 1 and12 are allowable. All other pending claims depend on claims 1 and 12.

Any comments considered necessary by applicant must be submitted no later than the payment of the issue fee and, to avoid processing delays, should preferably accompany the issue fee. Such submissions should be clearly labeled “Comments on Statement of Reasons for Allowance.”

Conclusion

Any inquiry concerning this communication or earlier communications from the examiner should be directed to MAZDA SABOURI whose telephone number is

(571)272-8892. The examiner can normally be reached on Monday-Friday from 9:00-5:30.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Charles N. Appiah can be reached on 571-272-7904. The fax phone number for the organization where this application or proceeding is assigned is 571-273-8300.

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see http://pair-direct.uspto.gov. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free). If you would like assistance from a USPTO Customer Service Representative or access to the automated information system, call 800-786-9199 (IN USA OR CANADA) or 571-272-1000.

Mazda Sabouri
Primary Examiner
Art Unit 2641

/MAZDA SABOURI/
Primary Examiner, Art Unit 2641

Examiner-Initiated Interview Summary	Application No.	Applicant(s)	
	14/518,868	ALLES ET AL.	
	Examiner	Art Unit	
	MAZDA SABOURI	2641	

All participants (applicant, applicant's representative, PTO personnel):

(1) *MAZDA SABOURI*. (3)_____.

(2) *Mark Comtois*. (4)_____.

Date of Interview: *04 June 2015*.

Type: ☒ Telephonic ☐ Video Conference
☐ Personal [copy given to: ☐ applicant ☐ applicant's representative]

Exhibit shown or demonstration conducted: ☐ Yes ☐ No.
If Yes, brief description: _____.

Issues Discussed ☐101 ☐112 ☐102 ☐103 ☒Others
(For each of the checked box(es) above, please describe below the issue and detailed description of the discussion)

Claim(s) discussed: *1 and 12*.

Identification of prior art discussed: *Shkedi*.

Substance of Interview
(For each issue discussed, provide a detailed description and indicate if agreement was reached. Some topics may include: identification or clarification of a reference or a portion thereof, claim interpretation, proposed amendments, arguments of any applied references etc...)

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Examiner recordation instructions: Examiners must summarize the substance of any interview of record. A complete and proper recordation of the substance of an interview should include the items listed in MPEP 713.04 for complete and proper recordation including the identification of the general thrust of each argument or issue discussed, a general indication of any other pertinent matters discussed regarding patentability and the general results or outcome of the interview, to include an indication as to whether or not agreement was reached on the issues raised.

☐ Attachment

/MAZDA SABOURI/ Primary Examiner, Art Unit 2641	

Notice of References Cited	Application/Control No. 14/518,868	Applicant(s)/Patent Under Reexamination ALLES ET AL.	
	Examiner MAZDA SABOURI	Art Unit 2641	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
*	A	US-2008/0070572	03-2008	Shkedi, Roy	455/435.1
	B	US-			
	C	US-			
	D	US-			
	E	US-			
	F	US-			
	G	US-			
	H	US-			
	I	US-			
	J	US-			
	K	US-			
	L	US-			
	M	US-			

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	Classification
	N					
	O					
	P					
	Q					
	R					
	S					
	T					

NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
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PTO/SB/08a (05-07)
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INFORMATION DISCLOSURE STATEMENT BY APPLICANT (**Not for submission under 37 CFR 1.99**)		
	Application Number	14518868
	Filing Date	2014-10-20
	First Named Inventor	Alles et al.
	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

U.S.PATENTS						
Examiner Initial*	Cite No	Patent Number	Kind Code[1]	Issue Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear
	1	7593738	B2	2009-09-22	Anderson	
	2	7440762	B2	2008-10-21	Maloney et al.	
	3	7427952	B2	2008-09-23	Bull et al.	
	4	7340259	B2	2008-03-04	Maloney	
	5	7271765	B2	2007-09-18	Stilp et al.	
	6	7167713	B2	2007-01-23	Anderson	
	7	7023383	B2	2006-04-04	Stilp et al.	
	8	6996392	B2	2006-02-07	Anderson	

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	Attorney Docket Number	AND01 083 CONT

	9	6876859	B2	2005-04-05	Anderson et al.	
	10	6873290	B2	2005-03-29	Anderson et al.	
	11	6782264	B2	2004-08-24	Anderson	
	12	6771625	B1	2004-08-03	Beal	
	13	6765531	B2	2004-07-20	Anderson	
	14	6661379	B2	2003-12-09	Stilp et al.	
	15	6646604	B2	2003-11-11	Anderson	
	16	6603428	B2	2003-08-05	Stilp	
	17	6563460	B2	2003-05-13	Stilp et al.	
	18	6546256	B1	2003-04-08	Maloney	
	19	6519465	B2	2003-02-11	Stilp et al.	

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	20	6492944	B1	2002-12-10	Stilp	
	21	6483460	B2	2002-11-19	Stilp et al.	
	22	6463290	B1	2002-10-08	Stilp et al.	
	23	6400320	B1	2002-06-04	Stilp et al.	
	24	6388618	B1	2002-05-14	Stilp et al.	
	25	6366241	B2	2002-04-02	Pack	
	26	6351235	B1	2002-02-26	Stilp	
	27	6334059	B1	2001-12-25	Stilp et al.	
	28	6317604	B1	2001-11-13	Kovach Jr. et al.	
	29	6317081	B1	2001-11-13	Stilp	
	30	6288676	B1	2001-09-11	Maloney	

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	31	6288675	B1	2001-09-11	Maloney	
	32	6285321	B1	2001-09-04	Stilp et al.	
	33	6281834	B1	2001-08-28	Stilp	
	34	6266013	B1	2001-07-24	Stilp et al.	
	35	6184829	B1	2001-02-06	Stilp	
	36	6172644	B1	2001-01-09	Stilp	
	37	6127975	A	2000-10-03	Maloney	
	38	6119013	A	2000-09-12	Maloney et al.	
	39	6115599	A	2000-09-05	Stilp	
	40	6108555	A	2000-08-22	Maloney et al.	
	41	6101178	A	2000-08-08	Beal	

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	42	6097336	A	2000-08-01	Stilp	
	43	6091362	A	2000-07-18	Stilp	
	44	6047192	A	2000-04-04	Maloney	
	45	5959580	A	1999-09-28	Maloney et al.	
	46	5608410	A	1997-03-04	Stilp et al.	
	47	5327144	A	1994-07-05	Stilp et al.	
	48	4728959	A	1988-03-01	Maloney	

If you wish to add additional U.S. Patent citation information please click the Add button.

U.S.PATENT APPLICATION PUBLICATIONS

Examiner Initial*	Cite No	Publication Number	Kind Code[1]	Publication Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear
	1	20080160952	A1	2008-07-03	Bull et al.	
	2	20080160953	A1	2008-07-03	Mia et al.	

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FOREIGN PATENT DOCUMENTS

Examiner Initial*	Cite No	Foreign Document Number[3]	Country Code[2] i	Kind Code[4]	Publication Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear	T[5]
	1	06088472	WO	A1	2006-08-24	Anderson et al.		☐

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Examiner Initials*	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc), date, pages(s), volume-issue number(s), publisher, city and/or country where published.	T[5]
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Examiner Signature	/Mazda Sabouri/	Date Considered	06/15/2015

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[1] See Kind Codes of USPTO Patent Documents at www.USPTO.GOV or MPEP 901.04. [2] Enter office that issued the document, by the two-letter code (WIPO Standard ST.3). [3] For Japanese patent documents, the indication of the year of the reign of the Emperor must precede the serial number of the patent document. [4] Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST.16 if possible. [5] Applicant is to place a check mark here if English language translation is attached.

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CERTIFICATION STATEMENT

Please see 37 CFR 1.97 and 1.98 to make the appropriate selection(s):

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☐ See attached certification statement.

☐ Fee set forth in 37 CFR 1.17 (p) has been submitted herewith.

☒ None

SIGNATURE

A signature of the applicant or representative is required in accordance with CFR 1.33, 10.18. Please see CFR 1.4(d) for the form of the signature.

Signature	/Mark C. Comtois/	Date (YYYY-MM-DD)	2015-05-19
Name/Print	Mark C. Comtois	Registration Number	46285

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	1					
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	1	20080161015	A1	2008-07-03	Maloney et al.	
	2	20020172223	A1	2002-11-21	Stilp et al.	
	3	20080132247	A1	2008-06-05	Anderson et al.	
	4	20080132244	A1	2008-06-05	Anderson et al.	
	5	20080158059	A1	2008-07-03	Bull et al.	

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	6	20080261614	A1	2008-10-23	Mia et al.	
	7	20080261613	A1	2008-10-23	Anderson et al.	
	8	20080261612	A1	2008-10-23	Mia et al.	
	9	20080261611	A1	2008-10-23	Mia et al.	
	10	20080137524	A1	2008-06-12	Anderson et al.	
	11	20080248811	A1	2008-10-09	Maloney et al.	
	12	20070111746	A1	2007-05-17	Anderson et al.	
	13	20070155489	A1	2007-07-05	Beckley et al.	
	14	20090005061	A1	2009-01-01	Ward et al.	
	15	20070155401	A1	2007-07-05	Ward et al.	
	16	20060030333	A1	2006-02-09	Ward et al.	

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	Attorney Docket Number	AND01 083 CONT

	17	20030064734	A1	2003-04-03	Stilp et al.	
	18	20060003775	A1	2006-01-05	Bull et al.	

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FOREIGN PATENT DOCUMENTS

Examiner Initial*	Cite No	Foreign Document Number[3]	Country Code[2] i	Kind Code[4]	Publication Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear	T[5]
	1							☐

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NON-PATENT LITERATURE DOCUMENTS

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[1] See Kind Codes of USPTO Patent Documents at www.USPTO.GOV or MPEP 901.04. [2] Enter office that issued the document, by the two-letter code (WIPO Standard ST.3). [3] For Japanese patent documents, the indication of the year of the reign of the Emperor must precede the serial number of the patent document. [4] Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST.16 if possible. [5] Applicant is to place a check mark here if English language translation is attached.

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☐ See attached certification statement.

☐ Fee set forth in 37 CFR 1.17 (p) has been submitted herewith.

☒ None

SIGNATURE

A signature of the applicant or representative is required in accordance with CFR 1.33, 10.18. Please see CFR 1.4(d) for the form of the signature.

Signature	/Mark C. Comtois/	Date (YYYY-MM-DD)	2015-05-19
Name/Print	Mark C. Comtois	Registration Number	46285

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EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	0	(signal and geographic$4 and street and intersection and callibrat$4 and (coordinate or latitude or longitude) and (associat$4 or correlat$4)).clm. and ("455"/$.ccls. or "709"/$.ccls. or "370"/$.ccls.)	US-PGPUB; USPAT	OR	ON	2015/06/15 11:26
L2	2	(signal and geographic$4 and street and intersection and calibrat$4 and (coordinate or latitude or longitude) and (associat$4 or correlat$4)).clm. and ("455"/$.ccls. or "709"/$.ccls. or "370"/$.ccls.)	US-PGPUB; USPAT	OR	ON	2015/06/15 11:26
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S3	3	"12026372" and (location adj data)	US-PGPUB; USPAT	OR	ON	2015/06/04 11:33
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		position or zone or area or coordinate or geolocation)) and @ad<"20070205" and gps	USPAT			
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S15	1	"14304352"	US-PGPUB; USPAT	OR	ON	2015/06/04 18:37

EAST Search History (Interference)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L3	2	(signal and geographic$4 and street and intersection and calibrat$4 and (coordinate or latitude or longitude) and (associat$4 or correlat$4)).clm. and ("455"/$.ccls. or "709"/$.ccls. or "370"/$.ccls.)	US-PGPUB; USPAT; UPAD	OR	ON	2015/06/15 11:26
L4	2	(signal and geographic$4 and street and intersection and calibrat$4 and (coordinate or latitude or longitude) and (associat$4 or correlat$4)).clm.	US-PGPUB; USPAT; UPAD	OR	ON	2015/06/15 11:27

6/15/2015 11:27:38 AM
C:\Users\msabouri\Documents\EAST\Workspaces\14518868.wsp

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Examiner Signature	/Mazda Sabouri/	Date Considered	06/15/2015

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Name/Print	Mark C. Comtois	Registration Number	46285

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INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	14518868
	Filing Date	2014-10-20
	First Named Inventor	Alles et al.
	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

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INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
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	Filing Date	2014-10-20
	First Named Inventor	Alles et al.
	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

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ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /M.S./

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	14518868
	Filing Date	2014-10-20
	First Named Inventor	Alles et al.
	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

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U.S.PATENT APPLICATION PUBLICATIONS

Examiner Initial*	Cite No	Publication Number	Kind Code[1]	Publication Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear
	1	20110136496	A1	2011-06-09	Klang et al.	
	2	20100056178	A1	2010-03-04	Kreher et al.	
	3	20090117907	A1	2009-05-07	Wigren	
	4	20040203539	A1	2004-10-14	Benes et al.	

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FOREIGN PATENT DOCUMENTS

Examiner Initial*	Cite No	Foreign Document Number[3]	Country Code[2] i	Kind Code[4]	Publication Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear	T[5]
	1	2008/097505	WO	A2	2008-08-14	Andrew Corporation		☐
	2	2007/015188	WO	A1	2007-02-08	Konin-Klijke Philips Electronics N.V.		☐

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	14518868
	Filing Date	2014-10-20
	First Named Inventor	Alles et al.
	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

	3	2364617	GB	A	2002-01-30	Smartone Mobile Communications Limited		☐
	4	00/18148	WO	A1	2000-03-30	PPM Inc./Rao et al.		☐

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NON-PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc), date, pages(s), volume-issue number(s), publisher, city and/or country where published.	T[5]
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INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	14518868
	Filing Date	2014-10-20
	First Named Inventor	Alles et al.
	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

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ALL REFERENCES CONSIDERED EXCEPT WHERE LINED THROUGH. /M.S./

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	14518868
	Filing Date	2014-10-20
	First Named Inventor	Alles et al.
	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

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If you wish to add additional non-patent literature document citation information please click the Add button

EXAMINER SIGNATURE

Examiner Signature	/Mazda Sabouri/	Date Considered	06/15/2015

*EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through a citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

[1] See Kind Codes of USPTO Patent Documents at www.USPTO.GOV or MPEP 901.04. [2] Enter office that issued the document, by the two-letter code (WIPO Standard ST.3). [3] For Japanese patent documents, the indication of the year of the reign of the Emperor must precede the serial number of the patent document. [4] Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST.16 if possible. [5] Applicant is to place a check mark here if English language translation is attached.

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	Application Number	14518868
	Filing Date	2014-10-20
	First Named Inventor	Alles et al.
	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

CERTIFICATION STATEMENT

Please see 37 CFR 1.97 and 1.98 to make the appropriate selection(s):

☐ That each item of information contained in the information disclosure statement was first cited in any communication from a foreign patent office in a counterpart foreign application not more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e)(1).

OR

☐ That no item of information contained in the information disclosure statement was cited in a communication from a foreign patent office in a counterpart foreign application, and, to the knowledge of the person signing the certification after making reasonable inquiry, no item of information contained in the information disclosure statement was known to any individual designated in 37 CFR 1.56(c) more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e)(2).

☐ See attached certification statement.

☐ Fee set forth in 37 CFR 1.17 (p) has been submitted herewith.

☒ None

SIGNATURE

A signature of the applicant or representative is required in accordance with CFR 1.33, 10.18. Please see CFR 1.4(d) for the form of the signature.

Signature	/Mark C. Comtois/	Date (YYYY-MM-DD)	2015-05-19
Name/Print	Mark C. Comtois	Registration Number	46285

This collection of information is required by 37 CFR 1.97 and 1.98. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 1 hour to complete, including gathering, preparing and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	14518868	ALLES ET AL.
	Examiner	Art Unit
	MAZDA SABOURI	2641

CPC- SEARCHED		
Symbol	Date	Examiner

CPC COMBINATION SETS - SEARCHED		
Symbol	Date	Examiner

US CLASSIFICATION SEARCHED			
Class	Subclass	Date	Examiner
455	456.1	6//20154	MS

SEARCH NOTES		
Search Notes	Date	Examiner
see keyword search, EAST	6/4/2015	MS

INTERFERENCE SEARCH			
US Class/ CPC Symbol	US Subclass / CPC Group	Date	Examiner
see keyword search	EAST	6/15/2015	MS

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	14518868	ALLES ET AL.
	Examiner	**Art Unit**
	MAZDA SABOURI	2641

CPC						
Symbol					**Type**	**Version**
G01S		5	/	021	F	2013-01-01
H04W		4	/	02	I	2013-01-01
G01S		5	/	0252	I	2013-01-01
G01S		5	/	0257	I	2013-01-01
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Symbol					**Type**	**Set**	**Ranking**	**Version**
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NONE		**Total Claims Allowed:**	
(Assistant Examiner)	(Date)	22	
/MAZDA SABOURI/ Primary Examiner.Art Unit 2641	06/15/2015	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	12	9

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
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	Examiner	**Art Unit**
	MAZDA SABOURI	2641

US ORIGINAL CLASSIFICATION		INTERNATIONAL CLASSIFICATION										
CLASS	SUBCLASS	CLAIMED					NON-CLAIMED					
455	456.1	H	0	4	W	24 / 00 (2009.01.01)						

CROSS REFERENCE(S)					
CLASS	SUBCLASS (ONE SUBCLASS PER BLOCK)				

NONE		Total Claims Allowed:	
(Assistant Examiner)	(Date)	22	
/MAZDA SABOURI/ Primary Examiner.Art Unit 2641	06/15/2015	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	12	9

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	14518868	ALLES ET AL.
	Examiner	**Art Unit**
	MAZDA SABOURI	2641

☒ **Claims renumbered in the same order as presented by applicant** ☐ **CPA** ☐ **T.D.** ☐ **R.1.47**

Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original

NONE		**Total Claims Allowed:**	
(Assistant Examiner)	(Date)	22	
/MAZDA SABOURI/ Primary Examiner.Art Unit 2641	06/15/2015	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	12	9

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CONFIRMATION NO. 6799

SERIAL NUMBER	FILING or 371(c) DATE	CLASS	GROUP ART UNIT	ATTORNEY DOCKET NO.
14/518,868	10/20/2014 RULE	455	2641	AND01 083 CONT

APPLICANTS

Andrew LLC, Hickory, NC

INVENTORS

Martin Alles, Vienna, VA;
John Carlson, Dulles, VA;
George Maher, Herndon, VA;
Selcuk Mazlum, Leesburg, VA;

**** CONTINUING DATA ***************************

This application is a CON of 12/026,372 02/05/2008 PAT 8938252
which claims benefit of 60/899,379 02/05/2007

**** FOREIGN APPLICATIONS ***************************

**** IF REQUIRED, FOREIGN FILING LICENSE GRANTED ****

10/27/2014

Foreign Priority claimed	35 USC 119(a-d) conditions met	Verified and Acknowledged	Met after Allowance	STATE OR COUNTRY	SHEETS DRAWINGS	TOTAL CLAIMS	INDEPENDENT CLAIMS
☐ Yes ☑ No	☐ Yes ☑ No	/MAZDA SABOURI/ Examiner's Signature	☐ Initials	VA	8	22	2

ADDRESS

Duane Morris LLP
505 9th Street, N.W.
Suite 1000
Washington, DC 20004
UNITED STATES

TITLE

System and Method to Collect and Modify Calibration Data

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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
14/518,868	10/20/2014	Martin Alles	AND01 083 CONT

CONFIRMATION NO. 6799

79172
Duane Morris LLP
505 9th Street, N.W.
Suite 1000
Washington, DC 20004

POA ACCEPTANCE LETTER

OC000000075711154

Date Mailed: 06/12/2015

NOTICE OF ACCEPTANCE OF POWER OF ATTORNEY

This is in response to the Power of Attorney filed 06/10/2015.

The Power of Attorney in this application is accepted. Correspondence in this application will be mailed to the above address as provided by 37 CFR 1.33.

Questions about the contents of this notice and the requirements it sets forth should be directed to the Office of Data Management, Application Assistance Unit, at **(571) 272-4000** or **(571) 272-4200** or **1-888-786-0101**.

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Document Description: Power of Attorney

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I am the Applicant (if the Applicant is a juristic entity, list the Applicant name in the box):

Andrew LLC

☐ Inventor or Joint Inventor (title not required below)
☐ Legal Representative of a Deceased or Legally Incapacitated Inventor (title not required below)
☑ Assignee or Person to Whom the Inventor is Under an Obligation to Assign (provide signer's title if applicant is a juristic entity)
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SIGNATURE of Applicant for Patent

The undersigned (whose title is supplied below) is authorized to act on behalf of the applicant (e.g., where the applicant is a juristic entity).

Signature		Date (Optional)	10/20/2014
Name	Laura J. Thomas		
Title	Assistant Secretary		

NOTE: Signature - This form must be signed by the applicant in accordance with 37 CFR 1.33. See 37 CFR 1.4 for signature requirements and certifications. If more than one applicant, use multiple forms.

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EFS ID:	22594645
Application Number:	14518868
International Application Number:	
Confirmation Number:	6799
Title of Invention:	System and Method to Collect and Modify Calibration Data
First Named Inventor/Applicant Name:	Martin Alles
Customer Number:	79172
Filer:	Mark Charles Comtois/laureen ponder
Filer Authorized By:	Mark Charles Comtois
Attorney Docket Number:	AND01 083 CONT
Receipt Date:	10-JUN-2015
Filing Date:	20-OCT-2014
Time Stamp:	17:41:30
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

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1		AND01083CONTPOA.pdf	275490 40d4ff63f52f044be9ba88273c8b9a215031a11b	yes	2

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National Stage of an International Application under 35 U.S.C. 371
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New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

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Document Description: Power of Attorney

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Application Number	14/518,868
Filing Date	20 October 2014
First Named Inventor	Alles, et al.
Title	System and Method To Collect and Modify Calibration Data
Art Unit	2641
Examiner Name	Mazda Sabouri
Attorney Docket Number	AND01 083 CONT

SIGNATURE of Applicant or Patent Practitioner

Signature	/Mark C. Comtois/	Date (Optional)	10 June 2015
Name	Mark C. Comtois	Registration Number	46285
Title (if Applicant is a juristic entity)			
Applicant Name (if Applicant is a juristic entity)			

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	First Named Inventor	Alles et al.
	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

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Examiner Initial*	Cite No	Patent Number	Kind Code[1]	Issue Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear
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	1	06-347529	JP		1994-12-22	NEC Corp.		☐

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	12	W.H. FOY, "Position-Location Solutions by Taylor-Series Estimation", IEEE Transactions Aerospace and Electronic Systems, Volume AES-12, No. 2, March 1976, pp.187-194	☐
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Name/Print	Mark C. Comtois	Registration Number	46285

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	First Named Inventor	Alles et al.
	Art Unit	2641
	Examiner Name	Mazda Sabouri
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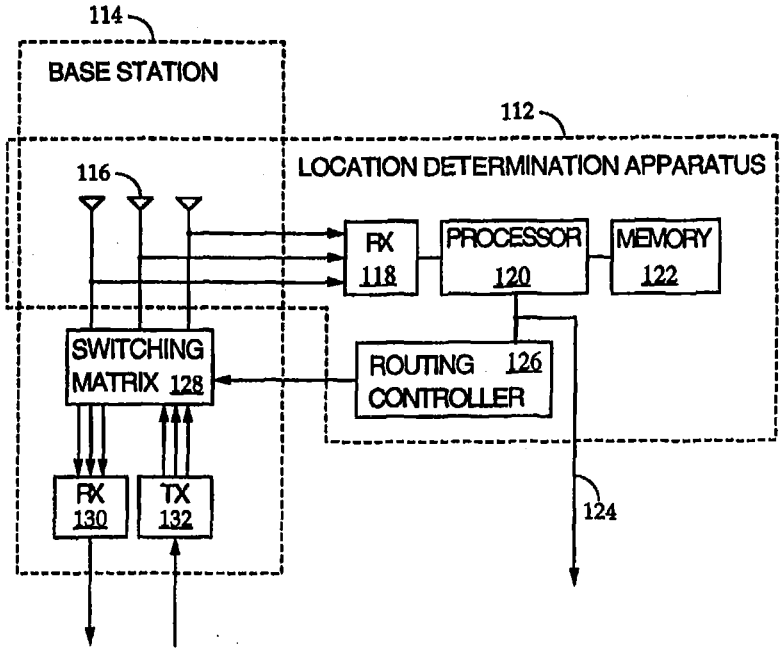
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(54) Title: WIRELESS LOCATION DETERMINATION USING SPATIAL SIGNATURE INFORMATION

(57) Abstract

A method for determining locations of mobile transmitters in a wireless communication system calculates a signature from signals received at an antenna array from the mobile, and matches the signature with calibrated signatures stored in a database to estimate the location of the mobile. The signature contains information characterizing the spatial channel between the mobile and the antenna array. An apparatus (112) implementing the method comprises an antenna array (116) and multi–channel receiver (118) for coherently receiving multi–dimensional signal vectors from a mobile transmitter. A processor (120) calculates a signature from the received signal vectors, which compared with calibrated signatures stored in a memory (122) to identify calibrated signatures that are similar to the calculated signature, and which corresponds to the likely locations of the mobile transmitter. Thus, the location of the transmitter can be accurately determined from the signals received at a single base station, even in a severe multipath environment.



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PCT PATENT APPLICATION OF U.S. WIRELESS CORPORATION

WIRELESS LOCATION DETERMINATION USING SPATIAL SIGNATURE INFORMATION

FIELD OF THE INVENTION

This invention relates generally to methods for determining the location of a radio transmitter. More particularly, it relates to methods for determining the location of cellular telephones, pagers, and other portable transmitters operating in urban environments characterized by a high degree of multipath.

BACKGROUND OF THE INVENTION

A long standing problem in radio communications is accurately determining the location of a mobile radio transmitter. Precise location information in a cellular telephone network is desirable for various reasons that have been recognized in the prior art. For example, cellular location information can be used to assist emergency dispatching, tracking unauthorized cell phone usage, and tracking or locating fleets of vehicles. Other applications include locating lost or stolen vehicles, assisting lost motorists, and providing various location-based services. These applications have yet to be realized, however, because they require accurate location information and no suitable method of providing such information has yet been developed. Generally, prior art location determination techniques fail for one or more of the following reasons: (1) they fail to operate in urban environments where multipath effects are severe, (2) they do not operate if fewer than three base stations are in range of the signal from a transmitter, (3) they do not provide location information with sufficient accuracy, precision, or confidence, and (4) they require extensive modifications to the mobile transmitter, to the communication system base stations, or to both.

Multipath is perhaps the most fundamental obstacle to prior art methods of solving the location finding problem. Multipath is typically caused by the reflection of signals from objects in the environment, such as buildings, hills, and other structures. A signal transmitted from a cellular phone will often be reflected from these structures, resulting in

multipath signals arriving at a base station in addition to a direct path signal. The angles of arrival of the multipath signals are usually different from the angle of arrival of the direct path signal. In addition, because the path lengths of the multipath signals differ from those of the direct path signal, the multipath signals and the direct path signal have different times of arrival. Moreover, in an urban environment where severe multipath is present, sometimes no direct path exists at all and the base station receives only the multipath signals. Conventional location determination techniques, however, are based on angle-of-arrival measurements or time-of-arrival measurements. As a result, they suffer significantly from the effects of multipath, and elaborate techniques are used in attempts to mitigate the multipath effects. For example, the prior art teaches signal averaging techniques, spread spectrum or frequency hopping techniques, and techniques for multipath identification and removal. In cases of severe multipath, however, there often is no direct path signal at all. In such cases, these approaches fail. Moreover, averaging techniques are based on assumptions about the distribution of multipath that are not generally valid, especially in severe multipath environments. Even in cases where such assumptions do hold, these averaging techniques do not yield accurate position information. The prior art approaches, therefore, operate only when multipath effects are minimal, and fail to provide reliable and accurate location information in urban environments where multipath effects are severe.

SUMMARY OF THE INVENTION

In contrast with all prior art location finding methods which attempt to eliminate or avoid multipath signals and their effects, the present invention advantageously uses multipath signals in order to accurately determine a transmitter's location. Surprisingly, in contrast to other techniques of location finding, the accuracy of the present technique is improved in severe multipath environments. Moreover, the present invention provides a method of location finding which, in contrast to other methods, can accurately determine a location from a single base station. This feature of the invention also distinguishes it from prior techniques which either require multiple base stations or provide only very inaccurate or imprecise location information. In addition, the present location determination technique does not require any modification to the transmitter, or to the existing base stations of the wireless communication system. The invention, therefore, provides a unique solution to the location finding problem which has heretofore remained unsolved.

According to the principles of the present invention, an antenna array of a location-finding apparatus coherently receives multi-dimensional signal vectors from a mobile transmitter. The specific technique for acquiring the signal vectors will depend on the wireless communication standard used by the transmitter. Once the signals are acquired, the apparatus

then calculates a transmitter signal signature from the received signal vectors. In general, a signal signature is defined as any location-dependent feature derived from the signals received at the antenna array from a transmitter at a given location. For example, the signature may be derived from various combinations of signal amplitude, phase, delay, direction, and polarization information derived from the signal vectors. Preferably, the signature is substantially invariant with respect to all variables unrelated to transmitter position, such as noise and interference. In a preferred embodiment, the signal signature comprises signal multipath characteristics of a spatial channel between the mobile and the location-finding apparatus. Most preferably, the signature comprises a signal covariance matrix formed from the signal vectors, or a subspace of the matrix spanned by its dominant eigenvectors.

The transmitter signal signature, together with calibrated signatures and corresponding calibrated locations are then used to determine one or more likely locations of the transmitter, for example, by calculating a similarity between the transmitter signature and each of the calibrated signatures. The likely locations correspond to the calibrated signatures that are most similar to the transmitter signature. In this manner, the location of the transmitter can be accurately determined from signals received at a single base station, even in a severe multipath environment. More sophisticated matching techniques can be used to reduce location ambiguity and provide more accurate location estimates. In addition, although the present techniques do not require more than one base station for accurate location determination, in the event that signatures from multiple base stations are available, they can be combined to increase the accuracy and confidence of the location estimates.

The calibrated signal signatures and corresponding locations are determined by a calibration procedure in which known locations are associated with transmitter signal signatures, preferably using a calibration transmitter equipped with a global positioning system (GPS) receiver. The calibrated signature and location information can then be collected, processed, organized, and stored in a database for subsequent use in real-time location determination.

The techniques of the present invention have various useful applications. For example, the database of signal signatures and locations can be used to derive antenna calibration information. This information, in turn, can be used to enhance location determination. In another useful application, the signature of a transmitter can be used to estimate its velocity. This velocity information, in turn, can be used to improve signal acquisition and signature determination, as well as location determination. The accurate location information provided by the present invention has a broad range of useful applications. To name just a few, the location information can be used to provide location-based services and information to mobile users, it can be used to track or locate people, vehicles, or other valuable objects that

may be missing, stolen, or in need of attention or assistance, and it can be used to provide to a wireless communications system operator real-time location-enhanced information that can assist in various types of network enhancement, diagnosis, planning, evaluation, analysis, or management.

DESCRIPTION OF THE DRAWINGS

FIGS. 1A, 1B, and 1C illustrate three levels of integration between an existing base station and a location determination apparatus (LDA) of the present invention. FIG. 1A shows an LDA closely integrated with a base station, FIG. 1B shows an LDA partially integrated with a base station, and FIG. 1C shows a stand-alone implementation of an LDA not directly connected to the base station.FIG. 2 is a block diagram of an LDA integrated with a base station, corresponding to the implementation shown in FIG. 1A.

FIG. 3 illustrates a spatial channel that is characterized by multipath propagation effects. According to the present invention, this spatial channel information measured and used to construct a signature that is highly correlated with the mobile position. Comparing the signature with calibrated signatures associated with known locations, the location of the mobile is estimated.

FIG. 4 is a block diagram of an LDA according to an embodiment of the present invention suited for a CDMA wireless system.

FIG. 5 illustrates the temporal structure of a CDMA signal according to the IS-95 standard. In particular, the CDMA signal is composed of a sequence of temporal frames, each having a duration of 20 ms. Each frame, in turn, is divided into 16 power control groups, each having a 1.25 ms duration.

FIG. 6 is a block diagram of an efficient receiver architecture according to an embodiment of the present invention suited for a CDMA wireless system.

FIGS. 7A, 7B, 7C, and 7D illustrate signal sampling schemes employed in a preferred embodiment of the present invention. FIG. 7A illustrates how approximately 100 signal samples are taken during a 1 ms sampling interval. FIG. 7B illustrates how a batch of signal samples from a given mobile device is collected once every 50 ms. FIG. 7C illustrates how batch covariance matrices for a given mobile device are collected over the course of a few seconds. FIG. 7D illustrates how a sequence of signal covariance matrices is generated over the course of time, with one covariance matrix added to the sequence every 5 s.

FIGS. 8A and 8B are schematic diagrams of geographical bins and sub-bins used in a calibration table compression technique of the present invention. The sub-bins shown

are squares about 10 m across, and the bins are squares about 30 m across. The locations of raw data points are shown in the figures as empty circles.

FIG. 9 is an illustration of the service region of an LDA containing a set of calibrated locations, shown in the figure as circled 'x' marks. The figure also shows an angular sector of the service region centered around an angle θ having an angular width $\Delta\theta$. According to one aspect of the invention, the calibrated signatures in the sector are used to calculate an array calibration vector.

FIG. 10 is a graph of a function $D(\mathbf{S},\mathbf{S}_k)$ with respect to calibrated locations k. The value of the function at a given location k is a measure of the similarity between a measured signature $\mathbf{S}$ and a calibrated signature $\mathbf{S}_k$. The graph also represents a "spectrum" of the signature $\mathbf{S}$ with respect to the entire set of calibrated signatures $\mathbf{S}_1,...,\mathbf{S}_N$. According to one matching technique, the likely locations of the mobile having signature $\mathbf{S}$ are the locations k(1),k(2),...,k(M) such that $D(\mathbf{S},\mathbf{S}_{k(j)}) > h$ for j=1,...M,, where h is a predetermined threshold value. This subset of points is illustrated in the figure as those points above the dotted line corresponding to the value of h.

FIG. 11 shows the graph for a measured signal spectrum $\mathbf{w}$ together with the graphs for two calibrated spectra $\mathbf{w}_{k(1)}$ and $\mathbf{w}_{k(2)}$. According to a preferred matching technique, the likely locations of a mobile having spectrum $\mathbf{w}$ are found by comparing $\mathbf{w}$ with the calibrated spectra $\mathbf{w}_1,...,\mathbf{w}_N$. For example, as is evident from the figure, the spectrum $\mathbf{w}_{k(2)}$ is more similar to the spectrum $\mathbf{w}$ than to the spectrum $\mathbf{w}_{k(1)}$. Thus, location k(2) is more likely than location k(1).

FIG. 12 is a graphical representation of mobile "tracks" according to a preferred ambiguity reduction technique. The tracks are illustrated in the figure by solid curves. The tracks, which represent past hypothetical trajectories derived from sets of likely locations collected over time, are used to predict a set of next points, shown as empty circles. Ambiguities in a current set of likely locations can be reduced by reducing the probabilities for locations that are not close to the predicted next points.

FIG. 13 illustrates a system used to implement a technique for resolving ambiguity by combining sets of likely locations obtained from multiple LDAs. A central hub collects the location information over communication lines. Because the location information is independently derived at separate LDAs, it can be combined to reduce ambiguity and increase confidence.

FIG. 14 is a schematic diagram of a hierarchical tree structure used in a technique to improve the computational efficiency of the real-time signature matching. The tree structure is composed of a number of nodes, shown as circles in the figure. Each calibrated location is assigned to at least one bottom node. The nodes higher in the tree contain the union of all nodes connected downward from them. In the search of similar

calibrated signatures, this tree can be used to eliminate a significant amount of computation.

DETAILED DESCRIPTION

Although the following detailed description contains many specifics for the purposes of illustration, anyone of ordinary skill in the art will appreciate that many variations and alterations to the following details are within the scope of the invention. Accordingly, the following preferred embodiment of the invention is set forth without any loss of generality to, and without imposing limitations upon, the claimed invention.

System Architecture

NETWORK OVERVIEW

A preferred embodiment of the present invention is designed to operate in the context of one or more wireless communication systems providing services to cellular telephones, pagers, wireless modems, and other portable communication devices. Each communication system includes a number of base stations, each designed to communicate with the portable devices in its geographical area, or cell. Downlink radio frequency (RF) signals are transmitted from the base station to the portable devices, and uplink RF signals are transmitted from the portable devices to the base station. A conventional base station typically has a set of six directional antennas for transmitting the downlink signals and receiving the uplink signals. These six antennas are normally grouped into three pairs, where each pair is designed to serve a 120-degree sector of the cell. When communicating with a portable device in a particular sector, only one of the six antennas is normally used. In particular, the antenna used for a particular mobile device is dynamically selected to provide the best signal. If the quality of the communication link between a base station and a mobile device degrades, the communication system typically attempts to hand-off the link to another base station that can provide a higher quality link. In this manner, a portable device moving throughout the communication system's network of cells can receive continuous service. The location of a particular device in these conventional systems is known only approximately. The network knows which base station is serving the mobile device, and can sometimes determine which antenna is being used for communication with the device. Using this information, however, the location of a user can be narrowed down to an area of several square kilometers, at best.

LOCATION FINDING APPARATUS

A location determination apparatus (LDA) according to the present invention is used to provide more accurate and precise location information of mobile devices. As illustrated in FIGS. 1A, 1B, and 1C, the LDA may be integrated partly or completely with an existing base station of a communication system, or may be a separate stand-alone apparatus operating idependent of other communication systems. For example, FIG. 1A shows and LDA 100 integrated with a base station 102. In this integrated implementation, the LFA makes use of the existing antennas of the base station, and has no antennas of its own. Because these antennas are directly connected to the LDA, they are considered part of the LDA. In a highly integrated implementation, the LDA is not only connected to the base station antennas, but is also connected to the internal electronic equipment of the base station. Such a connection can be used, for example, to communicate user channel assignment information from the base station to the LDA, and/or to communicate location information from the LDA to the base station. In a partial integration, as shown in FIG. 1B, an LDA 104 has its own antennas and is independent and separate from the base station, with the exception of a communication link for exchanging information. In a stand-alone implementation, shown in FIG. 1C, an LFA 108 and a base station 110 are not directly connected at all, although they may be indirectly connected via a larger network.

An integrated implementation of an LDA 112 with a base station 114 is illustrated in FIG. 2. The LDA 112 comprises a set of p antennas 116, a multichannel receiver 118 which coherently receives signals from the p antennas, a multi-purpose signal processor 120 which performs signal signature identification, database searching, and other required processing as will be described in detail below, and a memory storage device 122 accessible by the processor and used to store signal signature calibration data, location data, geographical map data, and/or other data as required. Location information determined by the processor is preferably sent over external communication lines 124 for use by other systems. The location information may also be provided to a routing controller 126 connected to a switching matrix 128 of the base station 114. The switching matrix 128 performs antenna beamforming or switching in dependence upon location-dependent signals from routing controller 126. A receiver 130 and transmitter 132 of the base station are connected to the antennas 116 by means of the switching matrix. Thus, the transmission and reception of the base station may be controlled by location-based routing information derived from LDA 112. The implementation shown in FIG. 2 is one example of a highly integrated implementation, corresponding to FIG. 1A. A stand-alone implementation of LDA 112 would not have routing controller 126, and would not share antennas 116 with base station 114. The essential principles of operation would otherwise be the same.

In contrast with the base station which communicates with a particular mobile using just one selected antenna at any given time, the LDA coherently receives signals from all the antennas simultaneously. The coherent multichannel receivers 118 preserve relative phase information between the signals received at the various antennas 116. As a result, subtle information about the spatial channel can be determined, as will be described in detail below. In particular, this spatial channel information includes multipath signal information, as shown in FIG. 3. Typically, in addition to a direct path signal 134 from a mobile device 136 to an LDA 138, there are one or more additional multipath signals 140 reflected from various environmental objects. In addition, there are typically various smaller local scatterers (not shown) positioned within a region 142 around the device. The coherently received signals at the LDA 138 thus include subtle spatial channel information corresponding to these reflected and scattered signals.

ARCHITECTURE FOR CDMA SYSTEMS

The wireless communication system can employ various conventional air standards and protocols, such as AMPS and CDMA. In the case of the more complicated CDMA standard, such as IS-95, some additional description will be helpful. In a CDMA communication system, all user devices share a common frequency band, and the different mobile devices are distinguished by their use of distinct PN spreading sequences. At the base station, the signals from a device are coupled to one of the antennas, downconverted to IF, and then digitized. The digitized signals are then correlated with PN sequences in order to separate the signals from different mobile devices. Low cross-correlation between the unique PN sequences ensures that there is little interference between mobiles within the base station service area. Well-known timing synchronization techniques are used to identify and lock onto the PN sequence for each mobile. After the user signal has been separated, it is typically sent into an inverse Hadamard transformer in order to extract Walsh symbols from the signal. Various decoding and interleaving functions may also be performed in order to reconstruct the information signal originating at the mobile device, as is well known in the art.

In an LDA 144 according to a CDMA embodiment of the present invention, the p antenna signals are coupled to coherent multichannel IF down-converters and A/D converters 146 to produce a set of p digitized complex signals, as shown in FIG. 4. Down-conversion and digitization are performed coherently so as to preserve the phase relationships between the separate signals from the p antennas. A common local oscillator and a master clock are used to maintain coherence between the parallel functions performed on all the signals from the p antennas. In the figure, the LDA 144 is integrated with a base station 148 which has its own

transmitter 150 and receiver 152. Stand-alone and partially integrated implementations, however, are also possible.

The p complex signals are separately despread in synchronized multichannel despreaders 154 of a CDMA receiver 156 of the LDA. In one embodiment, user PN sequence information is provided from the base station 148 so that the LDA can despread the signals. Alternatively, in stand-alone implementations, the LDA can obtain this information from the user device. For example, the user device can transmit its code channel information to an internet computer via a wireless modem link. The LDA can then query the computer and obtain the user information, thus by-passing the need to obtain it from the base station. In any case, once the PN sequence information for the user is obtained, the LDA despreads the p signals. In contrast with the base station receiver 152 which simultaneously performs despreading for all mobiles being served, the receiver 156 of the LDA sequentially time samples the signals from the set of current mobiles, thereby dramatically reducing hardware requirements and cost. To perform this sequential despreading, accurate code timing information is required. This information can be obtained from base station receiver 152. Alternatively, the code timing information can be acquired and tracked by the receiver of the LDA using well known techniques. Intermittent time samples are sufficient for the LDA because its purpose is not to acquire all the original signal information, but to acquire a spatial channel signature.

Although the LDA receiver architecture in a CDMA system is preferably adapted in the above manner, the high-level LDA architecture and principle of operation is the same.

Signal Measurement

Signal Vector Sample Acquisition

The LDA hardware coherently receives complex signal samples. These samples are later used to calculate spatial channel signatures, which are the basis for location determination. More specifically, the p antennas are used to receive complex signals $x_1(t)$, $x_2(t)$,..., $x_p(t)$, respectively, which are represented by a p-dimensional signal vector $\mathbf{x}(t) = [x_1(t), x_2(t),..., x_p(t)]^T$. At a moment t in time, each component $x_j(t)$ of this vector is a complex number having both amplitude and phase information from one of the antennas. In general, the dimension of the array vector $\mathbf{x}(t)$ is equal to p, the number of antennas in the array. The value of p is preferably in the range from 2 to 12, and is more preferably in the range from 4 to 8. Most preferably, the value of p is conveniently chosen to be 6 so that the existing antennas of a base station may be used.

SIGNAL ACQUISITION IN CDMA SYSTEMS

Signal acquisition in a CDMA system is more complicated, and therefore will be discussed in more detail. As is well known in the art, a conventional CDMA receiver can isolate multipath parts of a signal if their differential delay is more than one chip length. The signal parts are normally extracted by "fingers" of the receiver and then combined after temporal alignment to get improved signal strength. Each finger comprises a correlation receiver matched to the exact delay associated with a particular multipath part. Note, however, that this standard technique only distinguishes temporally distinct multipath parts, and does not distinguish spatially distinct multipath parts that have similar temporal delays.

The CDMA receiver 156 in the LDA 144 of FIG. 4 adapts the above technique for separating multipath parts in order to provide refined discrimination in location finding. For simplicity in the following discussion, we consider a signal from a single mobile device. At the p antennas of the LDA, this signal gives rise to a set of p coherently received signals $x_1(t)$, $x_2(t)$,..., $x_p(t)$. In the synchronized multichannel despreaders 154, each component $x_j(t)$ of this set is then decomposed using q correlation receivers into q temporally distinct signals $x_{j,1}(t),...,x_{j,q}(t)$, where j is the antenna index of the signal and q is the number of fingers used. Thus, a total of p×q correlation receivers are used. Preferably, q is in the range from 1 to 8. More preferably q is in the range from 2 to 6. Most preferably, q=4. The multipath parts contained within a given finger all have delays within one chip from each other, while the delays between fingers are more than one chip. Each set of p samples from a given finger i is represented by a p-dimensional vector $\mathbf{x}^{(i)}(t)=[x_{1,i}(t),...,x_{p,i}(t)]^T$. All q vectors $\mathbf{x}^{(1)},...,\mathbf{x}^{(q)}$ are then sent to a signal processor 158 for subspace determination, as will be described further below.

The CDMA receiver 156 contains a searcher 160 that searches the original signals $x_1(t)$, $x_2(t)$,..., $x_p(t)$ for the best code delays to be used by the q despreaders. The searcher produces a code correlation output that represents the degree to which the delayed code matches the incoming signals. A sequence of L delay values $\tau_1,...,\tau_L$ are selected that are spaced by 1/2 chip length. Typically, L is approximately 200, so that the temporal span of the sequence is 100 chips. At each of the delay values, a corresponding code correlation value for the signal is measured from the code correlation output. The code correlation values from the jth antenna is represented as a sequence $C^{(j)}(\tau_1),...,C^{(j)}(\tau_L)$, where $C^{(j)}(\tau_i)$ is the value of the correlation between the signal $x_j(t)$ and a code with temporal delay τ_i. The

correlation output sequences for all p signals are sent to the signal processor 158 for construction of the correlation signature.

The searcher 160 examines the code correlation output to determine a set of q time delays $\tau^{(1)},...,\tau^{(q)}$ which correspond to the strongest correlations. There are various well known methods of determining such time delays. For example, these time delays may be determined by selecting the q values of τ that correspond to the q largest local maxima in the set $\{C^{(j)}(\tau_i) : j=1,...p; i=1,...,L\}$. Once these delays are determined, they are then sent to the despreaders 154 to control the despreading of each of the q fingers corresponding to these delays. The delays are also sent to the processor 158 for signature determination.

In order to achieve optimal use of hardware, the signals from the receivers can be sampled at regular time intervals. This optimization, however, requires some modification of conventional CDMA receiver architecture, which will now be described in detail with reference to FIGS. 5 and 6. In the following description, it is assumed that p=6 and that the IS-95 standard is used. The principles of this optimization, however, do not depend on these particular assumptions. Moreover, it should be emphasized that the present invention does not require this optimization in order to be usefully implemented.

It should be noted that the CDMA signal from each device has a standard temporal structure. In particular, the CDMA signal is composed of a sequence of temporal frames, each having a duration of 20 ms and containing 192 bits of information, as shown in FIG. 5. Each frame, in turn, is divided into 16 power control groups, each having a 1.25 ms duration. At high data rates, all 16 power control groups contain information. At the lowest data rate, only two power groups are active, i.e. contain information. At low rates, the placement of the active groups within the frame is pseudorandom.

As shown in FIG. 6, the signals from each user device in the coverage area of the LDA are coupled to the six antennas and received by a corresponding bank of six receivers 164. These receivers are coherently synchronized so that they preserve the relative phase information between the signals coupled to the six antennas. Each receiver downconverts the signal from one antenna to baseband, and then digitizes the signal to produce I and Q signal components. At this point, the signals from the various user devices have not yet been distinguished. The six digitized signals produced by the receiver bank 164 are sent to a corresponding bank of six signal buffers 166. Each signal buffer stores data samples covering several recently received digitized signal frames. Typically, each buffer is large enough to store three or more frames of data. At periodic intervals of 1.25 ms, a buffer

control circuit 168 calculates a buffer address that is used to select a power control group from the signal frames currently in each buffer. The specific buffer address is calculated so that during each power group time interval an active power group is selected from one of up to 16 distinct user phones. The output from each of the six buffers, therefore, is a data stream of selected power groups delayed by approximately three frames, where each of the 16 power group intervals in a frame can contain an active power group from one of up to 16 distinct user signals. Buffer control 168 sends a common set of signals to the buffers in signal buffer bank 166. These signals include buffer record and playback addresses, read/write signals, and buffer configuration data.

The six data streams from the buffer bank 166 are sent for despreading to a bank of six corresponding despreaders 170. In each despreader, the incoming data stream of selected power groups is correlated with appropriate PN sequences in order to despread the data. In a CDMA communication system, all users share a common frequency band, and the different mobile phones are distinguished by their use of distinct PN spreading sequences. Low cross-correlation between the unique PN sequences ensures that there is little interference between different users within the base station service area. In addition, low cross-correlation between distinct delayed versions of a given PN sequence ensures that there is little interference between various multipath parts of a signal originating from a single user. Well-known timing synchronization techniques are used to identify and lock onto the PN sequences of the multipath parts for each user.

In contrast with conventional use, despreaders in the present apparatus have their PN sequences changed every 1.25 ms by a despreader control circuit 172. The PN sequence is changed in synchronization with the transition between power groups so that, during each of the 16 power groups in a frame, the despreader uses the PN sequence corresponding to one of 16 users. The output from each despreader, therefore, is a despreaded I/Q data stream where each of the 16 power group intervals in a frame contains the despreaded signal from one of up to 16 user signals.

It is significant to note that the resulting six signal data streams do not contain all the information transmitted from the mobile phones. Rather, each frame coming out of the despreaders contains up to 16 active power group samples derived from up to 16 different mobile phones. Note that since the despreading essentially separates the multipath parts with differential delays greater than the chip period, it is possible to obtain the spatial signatures of all the significant multipath parts (referred to as fingers) of every mobile. In the present system, up to four fingers per mobile can be despread. The despreader output is used for determining spatial signal information, as will be described in more detail below.

We now turn to a description of the operation of buffer control circuit 168 and despreader control circuit 172. A common set of signals are sent from despreader control 172 to despreader bank 170. Specifically, these signals include two PN sequences: a combined I despreading sequence and a combined Q despreading sequence. Each of these sequences is a chip-by-chip product of all the spreading signals involved in spreading the signal in the transmitter. In the case of IS-95, these spreading signals include the long code, the Walsh codes, and the short I or Q sequences.

It is important to note that the Walsh codes are normally used as the transmitted symbols and thus contain the transmitted signal information. The present technique, however, treats the Walsh code as just another spreading signal. Including the Walsh code as part of the spreading signal provides improvements in processing at the LDA receiver in determining the phase of the received signals. In the preferred embodiment, the Walsh code information is obtained by sending the decoded data bits from the CSM board through a convolutional encoder, an interleaver, and a Walsh encoder, just as was done in the mobile prior to transmission. It will be appreciated that other codes or training sequences used by various other standards can be used just as the Walsh codes are used in the IS-95 standard described in this embodiment. It will also be appreciated that the Walsh codes could, in principle, be provided by the CSM board since the decoders determine the Walsh codes in order to produce the data stream. Although presently existing CSM integrated circuits do not provide Walsh code output, such integrated circuits may be produced in the future and could be used in the context of the present invention.

A despread IRQ (DES. IRQ) signal is issued on any power control group timing interval transition and serves to trigger the microprocessor 174 to load the next set of despreading parameters into the despread control and buffer control. The GPS IRQ is issued on each UTC second boundary and triggers the microprocessor to perform various housekeeping tasks. The system bus 176 carries information between system components. For example, data sent over the bus includes system reset commands, buffer address information for data playback, PN sequence states for despreading, PN mask information for data despreading, Walsh codes for data despreading, and CSM data and control information.

The six digitized signals produced by the receiver bank 164 are sent to a conventional CDMA modem board 178 which contains 16 conventional CSM integrated circuits which contain searchers, despreaders, fast Hadamard transform (FHT) processors, deinterleavers, decoders, and other well-known circuitry required to produce Walsh symbols and other signal information from the signals received from up to 16 mobile devices. The conventional CDMA modem board 178 does not produce spatial signal information. It does, however, provide data transmitted by each one of the user devices, the rates of transmission for each

user, PN sequence information, finger offset information for up to eight paths per user, frame offset information, and power group placement information. This information is made available over the data bus 176 to the microprocessor 174, which computes buffer addresses that are sent over the bus to the buffer control circuit 168, and PN sequences that are sent over the bus to the despreader control circuit 172. The purpose of the three-frame delay of the buffers is to allow time for the microprocessor to compute the buffer addresses, PN sequences, and other control parameters. A GPS timing circuit 180 is used to provide precise timing and synchronization information to CDMA modem board 178, buffer control circuit 168, and despreader control circuit 172. The signals sent from GPS timing circuit to receiver board 178, buffer control 168, and despread control 172 include a CHIPx16 clock (1.2288 x 16 MHz) and a pulse per 2 second signal (even second pulse).

The six output data streams from the despreaders 170 are low-pass filtered and then made available on a DSP data bus 182. These samples are then collected by a digital signal processor (DSP) 184. The DSP first performs a frequency estimation that is aimed at nulling the frequency error of the sampled signals. This frequency error is the result of the difference in frequencies between the user transmitter and the base station receiver. Since the frequency error can be up to several hundred Hertz, when the signal is despreaded and downconverted to baseband, it will have a residual non-zero frequency. Therefore, since signal samples in the present system are averaged over relatively long periods of time, the residual frequency must be corrected to prevent the samples from averaging out to zero. The DSP therefore first determines the residual frequency, and then corrects it before averaging the samples. This correction data is used by receiver control 186 to set receiver frequency and attenuation of receivers 164.

The specific functions performed by the microprocessor 174 include:

1. Initializing and controlling CSMs, GPS timing, buffer control, and despreader control.
2. Reading rates, offsets, active power groups, and transmitted data of subscribers from CSMs.
3. Computing transmitted Walsh codes from the received data.
4. Loading Walsh codes into despreader control before each power control group interval transition.
5. Loading playback address into buffer control before each power control group interval transition.
6. Receiving subscriber data from the DSP for despreading.
7. Sending, for each batch of data sent to the DSP from the despreader, a descriptor to the DSP identifying the subscriber associated with the data.

The specific functions performed by the DSP 184 include:

1. Computing a frequency error for each subscriber.
2. Correcting the frequency error for each received data batch.
3. Computing covariance matrices for each data batch.
4. Transferring covariance matrices to the location finding processor 188.
5. Transferring instructions to the microprocessor (e.g., subscriber lists and parameters)

The specific functions performed by the receiver control 186 include:

1. Setting the receiver frequency.
2. Setting the receiver attenuation.

In order to compute the spatial signature of a CDMA signal, one must first despread it. To determine the spatial signature, however, it is not necessary to capture or even compute the actual information data stream. For the purposes of the spatial signature measurement technique of the present invention, the important information is not the information data stream itself, but rather the spatial channel information derived in part from the relative phase information between the antennas of the array. Consequently, the present technique is distinct in motive, method, and result from known CDMA reception techniques. It provides an efficient method and system for simultaneously determining spatial signal information for multiple users in a CDMA communications system.

Data Collection and Averaging

SIGNAL BATCHES AND STANDARD AVERAGING

In a preferred embodiment, a p-dimensional received signal $\mathbf{x}(t)$ for a specific mobile device is regularly sampled during a sampling interval to produce a batch of signal vector samples, $\mathbf{x}(t_1)$, $\mathbf{x}(t_2)$,..., $\mathbf{x}(t_N)$. In one embodiment illustrated in FIG. 7A, approximately 100 samples are taken during a 1 ms sampling interval, i.e., the signal is sampled every 10 μs, so that the difference $\Delta t_j = |t_i - t_{i+1}|$ is 10 μs. The outer products of these 100 vectors in the 1 ms batch are then combined to form a p×p covariance matrix for the batch.

For each mobile device, a batch of signal samples is collected once every 50 ms, as shown in FIG. 7B, and a corresponding batch covariance matrix is calculated. The batch covariance matrices for a given mobile device are then collected over the course of a few seconds (e.g., 5 s), as shown in FIG. 7C. These batch covariance matrices are then averaged to form a p×p signal covariance matrix, **R**, which is normalized such that Tr **R** = 1. This normalized covariance matrix is used as the basis for subsequent calculations, as will be described below.

Because each batch spans only 1 ms, there is sufficient time using this technique to sample signals from up to 50 different user devices in a 50 ms interval. In other words, the signals from a first user device are sampled during a first 1 ms interval, the signals from a second user device are sampled during a second 1 ms interval, and so on. After 50 ms, the signals from the first user device are again sampled.

Those skilled in the art will appreciate that similar sampling method also may be implemented using various other values for the time intervals, number of signal vectors sampled per batch, etc. In addition, one can also use a non-uniform sampling scheme wherein each mobile is sampled at a period inversely proportional to the speed of its physical movement, or according to other criteria. Although the present description is focused upon the processing of the signals from a single user device, in the preferred embodiment, the techniques described herein are applied to signals from a number of users.

It will be recognized by those skilled in the art that although this sampling procedure is appropriate for the AMPS cellular standard it can be adapted to various other modulation schemes as well. In the case of a CDMA cellular network, for example, spread spectrum signals from the antenna array are digitized and passed through synchronized multichannel despreaders to produce the p-dimensional array vectors **x**(t) corresponding to each mobile. These vectors can then be sampled and averaged to form a covariance matrix in the manner outlined above. More specific details of such a CDMA implementation will now be described.

In the preferred embodiment, a batch of signals for a given mobile is collected every 60 ms in a time interval of length 1.25 ms. Thus, up to 48 different mobiles can be sampled in the 60 ms interval. Obviously, more mobiles can be handled by either decreasing the 1.25 ms batch interval length, or increasing the 60 ms repetition interval. In addition, the hardware can be duplicated so that several mobiles are processed in parallel rather than sequentially. These various implementations involve consideration of various trade-offs, but do not alter the essential technique of the present invention.

The outer products of the signals in each batch are combined to form a batch covariance matrix. If signals from multiple fingers are available, there will be a batch covariance matrix for each finger. The batch covariance matrices for each finger are then averaged over several seconds to produce a signal covariance matrix **R**. If there are multiple fingers, there will be multiple signal covariance matrices.

The sampled time delays and correlation data are also averaged in an analogous manner over the several second period. These averaging techniques help to reduce the effects of noise in the measured signature.

VELOCITY DEPENDENT AVERAGING

In addition to uniform averaging, various types of nonuniform averaging can be used to increase the efficiency and performance of the signal acquisition. In particular, estimates of the mobile device velocity can be used to control the averaging, as will now be described in relation to FIG. 7D. For a given mobile device, the batch covariance matrices for approximately 100 batches are averaged over a few seconds as described earlier to form a p×p signal covariance matrix **R**. According to the present velocity-dependent averaging technique, this initial covariance matrix is denoted $\mathbf{R}_{t_0}$, where t_0 is the time **R** is measured. As the system continues to operate in real time, another signal covariance matrix $\mathbf{R}_{t_1}$ is determined in the same way from the batch covariance matrices measured over the course of a few seconds that elapse between time t_0 and a later time t_1. In this manner, a sequence of signal covariance matrices $\mathbf{R}_{t_0}$, $\mathbf{R}_{t_1}$, $\mathbf{R}_{t_2}$,..., $\mathbf{R}_{t_n}$ is generated, where $\mathbf{R}_{t_n}$ denotes the most recent covariance matrix. Preferably, the difference $\Delta t_i = |t_i - t_{i+1}|$ is in the range from 0.1 to 20 seconds, but is more preferably between 1 and 10 seconds, and most preferably 5 seconds (assuming uniform sampling).

In accordance with the teaching of the present invention, an average signal covariance $\overline{\mathbf{R}}_{t_n}$ is produced in real time by forming a linear combination of the covariance matrices $\mathbf{R}_{t_0}$, $\mathbf{R}_{t_1}$, $\mathbf{R}_{t_2}$,..., $\mathbf{R}_{t_n}$. In the preferred embodiment, the specific manner in which the covariance matrices are combined to produce the average covariance matrix depends on estimates of the transmitter velocity, represented by $v_{t_0},\ldots,v_{t_n}$. Preferably, the covariance matrices combined to form the average covariance matrix are those collected over a time interval in which the transmitter has moved a distance D, where D is a predetermined distance corresponding to the average spatial span between the calibrated signature locations. Generally, if the velocity estimate is large, then the matrices are combined such that the most

recent covariance matrices contribute significantly to the average covariance, while the less recent covariance matrices contribute relatively little to the average covariance matrix. Conversely, if the velocity estimate is small, then the contribution of the less recent covariance matrices is not so small. The velocity estimates can be determined using various techniques known in the art. Alternatively, velocity can be estimated based on recent location estimates derived from techniques of the present invention, or directly from recent covariance matrices, as will be described below. For the purposes of this description, we assume velocity estimates are positive velocity magnitudes.

In one implementation of the preferred embodiment, an average covariance matrix $\bar{\mathbf{R}}_{t_n}$ is calculated by evaluating

$$\bar{\mathbf{R}}_{t_n} = (1/D_m) \sum_{i=m}^{n} v_{t_i} \Delta t_i \mathbf{R}_{t_i} = (v_{t_m} \Delta t_m \mathbf{R}_{t_m} + \ldots + v_{t_n} \Delta t_n \mathbf{R}_{t_n})/D_m,$$

where $D_m = v_{t_m} \Delta t_m + \ldots + v_{t_n} \Delta t_n$ and m is selected such that $D_m \approx D$. In other words, m is selected so that the past covariance matrices $\mathbf{R}_{t_m}, \ldots, \mathbf{R}_{t_n}$ are those collected over a time interval in which the transmitter has moved a distance D. It will be noted that, assuming the time intervals $\Delta t_m, \ldots, \Delta t_n$ are constant, the coefficients that determine the relative weights of the past covariance matrices are proportional to the estimated transmitter velocities. A covariance matrix corresponding to a small velocity will therefore contribute less to the average covariance matrix than a covariance matrix corresponding to a large velocity. In accordance with this general principle, those skilled in the art will be able to construct many other formulas for calculating the average covariance matrix from past covariance matrices.

In another implementation of the preferred embodiment, the average covariance matrix is calculated from the most recent past covariance matrix and velocity estimate and the last average covariance matrix. In other words, $\bar{\mathbf{R}}_{t_n}$ is calculated recursively by evaluating

$$\bar{\mathbf{R}}_{t_n} = f(v_{t_n}, \mathbf{R}_{t_n}, \bar{\mathbf{R}}_{t_{n-1}}),$$

where f is a function of the current estimated velocity of the transmitter v_{t_n}, the current covariance matrix $\mathbf{R}_{t_n}$, and the most recent prior average covariance matrix $\bar{\mathbf{R}}_{t_{n-1}}$. This is a recursive definition since the covariance matrix $\bar{\mathbf{R}}_{t_{n-1}}$ is similarly calculated from

$$\bar{\mathbf{R}}_{t_{n-1}} = f(v_{t_{n-1}}, \mathbf{R}_{t_{n-1}}, \bar{\mathbf{R}}_{t_{n-2}}).$$

Thus, one may write

$$\bar{\mathbf{R}}_{t_n} = f(v_{t_n}, \mathbf{R}_{t_n}, f(v_{t_{n-1}}, \mathbf{R}_{t_{n-1}}, \ldots f(v_{t_1}, \mathbf{R}_{t_1}, f(v_{t_0}, \mathbf{R}_{t_0}, \mathbf{R}_{t_0}))\ldots)),$$

where $v_{t_0},\ldots,v_{t_n}$ are the estimated velocities at times $t_0,\ldots,t_n$. Although many possible functions f may be selected for use, in one implementation the function f is defined by forming the following linear combination of $\bar{\mathbf{R}}_{t_{n-1}}$ and $\mathbf{R}_{t_n}$:

$$\bar{\mathbf{R}}_{t_n} = f(v_{t_n}, \mathbf{R}_{t_n}, \bar{\mathbf{R}}_{t_{n-1}}) = \lambda_{t_n} \bar{\mathbf{R}}_{t_{n-1}} + (1-\lambda_{t_n}) \mathbf{R}_{t_n},$$

where λ_{t_n} is a velocity-dependent coefficient that takes values between 0 and 1. Values of λ_{t_n} near 1 result in large retention of past covariance information, while values of λ_{t_n} near 0 result in large forgetting of past covariance information.

In one implementation of the present invention, the values for $\lambda_{t_0},\ldots,\lambda_{t_n}$ are calculated from time-dependent velocity estimates $v_{t_0},\ldots,v_{t_n}$. The value of λ_{t_n} is calculated such that a very large velocity estimate v_{t_n} results in a value of λ_{t_n} near 0, and hence large forgetting of past covariance information, while small velocity estimates result in values of λ_{t_n} near or equal to 1, and hence large or total retention of past covariance information. Although many formulas have these properties, one example of a formula for calculating λ_{t_n} is the following:

$$\lambda_{t_n} = e^{-v_{t_n}\Delta t_n / D},$$

where Δt_n is on the order of a few seconds, D is on the order of a few tens of meters, and v_{t_n} is the current estimate of the transmitter velocity. For example, in the case where $\Delta t_n = 1$ s and D=25 m, a velocity of $v_{t_n} = 0$ will result in $\lambda_{t_n} = 1$. A velocity of

v_{t_n} = 25 m/s = 90 km/hr), on the other hand, will result in $\lambda_{t_n} = e^{-1} = 0.368$. It will be appreciated that many other equations for λ_{t_n} may be used to produce substantially equivalent effects. For example,

$$\lambda_{t_n} = 1/(1 + v_{t_n})$$

or

$$\lambda_{t_n} = 1/(1 + (v_{t_n})^2).$$

In an alternate embodiment, the value for λ_{t_n} is selected from a finite set of predetermined values $\lambda_1,...,\lambda_m$. The particular value selected depends on the value of v_{t_n}. For example,

$$\lambda_{t_n} = \begin{cases} 1 \text{ if } v_{t_n} < v_{low} \\ 0 \text{ if } v_{t_n} > v_{high} \\ .5 \text{ otherwise,} \end{cases}$$

where v_{low} and v_{high} are predetermined low-velocity and high-velocity thresholds, respectively.

This technique for calculating an average covariance matrix from past covariance matrices has important advantages. Because the current covariance matrix of a very slowly moving or stationary transmitter has less information than that of a moving transmitter, it correlates weakly with location and introduces ambiguity into the location finding process. The present technique, however, retains past covariance information when the velocity is small or zero, and overcomes this problem. When the transmitter is moving quickly, on the other hand, the current covariance matrix correlates strongly with the current location, while the past covariance matrices correlate strongly with past locations. Because the present technique forgets past covariance information in this case, it provides an automatic and adaptive way to generate an average covariance matrix that is most highly correlated with the current location.

Signature Computation

The signal signature for a mobile device captures the essential spatial channel information derived from the signals received at the antenna array. Because the signal signature depends on the spatial channel information, it is highly correlated with the spatial location of the mobile. The signal signature preferably includes location-dependent aspects of the spatial channel, and preferably excludes as much as possible location-independent aspects such as noise. More preferably, the signal signature includes signal multipath information resulting from multipath propagation effects in the environment, preferably derived from phase and amplitude information measured at an antenna array. Most preferably, the signal signature includes one or more of the following elements: a spatial subspace of the signal covariance matrix, relative time delays of signal multipath parts, and code correlation information. The signature can also be represented in other ways, such as higher order spectra of the signals. Signal subspaces may be also extracted via other techniques involving cumulants and higher order statistics in conjuction with second order statistics represented by the signal covariance matrix. Cumulants can then be used to recover more phase information than is possible from the covariance matrix alone and in addition possess more robust properties in the presence of additive Gaussian observation noise.

Covariance Matrix Subspace Calculation

In a preferred embodiment, the signal signature includes as its primary component a signal subspace $\mathbf{U}$ spanned by the dominant eigenvectors of the signal covariance matrix $\mathbf{R}$. The dominant eigenvectors are defined as the eigenvectors of $\mathbf{R}$ corresponding to the largest eigenvalues that collectively capture at least certain percentage of the total signal energy. Preferably, this percentage is at least 70%, but is more preferably 90%. It should be emphasized that the signal subspace may be determined by various different criteria as well.

In the case of a CDMA system, q signal subspaces $\mathbf{U}^{(1)},\ldots, \mathbf{U}^{(q)}$ are preferably calculated for the q signal covariance matrices $\mathbf{R}^{(1)},\ldots, \mathbf{R}^{(q)}$ of the q fingers. It should be noted that each multipath signal in a finger i normally contributes an extra dimension to the subspace $\mathbf{U}^{(i)}$. Consequently, the subspace will have an increased dependence upon location in the presence of severe multipath.

Correlation and Time Delay Information

In addition to the signal subspace, differential time delays for the multipath parts can also be used as part of the signal signature. These delays can be used to further enhance the signal

signature in order to provide additional location dependence. As a result, the delays provide the system with increased location accuracy, and also can be used to resolve ambiguities in location, such as may arise in the case of a stationary phone using a narrowband modulation scheme. (Note that, in contrast with the time difference data in the prior art which consists of time differences of the direct signals arriving at several different base stations, the differential time delay data used herein involves the time differences between the multipath signal parts arriving at a single base station.)

In one embodiment, differential time delays between multipath signals may be calculated as follows. First one performs a blind estimation of the array response matrix **A** during the calibration procedure by techniques well-known in the art, such as high-order statistics. The columns of the matrix **A** consist of the set of linearly independent array response vectors. Note that in the case where the differential delays are small compared with the reciprocal of the signal bandwidth, the invention exploits transmitter movement to decorrelate signals and determine **A**. The matrix **A** is then used to determine a weight matrix **W** such that $\mathbf{WA}=\mathbf{I}$. Using **W** and the sampled signals, one then resolves the q multipath signal parts and calculates their relative time delays, $\tau^{(1)},...,\tau^{(q)}$. These time delays and the matrix **A** associated with each location are stored in the calibration database. (Since the signal subspace may be determined from **A**, it is not necessary to store the signal subspace if **A** is stored.) When attempting to locate a transmitter with an unknown location, this additional information in the database may be used to improve the accuracy as follows. After determining a set of likely locations using subspace matching, the stored matrix **A** is used to calculate differential time delays based on the sampled signals, as was done in the calibration procedure. These time delays are then compared with the stored time delays to help resolve location ambiguities.

In the case of a CDMA implementation, the blind estimation technique is not required to obtain the time delays $\tau^{(1)},...,\tau^{(q)}$ since this delay information is provided by the signal acquisition, as was described above. Preferably, the time delay signature is represented as a vector defined by $\tau=[\tau^{(1)},...,\tau^{(q)}]^T$. In addition, a CDMA implementation also provides the code correlation data represented as a matrix $\mathbf{C}=[\mathbf{C}^{(1)T},...,\mathbf{C}^{(p)T}]^T$, where $\mathbf{C}^{(j)}=[C^{(j)}(\tau_1),...,C^{(j)}(\tau_L)]^T$. The subspaces $\mathbf{U}^{(1)},...,\mathbf{U}^{(q)}$, together with the matrix **C** and the vector τ, are used to construct a signal signature that captures essential location-dependent information about the spatial channel for the mobile at its current location. In addition, the covariance matrices $\mathbf{R}^{(1)},...,\mathbf{R}^{(q)}$ can also be used as part of the signature.

The signal signature in the database for each location $\mathbf{d}_k$ preferably includes the calibrated spatial signature $\mathbf{S}_k=\{\mathbf{U}_k^{(1)},...,\mathbf{U}_k^{(q)};\ \mathbf{R}_k^{(1)},...,\mathbf{R}_k^{(q)}\}$, the calibrated temporal delay signature $\tau_k=[\tau_k^{(1)},...,\tau_k^{(q)}]^T$, and the calibrated correlation signature $\mathbf{C}_k=[\mathbf{C}_k^{(1)T},...,\mathbf{C}_k^{(p)T}]^T$. It should be emphasized that the signal signature is not limited to the specific examples given here, but may include other characterizations as well. In addition, it should be emphasized that the signal signature need not contain all the above components. For example, it might contain just a single subspace, $\mathbf{U}_k$.

Velocity Estimation

In accordance with the present invention, the real-time velocity of the phone can be determined by the following method. Because the 1 ms batch sampling time is short compared to the movement of the phone, the batch covariance matrix will have, to a close approximation, rank 1. Thus, denoting the batch covariance matrix by $\mathbf{R}$, we may write

$$\mathbf{R} \approx \mathbf{x}\,\mathbf{x}^H, \tag{1}$$

where $\mathbf{x}\,\mathbf{x}^H$ represents the rank-1 approximation to $\mathbf{R}$, i.e. the vector $\mathbf{x}$ is the dominant eigenvector of $\mathbf{R}$ and $\mathbf{x}^H$ is its Hermetian conjugate.

Now consider a second covariance matrix $\mathbf{R}'$ measured a short time δt after $\mathbf{R}$ is measured (e.g., δt=50 ms), again over the course of a 1 ms time interval. Then write

$$\mathbf{R}' \approx \mathbf{x}'\,(\mathbf{x}')^H, \tag{2}$$

where $\mathbf{x}'\,(\mathbf{x}')^H$ represents the rank-1 approximation to $\mathbf{R}'$.

In a typical multipath environment, the physical displacement of the transmitter is, to a first order approximation, proportional to the angular displacement between the vectors $\mathbf{x}$ and $\mathbf{x}'$ in signal space. The greater the displacement of the phone during the interval δt, the greater the angle between $\mathbf{x}$ and $\mathbf{x}'$. Thus, in order to estimate the velocity of the phone, it would be desirable to measure the angular velocity of the signal vector by comparing two consecutive

measurements of $\mathbf{x}$ separated by a known time interval δt. The computation of $\mathbf{x}$, however, would involve a computationally expensive calculation of the eigenvalues and eigenvectors of $\mathbf{R}$. Accordingly, the present inventors have developed the following technique for determining velocity without the need for such complex computations.

Define

$$\delta\mathbf{R} = \mathbf{R}' - \mathbf{R} \tag{3}$$

and

$$\delta\mathbf{x} = \mathbf{x}' - \mathbf{x}. \tag{4}$$

Using these definitions, we may rewrite eq. 2 as

$$\mathbf{R} + \delta\mathbf{R} = (\mathbf{x} + \delta\mathbf{x})(\mathbf{x} + \delta\mathbf{x})^H. \tag{5}$$

Expanding the right-hand side of eq. 5, we obtain

$$\mathbf{R} + \delta\mathbf{R} = \mathbf{x}\,\mathbf{x}^H + \delta\mathbf{x}\,\mathbf{x}^H + \mathbf{x}\,\delta\mathbf{x}^H + \delta\mathbf{x}\,\delta\mathbf{x}^H. \tag{6}$$

Subtracting eq. 1 from this, we then get

$$\delta\mathbf{R} = \delta\mathbf{x}\,\mathbf{x}^H + \mathbf{x}\,\delta\mathbf{x}^H + \delta\mathbf{x}\,\delta\mathbf{x}^H. \tag{7}$$

Now, using eq. 7, one can calculate $\|\delta\mathbf{R}\|^2 = \mathrm{Tr}(\delta\mathbf{R}\,\delta\mathbf{R}^H)$ and $|\mathrm{Tr}(\delta\mathbf{R})|^2$, and then subtract the resulting expressions to yield

$$\|\delta\mathbf{R}\|^2 - |\mathrm{Tr}(\delta\mathbf{R})|^2 = 2|\mathbf{x}|^2|\delta\mathbf{x}|^2 - 2|\mathbf{x}^H\,\delta\mathbf{x}|^2. \tag{8}$$

Define

$$\delta\mathbf{x}_T = \delta\mathbf{x} - (\delta\mathbf{x}^H\,\mathbf{x}_U)\,\mathbf{x}_U, \tag{9}$$

where $\mathbf{x}_U = \mathbf{x}/|\mathbf{x}|$ is the unit vector in the direction of $\mathbf{x}$. Thus, $\delta\mathbf{x}_T$ is $\delta\mathbf{x}$ minus the portion of $\delta\mathbf{x}$ in the direction of $\mathbf{x}$. We can therefore think of $\delta\mathbf{x}_T$ as the tangential component of $\delta\mathbf{x}$.

Using eq. (9) we can rewrite eq. (8) as

$$\| \delta \mathbf{R} \|^2 - | \mathrm{Tr}(\delta \mathbf{R}) |^2 = 2|\mathbf{x}|^2 |\delta \mathbf{x}_T|^2. \quad (10)$$

Let $\delta\theta$ be the angle between $\mathbf{x}'$ and $\mathbf{x}$. Then, assuming $\delta \mathbf{x}_T << \mathbf{x}$, we have $|\delta \mathbf{x}_T|/|\mathbf{x}| = \tan(\delta\theta) \approx \delta\theta$, and hence $|\delta \mathbf{x}_T| \approx |\mathbf{x}|\, \delta\theta$. Substituting this in eq. 10, we get

$$\| \delta \mathbf{R} \|^2 - | \mathrm{Tr}(\delta \mathbf{R}) |^2 \approx 2|\mathbf{x}|^4 (\delta\theta)^2. \quad (11)$$

Finally, because $\mathbf{R} = \mathbf{x}\, \mathbf{x}^H$, we have $\mathrm{Tr}(\mathbf{R}) = \mathrm{Tr}(\mathbf{x}\, \mathbf{x}^H) = |\mathbf{x}|^2$, and hence $|\mathbf{x}|^4 = [\mathrm{Tr}(\mathbf{R})]^2$. Substituting this in eq. 11 gives

$$\| \delta \mathbf{R} \|^2 - | \mathrm{Tr}(\delta \mathbf{R}) |^2 \approx 2[\mathrm{Tr}(\mathbf{R})]^2 (\delta\theta)^2. \quad (12)$$

Solving this for $\delta\theta$ we obtain

$$\delta\theta \approx \sqrt{ \{ \| \delta \mathbf{R} \|^2 - | \mathrm{Tr}(\delta \mathbf{R}) |^2 \} / 2[\mathrm{Tr}(\mathbf{R})]^2 } \quad (13)$$

Notice that the right-hand side of this equation can be calculated with simple algebraic operations involving only $\delta\mathbf{R}$ and $\mathbf{R}$. This equation, therefore, is a function that gives a simple and computationally efficient way to compute the angular change in the signal vector directly from the measured batch covariance matrices.

The physical displacement of the phone, to first order approximation, is proportional to the angular displacement of the signal vector. To estimate the magnitude of the velocity of the phone at a time t, therefore, the following expression is computed:

$$|v_t| = \alpha\, \delta\theta/\delta t\,, \quad (14)$$

where δt is the time difference between the measurements of $\mathbf{R}'$ and $\mathbf{R}$, and α is a constant of proportionality that is determined empirically. Notice that $|v_t|$ is an estimate of the velocity over the period δt which is typically 5 to 50 ms. To obtain the average velocity over a longer period, say one second, one can use any of the averaging and smoothing techniques described above to a collection of velocity estimates collected within the longer period. It will be appreciated that other equations similar to eqs. 13 and 14 may be used to make similar

estimates of the phone velocity. Such substantially similar equations include, for example, mathematically equivalent expressions as well as equations involving a similar combination of the quantities $\mathrm{Tr}(\mathbf{R})$, $\mathrm{Tr}(\delta\mathbf{R})$, and $\mathrm{Tr}(\delta\mathbf{R}\,\delta\mathbf{R}^{H})$, or multiples of these quantities. The essential feature of the equation is that it is a simple, closed-form expression in terms of just $\mathbf{R}$ and $\mathbf{R}'$. It will also be appreciated that the direction of the velocity can be estimated by comparing successive locations that have been determined using a location-finding technique. Combining this direction estimate with the magnitude estimate, one may estimate the actual velocity vector, $\mathbf{v}$.

The value of $|\mathbf{v}|$ may be used in various ways to improve the performance of a location finding system, as well as for other applications where a knowledge of transmitter movement may be of use.

Calibration Data Collection Procedure

The real-time location determination technique of the present invention makes use of a stored database of calibrated signal signature information and associated locations. The initialization of the system, therefore, preferably involves a calibration procedure in which signal signature and location information is collected. One procedure for collecting this data is as follows.

According to a preferred calibration procedure, a calibration vehicle follows an arbitrary trajectory in the vicinity of a LDA. The vehicle contains an active cellular telephone, a GPS receiver, and a computer for storing the real-time GPS position data of the vehicle along its trajectory. In a typical calibration procedure, the GPS location data along the trajectory are periodically stored on the computer together with the GPS clock time-stamp, typically at intervals on the order of 10 to 100 ms. Meanwhile, the transmitted signal from the cellular phone is received at the LDA, which is also equipped with a GPS receiver, and the signal signature is calculated and stored with the GPS clock time stamp. When the data from the vehicle and the LDA are combined and processed, differential GPS correction data obtained from the LDA are standard techniques are used to determine with high accuracy the vehicle location corresponding to each signature measured at the LDA. The signal signature and location information are then stored as raw calibration data at the base station.

Note that the calibration procedure may include the simultaneous use of several base stations and/or several vehicles moving within the service area. In addition, each vehicle may include several phones operating on different channels. For example, in an implementation for the AMPS standard, a set of 6 phones in a vehicle may be used to transmit at frequency intervals

of 2 MHz in order to provide the signature data with frequency coverage across a 10 MHz bandwidth. In this case, the raw calibration data contains 6 signatures corresponding to the 6 frequencies for each location along the vehicle trajectory. It will also be appreciated that the location data may be derived from techniques other than, or in addition to, GPS techniques. For example, the GPS location information can be supplemented by dead reckoning or other navigational information. Such supplementary location information is especially useful in cases where GPS reception is poor. The supplementary location information can be stored with the GPS information and post-processed in an off-line procedure as described above. Alternatively, the location information can be transmitted in real time to the base station during the calibration procedure.

The result of the calibration procedure for a single vehicle with a single phone is a sequential set of raw calibration data for a single trajectory, including a set of covariance matrices $\mathfrak{R}=\{\mathbf{R}_1,...,\mathbf{R}_N\}$ and a set of N corresponding locations $\mathfrak{D}=\{\mathbf{d}_1,...,\mathbf{d}_N\}$. The raw calibration data for a single trajectory is conveniently represented as a single set of ordered pairs, $\mathfrak{T}=\{(\mathbf{R}_1,\mathbf{d}_1),...,(\mathbf{R}_N,\mathbf{d}_N)\}$ indexed by the integers 1 to N. Because locations $\mathbf{d}_i$ and indices i are in one-to-one correspondence, locations may be identified by their corresponding location index, and vice versa. If time delay and/or code correlation information is also measured, this data is also recorded as part of the raw calibration data, so that data for a single trajectory is represented as ordered triplets or ordered quadruplets.

Typically, the calibration procedure will use one or more vehicles following M routes at the same or different times. The raw data collected from M routes is initially stored in a set of M files, which are also represented by $\mathfrak{T}_1,...,\mathfrak{T}_M$. In the case where only covariance matrix information is measured, each file $\mathfrak{T}_m$ contains a temporally sequential list of ordered pairs $(\mathbf{R}_1,\mathbf{d}_1),...,(\mathbf{R}_{N(m)},\mathbf{d}_{N(m)})$, where N(m) is the number of data points in route m. If additional information is measured, each file contains a list of ordered triplets, quadruplets, etc. Each data point, therefore, may be assigned a unique index pair (m,n), where m=1,...,M specifies the route and n=1,...,N(m) specifies the data point within the route, as shown in TABLE 1.

TABLE 1

Route 1	Route 2	...	Route m	...	Route M
(1,1)	(2,1)		(m,1)		(M,1)
(1,2)	(2,2)		(m,2)		(M,2)
. :	. :		. :		. :
(1,n)	(2,n)	...	(m,n)	...	(M,n)
. :	. :		. :		. :
(1,N(1))	(2,N(2))		(m,N(m))		(M,N(M))

Note that each route m will usually have a different number of data points N(m). The columns of Table 1, therefore, do not necessarily have the same number of rows.

The raw calibration data is used to form the calibration database which contains K calibrated signal signatures and K associated locations, as shown in TABLE 2. Each of the locations $\mathbf{d}_1,...,\mathbf{d}_K$ may be two or three dimensional, and may be assigned a date upon which it was last calibrated. The signal signature in the database for each location $\mathbf{d}_k$ includes the calibrated spatial subspace information, $\mathbf{S}_k$, and possibly also calibrated temporal delay information, τ_k, and code correlation information, $\mathbf{C}_k$. In a preferred embodiment, the covariance signature is $\mathbf{S}_k=\{\mathbf{U}_k;\ \mathbf{R}_k\}$ or, if multipath parts are resolved, $\mathbf{S}_k=\{\mathbf{U}_k^{(1)},...,\mathbf{U}_k^{(q)};\ \mathbf{R}_k^{(1)},...,\mathbf{R}_k^{(q)}\}$. The temporal delay signature preferably is $\tau_k=[\tau_k^{(1)},...,\tau_k^{(q)}]^T$, and the code correlation signature is $\mathbf{C}_k=[\mathbf{C}_k^{(1)T},...,\mathbf{C}_k^{(p)T}]^T$. It should be emphasized that the signal signature is not limited to the specific examples given here, but may include other characterizations as well.

TABLE 2

Location (x, y, z)	Signal Signature		
	Spatial Signature	Temporal Signature	Correlation Signature
$\mathbf{d}_1$	$\mathbf{S}_1$	τ_1	$\mathbf{C}_1$
.	.	.	.
.	.	.	.
.	.	.	.
$\mathbf{d}_K$	$\mathbf{S}_K$	τ_K	$\mathbf{C}_K$

Although the signal signature is a relatively stable function of location, certain changes in the signature may take place which may affect the accuracy of the database of calibrated signal signatures. Such changes may result from the construction or destruction of buildings, or from seasonal changes in the natural environment that affect multipath. Accordingly, the preferred embodiment of the present invention includes techniques for updating the database. A direct method involves performing the calibration procedure at regular intervals or continuously. A cost-effective method of continuous calibration could use a fleet of commercial delivery vehicles. Since such vehicles typically pass through many locations in a localized region, a dedicated calibration system could piggy-back on these vehicles and allow continuous updating of the database. Alternatively, or in addition, specialized vehicles could be sent out periodically to calibrate the service region. It should also be noted that in the case where two or more base stations can simultaneously receive signals from such a calibration unit, its signals can be used by all these base stations to independently calibrate their respective databases.

It is also possible to perform certain database corrections using only signals from regular phones, i.e., without using special calibration vehicles. For example, in the case where seasonal atmospheric changes cause alterations in the multipath, an analysis of signals over the course of several days or weeks can detect a gradual drift in the collective signal signatures. After clearly identifying such a drift, the database signatures can be corrected to compensate for the drift, thus eliminating the need for performing a calibration procedure. A similar technique can be used to correct the database to compensate for signal signature changes caused by the construction or destruction of reflecting objects in the environment. In this case, an analysis of signal signatures over time will display a consistent and gradual shift for those signatures associated with locations in the vicinity of the objects. Having

identified such bias, the database can then be compensated accordingly. As an aid to the identification of these environmental biases, base stations may share with each other certain information, e.g. the array response matrix **A** for a certain location. If both base stations detect a shift, it is likely due to an environmental change. It is a significant feature that high bandwidth communication channels are not required to communicate such information between base stations. In addition, geographical and environmental information can be used to detect these shifts. For example, because major highways do not typically change their location, vehicles being tracked regularly along such a highway will have known trajectories. This trajectory information can be used to identify and correct drifts in the calibration data.

It should be noted that, if a transmitter is stationary and if the differential time delays are much smaller than the reciprocal of the signal bandwidth, then the multipath and direct path signals will be coherent, i.e. they will differ only by a complex scalar factor. In this case, the measured signal subspace will be one-dimensional since the multipath signal does not contribute an additional dimension to the signal subspace. A moving transmitter, on the other hand, will decorrelate the direct and multipath signals over a distance of several wavelengths. For example, two multipath signals from a moving transmitter result in sufficient variation of subsequent signal vectors $\mathbf{x}(t_1),\ldots, \mathbf{x}(t_M)$ to permit the full subspace to be determined. Because it is preferable in the calibration procedure to have signal signatures comprising multi-dimensional subspaces, the calibration procedure of the present invention uses moving vehicles to advantageously decorrelate the direct and multipath signals, thereby permitting determination of the complete signal subspace. Although a stationary transmitter will have only a one-dimensional subspace, because this subspace is within the calibrated signal subspace it is still possible to locate the transmitter, albeit with less certainty than with a moving transmitter. In the case of wideband modulation schemes or frequency hopping, however, the full signal subspace may be determined even for a stationary transmitter.

Calibration Data Processing

In the preferred embodiment, the calibration process includes post-processing to optimize the calibration table. This optimization can involve eliminating redundant information, compressing the data for more efficient storage, and organizing the data for more efficient searching. The raw data contains redundancy due primarily to arbitrary and uncontrolled vehicle speeds and trajectories during the calibration data collection. A stopped or very slow moving vehicle, for example, can result in many redundant data points corresponding to nearly the same location (assuming uniform sampling of data points). Overlapping route trajectories also result in redundant data points. It is therefore advantageous to remove these

redundancies in order to generate an optimal calibration table from this raw data. The post-processing method comprises two main parts: data association and grid generation.

DATA ASSOCIATION

The data association procedure is preferably separated into two steps. The first step generates a route neighbor file for each route, while the second step generates a total route neighbor file for all routes.

The first step is performed as follows. For each data point (m,n) in a route m, a list $\mathfrak{N}_m$ of neighboring data points in the same route m is determined. A neighboring data point is defined to be any data point whose location is less than a predetermined distance D from the location of (m,n). In the preferred embodiment, the predetermined distance D is 5 to 10 meters, as this is the approximate accuracy of present GPS receivers and is comparable to a lane width on a typical road. It will be appreciated that other distances D may also be used. In this manner, a route neighborhood file $\mathfrak{N}_m$ for route m is constructed which contains a route neighbor list for each point in the route. TABLE 3 shows an example of a route neighborhood file $\mathfrak{N}_m$ containing route neighbor lists in route m for all points in route m.

TABLE 3: Route Neighbor File

Data Point	Route Neighbor List
(m,1)	(m,2);(m,3)
(m,2)	(m,1);(m,3);(m,4)
. :	
(m,n)	(m,n-2);(m,n-1);(m,n+1);(m,n+2);(m,n+3)
. :	
(m,N(m))	(m,N(m)-2);(m,N(m)-1)

Similarly, a route neighborhood file is produced for each of the M routes, resulting in a total of M route neighborhood files $\mathfrak{N}_1,\ldots,\mathfrak{N}_M$. corresponding to each of the routes $\mathfrak{T}_1,\ldots,\mathfrak{T}_M$.

After the M route neighborhood files are constructed, the second step of the data association procedure is performed. In this step, a total neighborhood file $\mathfrak{M}$ is constructed, combining information from all the routes. The total neighborhood file $\mathfrak{M}$ contains, for each data point in each route, a total neighbor list. The total neighborhood list for a point contains all the neighbors of the point selected from all data points in all routes. In other words, the total neighbor list for a point contains not only neighbors in the same route, but also neighbors taken from all the other routes. TABLE 4 shows an example of a total neighborhood file.

TABLE 4: Total Neighbor File

Data Point	Total Neighbor List
(1,1)	(1,2);(1,3);(2,12);(2,13);...;(M,54);(M,55)
. :	. :
(1,N(1))	(1,N(1)-1);(2,11);(2,12);...;(M,128)
. . .	. . .
(m,1)	(1,32);(2,78);...;(m,2);(m,3);...;(M,98)
. :	. :
(m,N(m))	(3,45);...;(m,N(m)-1);...;(M-1,32)
. . .	. . .
(M,1)	(1,16);...;(M,2);(M,3)
. :	. :
(M,N(M))	(2,68);(2,69);...;(M,N(M)-2);(M,N(M)-1)

The data processing described above may be performed conveniently through the repeated execution of certain general procedures. A fundamental procedure NEIGHBOR(m_1,n_1,m_2,n_2) checks if data point (m_1,n_1) is a neighbor of (m_2,n_2) by calculating the Euclidean distance between the GPS position $\mathbf{d}_{n_1}$ in route m_1 with GPS position $\mathbf{d}_{n_2}$ in route m_2. If the distance is less than D meters, then the procedure returns a TRUE value; otherwise it returns a false value. Using this procedure, it is straightforward to

devise a procedure ASSOCIATE_ROUTES(m_1,m_2) that calculates, for each data point in route m_1, the list of neighboring points in route m_2. With m_1=m_2, this procedure can be used to generate the initial route neighborhood files. This procedure can also be used to generate the total neighborhood file from the collection of route neighborhood files by calling the procedure for all cases where $m_1 \neq m_2$ and adding the results of each call to the total neighborhood file. Note that since ASSOCIATE_ROUTES is symmetric, i.e. ASSOCIATE_ROUTES(m_1,m_2) = ASSOCIATE_ROUTES(m_2,m_1), half of the distance calculations need not be performed.

A new route M+1 can be added to the total neighborhood file by calling ASSOCIATE_ROUTES(M+1,m) for all m, and also calling ASSOCIATE_ROUTES(m,M+1) for all m. The first series adds to the new route all neighbors from all existing routes, while the second series of calls adds to the existing routes the neighbors in the new route. Similarly, any route m can be deleted from the total neighborhood file by removing all data points (m,1),...,(m,N(m)) and removing all references to these data points which may be contained in the total neighborhood lists of the data points for the other routes.

GEOGRAPHIC BINNING

The binning procedure uses the contents of the total neighborhood file to construct a collection of geographical bins that represent the area covered by the routes. A bin is defined to be a contiguous geographical region corresponding to a portion of one or more routes. The binning step constructs a collection of bins that correspond to the trajectories of the routes. This collection of bins is a basic component of the final calibration table.

Bins are created sequentially as follows. Initially, all the points in all the routes are tagged as unbinned. A current route variable is initially set to be the first route, and a current point in the current route is initially set to be the initial point in the route. Next, a bin is created that covers a sequence of points starting with the current point and ending with the last successive point in the route that is still within a minimum binning distance from the current point. The bin is assigned a bin location and a signature based on the signatures and locations of the points in the bin, as will be described in more detail below. After the bin is created, the current point is the first point along the route outside the bin. This point becomes the first point for the next bin, and a new bin is created. Bins are successively created along the route in this way until no points remain in the route. After the first route is binned, the current route is then incremented and the binning is repeated in the same manner

for the next route. When all routes have been binned in this way, the binning procedure is completed.

The step of creating a single bin is performed as follows. An initial bin point is set to be the current point. All the neighbors of the current point are identified by inspecting the total neighbor list for the point. These neighbors are the points (from any route) that are within a circular neighborhood of the current point. From the list of these neighbors and the current point itself, all the unbinned points are selected. These selected points will be tagged as binned when the bin is completed, so that they are not included as data for other bins. The covariance matrices of these points are then averaged to form an average covariance matrix **R** associated with the current point. From this average covariance matrix, a covariance signature **U** corresponding to this point is then determined. In the preferred embodiment, the covariance signature **U** corresponding to a covariance matrix **R** is the subspace spanned by the dominant eigenvectors of **R**. In addition, the covariance matrix itself can be used as the signature. In the case where there are no unbinned points among the neighbors of the current point, then no signature value is calculated for the point. In the case where the raw data includes time delay and code correlation data, these are also averaged and included in the signature values for the point.

The current point is then incremented to the next point in the current route. If the current point is less than a predetermined binning distance (e.g., 30 meters) from the initial bin point, then the above procedure is repeated to again produce a signature for this point. As a result, one obtains a series of signature values that correspond to points along the current route within the predetermined binning distance of the initial bin point. In general, the binning distance may be selected to be any value greater than the neighbor distance D. In the preferred embodiment, the binning distance is selected to be approximately 50 meters for typical suburban environments. For dense urban environments, the binning distance is preferably 30 meters, while in rural environments the binning distance is preferably 50 meters or more. The signature values in a given bin are then averaged to form a bin signature, and the corresponding locations are averaged to form an average location. A bin location is selected to be the location of the data point closest to the average location.

In a variation of the above step, each of the bins is divided into sub-bins, as illustrated in FIGS. 8A and 8B. The size and shape of the sub-bins is determined by the location information error. In the case of GPS with differential correction, the sub-bins are preferably squares whose size is about 10 m, and the bins have a size of about 30 m. The locations of raw data points are shown in the figures as empty circles. FIG. 8A shows the vehicle routes as dotted lines. FIG. 8B shows detail of a bin containing nine sub-bins. For each sub-bin an average **R** of the covariance matrices whose locations are within the sub-bin

is calculated, together with a centroid $\underline{\mathbf{d}}$ of their locations. These sub-bin centroids are shown in FIG. 8B as solid circles. The same procedure is repeated for the bins. That is, for each bin k an average $\mathbf{R}_k$ of the sub-bin covariances $\underline{\mathbf{R}}$ belonging to the bin is calculated, together with a centroid $\mathbf{d}_k$ of the sub-bin locations $\underline{\mathbf{d}}$ in the bin. The centroid for the bin is shown in the figure as a circled 'x' mark. In addition, a bin signature $\mathbf{U}_k$ is calculated from $\mathbf{R}_k$.

This process is continued until the points in the route are all binned. The other routes are then binned in the same way, resulting in a calibration table that incorporates the data from all the routes. In a preferred embodiment adapted for the AMPS standard, distinct calibration tables are constructed for various different frequency bands in use, e.g., one calibration table for each 3 to 6 MHz band of frequency channels. Thus, the calibration table used to derive a location will be selected in dependence upon the frequency of the signal.

Data from a new route can be incorporated into an existing calibration table without repeating many calculations unnecessarily. In particular, data from a new route is used to create a new total neighbor file in the manner already described. All neighbors of the new route, as well as all the points in the new route, are tagged as unbinned. The calibration table can then be updated by executing the binning procedure for the new route.

The optimized calibration table does not contain temporally or spatially redundant data, and contains accurate data due to averaging within each bin. The method also enjoys the advantage that it does not place constraints upon the specific routes that the vehicles take. Those skilled in the art will recognize that the present method produces a contiguous map of a region, providing accuracies often exceeding those of existing survey maps. Thus, the present method has application to accurate map generation, as well as to location determination techniques.

DATA COMPRESSION AND ORGANIZATION

In order to provide a fast real-time location finding system, it is preferable to efficiently store and organize the calibration data. In addition to the signal signature data, it is also preferable to store some precomputed data that allows for more efficient signature matching during real-time location determination. One example of a type of precomputed data is a set of N-dimensional vectors $\mathbf{w}_1,\ldots,\mathbf{w}_N$, each of which is derived from the covariance matrices $\mathbf{R}_1,\ldots,\mathbf{R}_N$ of all N locations. As will be described in more detail later, these vectors can be used in the signature matching procedure to improve matching accuracy. Each vector is defined by $\mathbf{w}_k=[\mathrm{Tr}\{\mathbf{P}_1\mathbf{R}_k\},\ldots,\mathrm{Tr}\{\mathbf{P}_N\mathbf{R}_k\}]^T$, where $\mathbf{P}_i = \mathbf{U}_i\mathbf{U}_i^H$ is the projector onto the subspace of location i. Thus, each component $\mathrm{Tr}\{\mathbf{P}_i\mathbf{R}_k\}$ of the vector measures the extent to

which the covariance matrix $\mathbf{R}_k$ of location k overlaps with the subspace $\mathbf{U}_i$ of location i. This vector can be used to match a real-time covariance matrix $\mathbf{R}$ to a calibrated covariance signature. As will be described in more detail later, a similar vector $\mathbf{w}$ can be calculated from $\mathbf{R}$, and then the quantity $G(\mathbf{w},\mathbf{w}_k) = |\mathbf{w} - \mathbf{w}_k|^2$ is computed to measure the similarity of the real-time signature with calibrated signature k. Because these N-dimensional vectors can take a large amount of storage space, it is desirable to store a more compact representation of their information. It can be shown that $\mathrm{Tr}\{\mathbf{P}_i\mathbf{R}_k\} = \mathbf{p}_i^T\mathbf{r}_k$, where $\mathbf{p}_i$ is a p^2-dimensional vector derived from $\mathbf{P}_i$, and $\mathbf{r}_k$ is a p^2-dimensional vector derived from $\mathbf{R}_k$. Moreover, both $\mathbf{p}_i$ and $\mathbf{r}_k$ have real-value components. Thus, $\mathbf{w}_k=[\mathbf{p}_1^T\mathbf{r}_k,...,\mathbf{p}_N^T\mathbf{r}_k,]^T$. More generally, for any p×p covariance matrix $\mathbf{R}$, one can derive a vector $\mathbf{w}=[\mathbf{p}_1^T\mathbf{r},...,\mathbf{p}_N^T\mathbf{r},]^T$, where $\mathbf{r}$ is a p^2-dimensional vector with real-valued components. In order to reduce the required data storage space as well as the time required to search the database during real-time location-finding, the p^2-dimensional vectors $\mathbf{r}_1,...,\mathbf{r}_N$ are stored instead of the N-dimensional vectors $\mathbf{w}_1,...,\mathbf{w}_N$. In addition, the p^2-dimensional vectors $\mathbf{p}_1,...,\mathbf{p}_N$ are also stored. The vectors $\mathbf{w}_1,...,\mathbf{w}_N$ can then be easily reconstructed in real time as needed.

Another similar technique is based on the following method, which is applicable to more general distance functions (i.e., functions that are not necessarily linear). Perform a singular value decomposition (SVD) of the matrix $\mathbf{W} = [\mathbf{w}_1...\mathbf{w}_N]$. Typically, the SVD of this matrix will have an effective rank dramatically smaller than N. For example, typically only about 100 statistically significant dominant eigenvectors result from an SVD of a matrix $\mathbf{W}$ with N=10,000. These dominant eigenvectors span a subspace $\mathbf{W}_S$ of the matrix $\mathbf{W}$. The projector onto this subspace is $\mathbf{P}_{W_s} = \mathbf{W}_S\mathbf{W}_S^H$. Now calculate $\underline{\mathbf{w}} = \mathbf{W}_S^H\mathbf{w}$ and $\underline{\mathbf{w}}_k = \mathbf{W}_S^H\mathbf{w}_k$ for k=1,...,N. The vector $\underline{\mathbf{w}}$ is the projection of the N-dimensional vector $\mathbf{w}$ onto the subspace spanned by the dominant eigenvectors of $\mathbf{W}$. Similarly, vector $\underline{\mathbf{w}}_k$ is the projection of the N-dimensional vector $\mathbf{w}_k$ onto the same subspace. The dimension of this subspace is typically about two orders of magnitude smaller than N. Consequently, the vectors $\underline{\mathbf{w}}$ and $\underline{\mathbf{w}}_k$ also have dimension two to three orders of magnitude less than N. Yet, because the other dimensions may be neglected, no significant information is lost by replacing the original N-dimensional vectors by these lower-dimensional vectors. Consequently, the size of the calibration table can be reduced by more than two orders of magnitude by storing these reduced vectors rather than their N-dimensional counterparts.

The matching of the vector $\mathbf{w}$ with vectors in the set of N vectors $\mathbf{w}_1,...,\mathbf{w}_N$ is performed by evaluating $G(\mathbf{w},\mathbf{w}_k)$ for k=1,...,N. It can be seen, however, that

$$G(\mathbf{w},\mathbf{w}_k) = \| \mathbf{w} - \mathbf{w}_k \|^2 \approx \| \mathbf{W}_S\mathbf{w} - \mathbf{W}_S\mathbf{w}_k \|^2 = \| \underline{\mathbf{w}} - \underline{\mathbf{w}}_k \|^2.$$

Thus, the compact vectors $\underline{\mathbf{w}}$ and $\underline{\mathbf{w}}_k$ can be used directly in the real time calculation, rather than the original vectors. Because the dimensions of $\underline{\mathbf{w}}$ and $\underline{\mathbf{w}}_k$ are much smaller than the dimensions of $\mathbf{w}$ and $\mathbf{w}_k$, the storage requirements are much smaller and the calculation speeds are much faster.

Estimation of Antenna Array Manifold Data

The set of array manifold vectors $\{\mathbf{a}(\theta) : \theta=\theta_1,...,\theta_L\}$ of antenna arrays are conventionally determined empirically through array calibration procedures well-known in the art. The calibration data of the present invention, however, allows the array manifold vectors to be determined without conventional array calibration procedures. Instead, the array manifold vectors can be calculated from the signature calibration table, as follows. As shown in FIG. 9, the service region of an LDA 190 contains a set of calibrated locations, shown in the figure as circled 'x' marks. Consider an angular sector of the service region having an angular width $\Delta\theta$ centered around an angle θ. In the preferred embodiment the value for $\Delta\theta$ is approximately one degree. This particular value, however, is not necessary for the practice of the present invention, and various other values will work as well. Contained within this sector are several calibrated locations $\mathbf{d}_1,...,\mathbf{d}_K$, having corresponding calibrated signature subspaces $\mathbf{U}_1,...,\mathbf{U}_K$. After these subspaces have been identified for a given sector, each subspace $\mathbf{U}_i$ is examined to determine if its largest eigenvector $\mathbf{e}_i$ has a magnitude significantly larger than the other eigenvectors in the same subspace. For example, if the largest eigenvector exceeds the next largest eigenvector by a predetermined factor, then it is considered to be significantly larger than all the other eigenvectors. Preferably, this predetermined factor is at least 2, but is more preferably 10 or more. The result of this examination of the subspaces results in a set of largest eigenvectors. For example, if all the subspaces have significantly large first eigenvectors, then the set of largest eigenvectors will contain one eigenvector from each subspace, $\mathbf{e}_1,...,\mathbf{e}_K$. These eigenvectors are then combined to form an average eigenvector for the sector, $\mathbf{e}_{av}$. Various techniques can be used to determine $\mathbf{e}_{av}$ from $\mathbf{e}_1,...,\mathbf{e}_K$. For example, the K eigenvectors can be stacked in a matrix, and the singular value decomposition of the matrix can be calculated to determine the best rank-1 approximation to the matrix. This best rank-1 approximation is then used as the value for $\mathbf{e}_{av}$. A more accurate estimate of $\mathbf{e}_{av}$ can be determined by using the initial estimate of $\mathbf{e}_{av}$ to exclude some outlying eigenvectors from the set of K eigenvectors and then repeating the procedure. The final value of $\mathbf{e}_{av}$ for the

sector is used as an initial estimate for the array calibration vector $\mathbf{a}(\theta)$ for the sector. Similar estimates are made for all the sectors around the LDA. These estimates then may be improved by imposing a continuity condition on the values of $\mathbf{a}(\theta)$ with respect to θ. The above procedure, therefore, can derive a set of L array calibration vectors $\mathbf{a}(\theta_1),...,\mathbf{a}(\theta_L)$ for a set of L directions $\theta_1,...,\theta_L$ around a LDA.

It should be noted that this technique for generating array calibration vectors from the location database has several important advantages over known methods of generating array calibration vectors. Prior techniques typically require that the array be installed and measured in a special antenna range. The known methods are not useful, therefore, with many existing antenna arrays. The present method, on the other hand, is effective with existing antenna arrays since no restriction is being made on the nature of the array or its supporting structure.

Location Estimation

The approach of the present location determination technique is to measure a real-time signature of a mobile device whose location is unknown, then match the signature with similar signatures in the calibration database. Because the signatures are highly correlated with location, the calibrated locations of the matching signatures will correspond to the location of the mobile device. Various matching procedures can be used that involve different types of signatures, different matching techniques, search optimization algorithms, ambiguity reduction techniques, and so on. The particular combination of techniques used for matching will depend on the type of signature information available, the characteristics of the wireless environment, and other factors.

Covariance Matrix ,Time Delay, and Correlation Matching

In a preferred embodiment, the location of a mobile device in the service area may be determined as follows. Signals originating from the device at an unknown location are received at the LDA, and a signal signature is determined from the signals as described in detail above. In one embodiment of the invention, the signature comprises a covariance signature **S** that includes a signal covariance matrix **R** and a signal subspace **U**. In another embodiment, the signature includes a signal covariance matrix and signal subspace for each of q multipath parts of the signal, i.e., $\mathbf{S}=\{\mathbf{U}^{(1)},...,\mathbf{U}^{(q)}; \mathbf{R}^{(1)},...,\mathbf{R}^{(q)}\}$. In yet another embodiment, the signature also includes time delay and/or code correlation information. Using the calibration table described above, the signal signature is then compared using a

measure of similarity to a set of calibrated signal signatures which correspond to a set of N calibrated locations.

The measure of similarity between the measured spatial signature $\mathbf{S}$ and a given calibrated spatial signature $\mathbf{S}_k$ may be determined by evaluating a function $D(\mathbf{S},\mathbf{S}_k)$ which maps two signatures to a number indicating their degree of closeness to each other. The value of $D(\mathbf{S},\mathbf{S}_k)$ represents the likelihood that a measured covariance signature $\mathbf{S}$ matches a calibrated signature $\mathbf{S}_k$. Because each signature $\mathbf{S}_k$ corresponds to a known location $\mathbf{d}_k$, the value of $D(\mathbf{S},\mathbf{S}_k)$ also represents the likelihood that the transmitter is at location $\mathbf{d}_k$. According to one suitable definition, $D(\mathbf{S},\mathbf{S}_k)$ is the sum of the traces of the projections of the measured finger covariance matrices $\mathbf{R}^{(1)},...,\mathbf{R}^{(q)}$ onto the corresponding calibrated subspaces, which can be calculated as follows:

$$D(\mathbf{S},\mathbf{S}_k) = \sum_{i=1}^{q} \mathrm{Tr}\, \mathbf{P}_k^{(i)}\, \mathbf{R}^{(i)},$$

where $\mathbf{P}_k^{(i)}=\mathbf{U}_k^{(i)}[\mathbf{U}_k^{(i)}]^H$ is the projector onto the subspace $\mathbf{U}_k^{(i)}$. In the case where no multipath parts are resolved (i.e., $q=1$), this formula simplifies to $D(\mathbf{S},\mathbf{S}_k) = \mathrm{Tr}\, \mathbf{P}_k\, \mathbf{R} = \mathbf{p}_k{}^T\mathbf{r}$, where the vectors $\mathbf{p}_k$ and $\mathbf{r}$ are the p^2-dimensional vectors discussed above in relation to the calibration table data compression. Note that this particular measure does not require that the subspace $\mathbf{U}$ be calculated from $\mathbf{R}$, i.e., it does not require calculating the dominant eigenvectors of $\mathbf{R}$. It will be appreciated that $D(\mathbf{S},\mathbf{S}_k)$ can be defined in many other ways to measure how closely the signal covariance resembles any given calibrated signature. For example, $D(\mathbf{S},\mathbf{S}_k)$ can be defined to be the mean of the squares of the cosines of the principal angles between the subspaces $\mathbf{U}$ and $\mathbf{U}_k$.

In addition to the covariance signature, the signal signature may also include a temporal code correlation for the signal, $\mathbf{C}=[\mathbf{C}^{(1)T},...,\mathbf{C}^{(p)T}]^T$, which can be compared with similar code correlations in the calibration database. This comparison can be made using, for example, a least-squares difference measure. For example, the difference measure between the measured correlation signature $\mathbf{C}=[\mathbf{C}^{(1)T},...,\mathbf{C}^{(p)T}]^T$ and a calibrated correlation signature $\mathbf{C}_k=[\mathbf{C}_k^{(1)T},...,\mathbf{C}_k^{(p)T}]^T$ may be calculated as follows:

$$D'(\mathbf{C},\mathbf{C}_k) = |\mathbf{C}-\mathbf{C}_k|^2 = \sum_{j=1}^{p} |\mathbf{C}^{(j)} - \mathbf{C}_k^{(j)}|^2,$$

where

$$| \mathbf{C}^{(j)} - \mathbf{C}_k^{(j)} |^2 = \sum_{i=1}^{L} | C^{(j)}(\tau_i) - C_k^{(j)}(\tau_i) |^2.$$

This function $D'(\mathbf{C},\mathbf{C}_k)$ provides a measure of the "distance" between the measured signal code correlation and the code correlation of calibrated location k. It can easily be transformed into a measure of similarity by any of various mappings from $[0,\infty) \rightarrow (0,1]$ that map 0 to 1 (e.g., $f(x)=1/(1+x)$). This separate measure can then be used in addition to $D(\mathbf{S},\mathbf{S}_k)$ in order to improve the accuracy of the match, for example, by keeping only those locations that closely match the measured signal with respect to both code correlation and covariance subspace measures.

Similarly, the temporal delay signature $\tau=[\tau^{(1)},...,\tau^{(q)}]^T$ of the measured signal can be compared to the calibrated temporal delay signature $\tau_k=[\tau_k^{(1)},...,\tau_k^{(q)}]^T$ to provide an additional measure $D''(\tau,\tau_k)$ of difference. For example, one may calculate

$$D''(\tau,\tau_k) = |\tau-\tau_k|^2 = \sum_{i=1}^{q} | \tau^{(i)} - \tau_k^{(i)} |^2.$$

This additional measure of difference (or the corresponding measure of similarity) can then be used in addition to $D(\mathbf{S},\mathbf{S}_k)$ and $D'(\mathbf{C},\mathbf{C}_k)$ in order to further improve the accuracy of the match, for example, by keeping only those locations that closely match the measured signal with respect to all three measures. More generally, it will be appreciated that various combinations of the measures $D(\mathbf{S},\mathbf{S}_k)$, $D'(\mathbf{C},\mathbf{C}_k)$, and $D''(\tau,\tau_k)$ can be used in various ways to select locations appropriately. It will also be appreciated that other formulas may be used to define these functions, provided they measure the degree of similarity or difference between signatures.

In one matching technique of the invention, the measures of similarity and/or difference are used to select a set of most likely locations as follows. First, by evaluating $D(\mathbf{S},\mathbf{S}_k)$ for all N locations, a set of likely locations can be selected by taking, for example, the calibrated locations whose corresponding calibrated spatial signatures are closest to the measured spatial signature. For example, from the locations k=1,...,N, select a subset of M locations

k(1),...,k(M) such that $\{D(\mathbf{S},\mathbf{S}_{k(1)}),...,D(\mathbf{S},\mathbf{S}_{k(M)})\}$ is the set of M largest values in the set $\{D(\mathbf{S},\mathbf{S}_1),...,D(\mathbf{S},\mathbf{S}_N)\}$. Alternatively, the set of likely locations can be selected by taking those locations whose corresponding calibrated spatial signatures have at least a minimum degree of similarity to the measured signature. For example, select a subset of locations k(1),k(2),...,k(M) such that for j=1,...M, $D(\mathbf{S},\mathbf{S}_{k(j)}) > h$, where h is a predetermined threshold value. This subset of points is illustrated in FIG. 10 as those points above the dotted line corresponding to the value of h.

Another approach to determining a set of likely locations is to consider the topographical structure of the surface defined by z = S(x,y), where the function S is defined at bin location points $(x_k,y_k)=\mathbf{d}_k$ by $S(x_k,y_k)=D(\mathbf{S},\mathbf{S}_k)$, and interpolated at other values of (x,y). The locations corresponding to the minima of this surface S should be the most likely locations of the mobile. A systematic search or other analysis of the surface can be used to produce a small set of locations corresponding to distinct minima of the surface. The best match corresponds to the least of these minima. Most probably, the actual location will have both the least minimum, as well as several other minima in close proximity.

Similar selections of likely locations can be made using the difference measures $D'(\mathbf{C},\mathbf{C}_k)$ and $D''(\tau,\tau_k)$, noting that these measures are difference measures, while $D(\mathbf{S},\mathbf{S}_k)$ is a similarity measure. The selected sets of likely locations using each measure can then be combined or intersected to obtain a single set of likely locations.

SIGNATURE SPECTRUM MATCHING

Another matching technique can be used in addition to the above techniques to further improve the performance of the location finding system. To describe this technique, we first define an N-dimensional vector **w** by

$$\mathbf{w} = [D(\mathbf{S},\mathbf{S}_1),...,D(\mathbf{S},\mathbf{S}_N)]^T.$$

The vector **w** characterizes how the spatial signature **S** compares to the entire set of calibrated spatial signatures $\mathbf{S}_1,...,\mathbf{S}_N$. This vector **w** can be thought of as describing a "spectrum" of the signature **S** with respect to the entire set of calibrated signatures $\mathbf{S}_1,...,\mathbf{S}_N$. This spectrum can be visualized as the graph of the function $D(\mathbf{S},\mathbf{S}_k)$ with respect to k, as illustrated in FIG. 10. Similarly, define a set of N vectors $\mathbf{w}_1,...,\mathbf{w}_N$ by

$$\mathbf{w}_k = [D(\mathbf{S}_k,\mathbf{S}_1),...,D(\mathbf{S}_k,\mathbf{S}_N)]^T.$$

The vector $\mathbf{w}_k$ characterizes how the calibrated signature $\mathbf{S}_k$ compares to the entire set of calibrated spatial signatures $\mathbf{S}_1,...,\mathbf{S}_N$. In other words, the vector $\mathbf{w}_k$ is a "spectrum" of the calibrated signature $\mathbf{S}_k$ with respect to the entire set of calibrated signatures, and corresponds to a graph similar to that shown in FIG. 10 for $\mathbf{w}$.

Because the spectrum $\mathbf{w}$ of a signature contains information about the signature, it can be used for matching. In particular, the spectrum $\mathbf{w}$ of a measured signature can be compared with the spectrum $\mathbf{w}_k$ of each calibrated signature. For example, FIG. 11 shows the graph for the spectrum $\mathbf{w}$ superimposed upon the graphs for spectra $\mathbf{w}_{k(1)}$ and $\mathbf{w}_{k(2)}$. As is evident from the figure, the spectrum $\mathbf{w}_{k(2)}$ is more similar to the spectrum $\mathbf{w}$ than to the spectrum $\mathbf{w}_{k(1)}$. Thus, location k(2) is more likely than location k(1). More generally, by comparing the spectrum $\mathbf{w}$ with each calibrated spectrum $\mathbf{w}_k$, a set of likely locations can be selected, just as the signatures themselves were compared. For example, define a measure of difference G between a real-time signature spectrum $\mathbf{w}$ and a calibrated signature spectrum $\mathbf{w}_k$ using some difference measure. There are many well known techniques for measuring the distance between two vectors. For example, one may define the distance between the vectors by a least-squares difference as follows:

$$G(\mathbf{w},\mathbf{w}_k) = |\,\mathbf{w} - \mathbf{w}_k\,|^2 = \sum_{i=1}^{N} |\,D(\mathbf{S},\mathbf{S}_i) - D(\mathbf{S}_k,\mathbf{S}_i)|^2.$$

A set of likely locations can be selected using this measure of difference alone or in combination with the various measures described above.

The above technique is advantageous and reduces location ambiguity because the comparison between the vectors $\mathbf{w}$ and $\mathbf{w}_k$ includes comparative information from all N components of the vectors, and does not merely select locations based on the components of $\mathbf{w}$ alone. Thus, more information is used to compare the measured signal covariance with the calibrated subspaces, and a more accurate match can be obtained.

Moreover, one can analogously define vectors $\mathbf{w}'$ and $\mathbf{w}''$ from $D'(\mathbf{C},\mathbf{C}_k)$ and $D''(\tau,\tau_k)$, respectively, to obtain functions $G'(\mathbf{w}',\mathbf{w}_k')$ and $G''(\mathbf{w}'',\mathbf{w}_k'')$, respectively. The functions G, G′ and G″ can then be used individually or together to select a set of most likely locations using techniques described above in relation to functions D, D′ and D″. It will be appreciated

that various combinations of the measures D, D′, D″, G, G′, and G″ can be used in various ways to select locations using the techniques described above, or similar techniques. It will also be appreciated that other formulas may be used to define these measures.

CALCULATION OPTIMIZATIONS

It should be noted that, in the case where $D(\mathbf{S},\mathbf{S}_k) = Tr\{\mathbf{P}_k\mathbf{R}\}$, this similarity measure can be easily computed by $D(\mathbf{S},\mathbf{S}_k) = \mathbf{p}_k{}^T\mathbf{r}$, where $\mathbf{p}_k$ is a p^2-dimensional vector derived from $\mathbf{P}_k$, and $\mathbf{r}$ is a p^2-dimensional vector derived from $\mathbf{R}$. Moreover, both $\mathbf{p}_k$ and $\mathbf{r}$ have real-value components. Thus, $\mathbf{w}_k=[\mathbf{p}_1{}^T\mathbf{r}_k,...,\mathbf{p}_N{}^T\mathbf{r}_k,]^T$ and $\mathbf{w}=[\mathbf{p}_1{}^T\mathbf{r},...,\mathbf{p}_N{}^T\mathbf{r},]^T$. This technique simplifies the computation of $D(\mathbf{S},\mathbf{S}_k)$ and $G(\mathbf{w},\mathbf{w}_k)$, as well as reducing the amount of storage space required for precomputed values.

With these simplified representations of $\mathbf{w}$ and $\mathbf{w}_k$, the closeness of the measured signature and a calibrated signature can be calculated, as before, with the function $D(\mathbf{w},\mathbf{w}_k)$. This measure, however, was defined using all N components of the vectors. It is desirable, therefore, to simplify the calculation of D to use the simplified representations of the vectors. One such technique for simplifying the calculation of D is as follows. Define the matrices $\underline{\mathbf{P}}^T = [\mathbf{p}_1{}^T...\mathbf{p}_N{}^T]$ and $\underline{\mathbf{R}} = [\mathbf{r}_1...\mathbf{r}_N]$. It can then be shown that the N×N calibration table matrix $\mathbf{W} = [\mathbf{w}_1...\mathbf{w}_N]$ is given by $\mathbf{V} = \underline{\mathbf{P}}\ \underline{\mathbf{R}}$, and that

$$G(\mathbf{w},\mathbf{w}_k) = |\ \mathbf{w} - \mathbf{w}_k\ |^2$$
$$= |\ \underline{\mathbf{P}}\ \mathbf{r} - \underline{\mathbf{P}}\ \mathbf{r}_k\ |^2$$
$$= |\ \mathbf{Q}\ \mathbf{r} - \mathbf{Q}\ \mathbf{r}_k\ |^2,$$

where $\mathbf{Q}^T\mathbf{Q}$ is the Cholesky factorization of $\underline{\mathbf{P}}^T\underline{\mathbf{P}}$. Since $\mathbf{Q}$ is a $p^2 \times p^2$ square matrix, and since both $\mathbf{r}_k$ and $\mathbf{r}$ are p^2-dimensional vectors, it is very simple to store $\mathbf{Q}$ and $\mathbf{Q}\mathbf{r}_k$, and to compute $G(\mathbf{w},\mathbf{w}_k) = |\ \mathbf{Q}\ \mathbf{r} - \mathbf{Q}\ \mathbf{r}_k\ |^2$. In a typical embodiment, with p=6 and N=10,000, this technique provides more than two orders of magnitude savings in storage and computation.

In an alternate technique, a vector $\underline{\mathbf{w}} = \mathbf{W}_S{}^H\mathbf{w}$ is the projection of the N-dimensional vector $\mathbf{w}$ onto the subspace $\mathbf{W}_S$ spanned by the dominant eigenvectors of $\mathbf{W} = [\mathbf{w}_1...\mathbf{w}_N]$. Similarly, vector $\underline{\mathbf{w}}_k = \mathbf{W}_S{}^H\mathbf{w}_k$ is the projection of the N-dimensional vector $\mathbf{w}_k$ onto the same subspace. These vectors have dimensions significantly smaller than N, and thus

require less storage space. The matching of the vector $\mathbf{w}$ with vectors in the set of N vectors $\mathbf{w}_1,...,\mathbf{w}_N$ is performed by evaluating $G(\mathbf{w},\mathbf{w}_k)$ for k=1,...,N. It can be seen, however, that

$$G(\mathbf{w},\mathbf{w}_k) = | \mathbf{w} - \mathbf{w}_k |^2 \approx | \mathbf{W}_S\mathbf{w} - \mathbf{W}_S\mathbf{w}_k |^2 = | \underline{\mathbf{w}} - \underline{\mathbf{w}}_k |^2.$$

Thus, the computation of $G(\mathbf{w},\mathbf{w}_k)$ is significantly simplified.

ANGULAR ENERGY DISTRIBUTION MATCHING

Another approach to signature matching that can be used separately or together with the above techniques involves the use of array manifold vectors $\{\mathbf{a}(\theta)\}$. These vectors can be determined using signature calibration information, as described above, or by other known techniques. Once these vectors are known, they can be used for locating a mobile device, as follows. The covariance matrix $\mathbf{R}$ for the device is measured as described above, and an angular energy distribution $B(\theta)$ for the signal is calculated for each value of θ. Typically, there are approximately 360 values. In the preferred embodiment, the angular energy distribution is calculated with a beamforming metric, as follows:

$$B(\theta) = \mathbf{a}(\theta)^H \mathbf{R}\, \mathbf{a}(\theta).$$

Alternatively, any high resolution angular energy distribution metric can be used, such as the MUSIC metric,

$$B(\theta) = \mathbf{a}(\theta)^H \mathbf{U}\mathbf{U}^H \mathbf{a}(\theta),$$

where $\mathbf{U}$ is the matrix of the dominant eigenvectors of $\mathbf{R}$. A similar function is precomputed in advance for each of the calibrated signal covariance matrices $\mathbf{R}_1,...,\mathbf{R}_N$. One then obtains a set of N angular energy distribution functions $B_1(\theta),...,B_N(\theta)$ corresponding to the set of N calibrated locations. For the beamforming metric, one calculates

$$B_k(\theta) = \mathbf{a}(\theta)^H \mathbf{R}_k\, \mathbf{a}(\theta).$$

Alternatively, for the MUSIC metric one calculates

$$B_k(\theta) = \mathbf{a}(\theta)^H \mathbf{U}_k \mathbf{U}_k^H \mathbf{a}(\theta),$$

where $\mathbf{U}_k$ is the matrix of the dominant eigenvectors of $\mathbf{R}_k$. This set of functions $B_1(\theta),...,B_N(\theta)$ is preferably calculated in advance and stored in the calibration database.

In a preferred embodiment, a set of likely locations is determined by comparing the real-time angular energy distribution $B(\theta)$ of the signal from the mobile device with the calibrated angular energy distributions $B_1(\theta)$, ..., $B_N(\theta)$. In the preferred embodiment, these distributions are compared using a statistical measure $\underline{G}$ to measure the similarity between B and each of the calibrated distributions $B_1,...,B_N$. For example, the measure $\underline{G}$ can be defined by the squared difference:

$$\underline{G}(B, B_k) = \sum_\theta | B(\theta) - B_k(\theta) |^2,$$

where the sum is over all angles $\theta=1,...,360$. Alternatively, the metric $\underline{G}$ can be defined as the Kullback-Liebler distance or other metric. Using this similarity measure $\underline{G}$, the set of likely locations is then selected using techniques such as those already described above for the similarity measures D, D′, D″, G, G′, and G″.

ADDITIONAL AMBIGUITY REDUCTION TECHNIQUES

In addition to the above techniques which use various types of signature analysis to resolve ambiguities and improve matching, various other techniques can be used for resolving ambiguities and improve the accuracy of the location determination technique.

Map Comparisons

One technique for reducing ambiguities is to compare the computed likely locations with locations on a map. For example, if the mobile device is known to be moving, it can be assumed that it is most likely in a vehicle constrained to known roads. Thus, any off-road locations can be eliminated or assigned lower likelihoods, especially if the mobile has a large velocity.

Tracking

Another technique for resolving ambiguity is a motion tracking system that associates sets of likely locations measured over the course of several seconds or minutes. Using realistic assumptions about the possible changes in phone location over the course of time, the ambiguities in location can be reduced or resolved. For example, it is very unlikely that a phone that has been located in one localized region of the service area will suddenly move to another location several miles away. Motion continuity constraints, in other words, can be used to eliminate or reduce the likelihood of some locations.

A preferred tracking technique will now be described in relation with FIG. 12. The technique includes constructing trajectories, called tracks, from the sets of likely locations over the course of time. These tracks are illustrated in the figure by solid curves. The technique also includes updating the tracks when each consecutive set of likely locations is obtained, and determining the likelihoods of the various tracks. Similar techniques are well-known in the art of military target tracking. The current tracks at any given point in time have an end point corresponding to the most recent location of the track, and a predicted next point. The end points are shown in the figure as solid circles at the right end of the tracks, while the predicted next points are shown as empty circles. Predicted paths, shown as broken lines, connect the end points with the predicted next points. A set of points corresponding to the next measured set of likely locations is then obtained using the matching techniques described above. These measured points are shown as disconnected solid circles. Typically, in the next measured set of likely locations, some points will be close to the predicted next points of the tracks and some others will not be close. Clearly, the points that are close to present tracks are more likely to correspond to the actual location.

Given a set of tracks and a set of likely locations, calculate for each track a predicted next location and compute its variance (e.g., using the well-known Kalman filter). Using the likelihoods of the data points in the track, calculate the a priori probability of the track. Next, among all the possible pairwise associations between predicted next locations of tracks and the measured set of likely locations, determine the association that maximizes the a posteriori probabilities of the pairwise associations, i.e. find the best match between the predicted track locations and the actual locations. Eliminate associations whose distance is greater than a predetermined association threshold. Terminate any tracks that have a predetermined number of consecutive association failures. For any unassociated locations, initiate new tracks. New tracks are considered tentative until they have been confirmed. A tentative track is confirmed when I locations are associated to it out of J consecutive attempts. The integers I and J are design parameters that are selected in dependence upon the particular desired system tracking performance. All the tracks are then filtered using the well-known Kalman filter. The most likely location of the mobile device is the new (filtered) endpoint of the most likely track. Typically, there will be various short tracks corresponding to erroneous

locations, and one longer track corresponding to the correct location. Other tracking methods may be used to achieve similar results. In addition, this tracking method may be used alone or in conjunction with other methods of reducing ambiguity.

Multi-Site Data

Another technique for resolving ambiguity is to combine sets of likely locations obtained from multiple LDAs. This technique makes use of a set of several LDAs in communication with each other, e.g., through a central hub. As illustrated in FIG. 13, a hub 192 collects location information over communication lines 194 connected to multiple LDAs 196, 198, and 200. Each LDA receives signals from a mobile 202, estimates its current location, and transmits these location estimates over conventional communication lines 194 to the hub 192. Thus, location estimates are derived independently by the multiple LDAs and sent to the hub. In the case where multiple LDAs have determined sets of likely locations for the same mobile device, the hub can intersect or otherwise combine these sets to improve the accuracy of and confidence in the location estimates.

The combination of the sets of likely locations from the distinct LDAs reduces the ambiguity because the propagation paths of the signal to the different LDAs are different and, consequently, only the true location is likely to be common to all sets. As a result, this technique proves highly effective in reducing location ambiguity. It is significant to note that no temporal synchronization between LDAs is necessary because the location information is determined independently at each of the separate LDAs. Conventional location determination techniques, in contrast, often require precise synchronization at multiple base stations in order to measure differential times of arrival between signals received at the different base stations. Such techniques also require high bandwidth communication to send batches of raw timing data to a central hub for location determination computations. The present technique, in contrast, computes the locations from the raw data at each LDA and only sends a small set of likely locations to the hub. Thus, no high speed or high bandwidth communication lines are required.

In an alternate version of multi-site ambiguity reduction, rather than sending likely location data from the LDAs to the hub, signal covariance matrices are sent to the hub and signature matching is performed by the hub rather than by each LDA. In this method, the calibration data for each LDA is stored at the hub rather than at each LDA. This system architecture reduces the hardware cost of the LDAs. The hub, on the other hand, is preferably provided with one or more very powerful computers, which it uses to perform signature matching for all the LDAs it serves. One approach to performing this matching simply uses the matching process that would have been used by each LDA, then combines the independently derived likely locations to reduce ambiguity, just as described above. Alternatively, the hub can take

advantage of the fact that it has signature data from multiple LDAs to perform more sophisticated matching. One technique for implementing this idea is as follows. Let $G_1(k)$ be a difference measure between a signature measured at a first LDA and the calibrated signature corresponding to location k for the same LDA. For example, if $\mathbf{w}$ and $\mathbf{w}_k$ are the measured and calibrated spectra at this LDA, then $G_1(k)$ might be defined by $G_1(k) = G(\mathbf{w},\mathbf{w}_k)$. One can also define $G_1(k)$ using various other measures described above. Similarly, define $G_2(k)$ to be a difference measure between a signature measured at a second LDA and the calibrated signature corresponding to the same location k for this second LDA. Now, rather than independently selecting sets of likely locations using $G_1(k)$ and $G_2(k)$ separately, one can select a set of likely locations in one step using $G_1(k)$ and $G_2(k)$ together. For example, select those locations k such that $G_1(k) + G_2(k) < F$, where F is a predetermined difference threshold. Alternatively, one could select the set of M locations $k(1),...,k(M)$ having the smallest sums $G_1(k) + G_2(k)$ of all the locations. Because this technique simultaneously compares the signals with both the calibrated databases, it provides a higher degree of accuracy and ambiguity reduction than the technique of comparing signals with the databases independently. It will be appreciated by those skilled in the art that this technique generalizes in a straightforward way to three or more base stations. It will also be appreciated that the transmission of covariance matrices from the LDAs to the hub does not require large bandwidth since each covariance matrix is typically only a six-by-six matrix, and is typically sent once every 5 seconds.

EFFICIENT SEARCHING TECHNIQUES

In order to improve the computational efficiency of the real-time signature matching, the calibration data can be organized, and a searching technique can be used to efficiently search the organized calibration information. According to one such technique, a hierarchical tree structure, as shown in FIG. 14, is associated with the set of N calibrated locations. The tree structure is composed of a number of nodes, shown as circles in the figure. Each node is connected to one higher level node (except for the top node, shown containing the numeral "1".) and each node is also connected to a number of lower level nodes (except the bottom nodes, shown containing the numerals "1/1024"). For simplicity of illustration, the tree in the figure has only two branches descending from each node. Preferably, there are actually 4 to 16 branches descending from each node, and 3 to 6 levels of nodes. The leaf nodes of the tree at the bottom level have no lower level nodes.

Using well-known data clustering methods, each location k is assigned to at least one leaf node at the lowest level of the tree. Typically, each leaf node contains 10 to 30 locations. A node at the second-lowest level contains the union of the points contained in the lower-level

nodes connected to it. A similar relationship holds between other nodes in the tree. Thus, the highest node contains the indices of all N locations in the calibration table, while the second-highest nodes contain (not-necessarily disjoint) subsets of these N indices. As discussed earlier, signatures preferably are matched by comparing the spectrum $\mathbf{w}$ of a measured signature with the spectrum $\mathbf{w}_k$ of calibrated signatures. This tree-searching technique, however, can be used with other matching techniques as well. The following description of the tree search, however, assumes for the sake of illustration that the matching is performed using the signal spectrum.

Each node q of the tree has associated with it a mean spectrum vector $\mathbf{w}_{av}(q)$ calculated by averaging all the vectors $\mathbf{w}_k$ corresponding to locations in the node q. Also associated with the node q are precomputed node parameters

$$G_{max}(q) = \max \{ G(\mathbf{w}_{av}(q),\mathbf{w}_k) \text{ such that location k is in node q}\},$$
$$G_{min}(q) = \min \{ G(\mathbf{w}_{av}(q),\mathbf{w}_k) \text{ such that location k is in node q}\},$$

Each leaf node also has associated with it a set of precomputed distances $G(\mathbf{w}_i,\mathbf{w}_j)$, for all pairs $\mathbf{w}_i,\mathbf{w}_j$ in the node such that $i > j$. These precomputed values are preferably stored with the calibration table data and updated whenever the table is recalibrated.

Using this hierarchical tree-structure and associated data, the process of searching the calibration database for a matching signature is made much more efficient. The preferred searching technique has two phases. The tree search procedure used in the first phase of the matching is an adaptation of the well-known branch and bound algorithm, which traverses the tree and efficiently eliminates all nodes from the search that cannot contain the best match. The elimination of nodes from the search is guided by the following rule. A node q is eliminated if either

$$G(\mathbf{w}, \mathbf{w}_{av}(q)) - G_{max}(q) > B$$

or if

$$G_{min}(q) - G(\mathbf{w}, \mathbf{w}_{av}(q)) > B$$

where B is the distance from $\mathbf{w}$ to the best matching vector among the vectors considered thus far in the tree.

Once a leaf node is reached, an efficient search technique is used to perform the matching within the node. In this technique, the precomputed values $G(\mathbf{w}_i,\mathbf{w}_j)$ for the node are used to quickly eliminate vectors within the node. Note that the storage requirement for the

precomputed distances $G(\mathbf{w}_i,\mathbf{w}_j)$ is quadratic in the number of points in the leaf node. Consequently, the number of points in the leaf nodes is preferably kept small in order to minimize storage requirements. In the preferred embodiment, the number of points in a leaf node is typically between 10 and 30. The elimination of points from the search process within a leaf node q is performed using the following rule. A location $\mathbf{d}_k$ is eliminated if

$$| G(\mathbf{w}, \mathbf{w}_{av}(q)) - G(\mathbf{w}_k, \mathbf{w}_{av}(q)) | > B,$$

or if

$$| G(\mathbf{w}_s,\mathbf{w}_k) - G(\mathbf{w}_s,\mathbf{w}) | > B,$$

where B is the distance from $\mathbf{w}$ to the best match among the set of vectors considered so far in the tree, and where s indexes a special point $\mathbf{d}_s$ selected within the leaf node. Note that this rule does not require any new distance computations beyond the single distance $G(\mathbf{w}_s,\mathbf{w})$. Thus, to quickly eliminate as many points as possible, it is important to choose $\mathbf{d}_s$ so that the distance between $\mathbf{w}_s$ and $\mathbf{w}$ is small. In the preferred embodiment, the index s for $\mathbf{d}_s$ is determined by the following approximation criterion:

$$s = \arg\min_s \max_k \{ | G(\mathbf{w}_s,\mathbf{w}_k) - G(\mathbf{w}_s,\mathbf{w}) |^2 \},$$

or

$$s = \arg\min_s \{ \sum_k | G(\mathbf{w}_s,\mathbf{w}_k) - G(\mathbf{w}_s,\mathbf{w}) |^2 \},$$

where the $\max_k$ and the $\sum_k$ are evaluated over all indices k corresponding to points considered so far in the node, and the $\arg\min_s$ function ranges over all indices s corresponding to points not considered yet in the node. This process of point elimination is continued until all the points in the leaf have been either eliminated or considered.

It should be noted that this efficient matching procedure can be easily extended to search for a multiple number of best locations. Alternatively, it can be extended to search for a set of likely locations that satisfy various other criteria. For example, one criterion for a likely location $\mathbf{d}_k$ is that $G(\mathbf{w}_k,\mathbf{w}) < \alpha B$, where B is the distance to the best match and α is a constant greater than 1.

Applications of Location Information

The location determination techniques of the present invention provide real-time location information of mobile devices with accuracy and confidence higher than any similar land-based systems. In addition, in contrast with other systems, the present techniques do not require multiple base stations to determine a location of a mobile device, nor do the present techniques require modification of existing communication system base stations or mobile devices. The present techniques also have the unique advantage that they provide accurate location information in severe multipath environments. Moreover, the accuracy of the present system actually improves in the presence of severe multipath. These and other advantages of the present invention provide a unique and practical solution to the long-standing problem of location determination in wireless communication systems. For the first time, accurate location information can be determined in severe multipath environments and in environments where only one base station can receive a mobile device signal. In addition, this accurate location information can be provided without expensive and elaborate modification or replacement of the existing communications network hardware. This significant improvement in location determination, therefore, provides for the first time techniques that enable the widespread practical realization of many location-based services that benefit the mobile device users, the wireless communications provider, and third parties.

Many useful applications of real time location information have long been known, but have not been commercially realized due to the technical and economic difficulties in obtaining accurate location information. Because the present invention overcomes these difficulties, these desirable applications can now be realized. Although these applications have been described in the prior art in relation to other location determination techniques, to the extent that they are independent of these particular techniques, they may be adapted to make use of the location determination technique of the present invention. In other words, the substitution of the present location finding technique in the place of a prior location finding technique in previously known applications is in most cases an obvious and straightforward modification. It should be noted, however, that because the present technique is based upon a unique approach to the location finding problem, new and useful applications of location information may be conceived that have not been previously known at all.

Wireless Subscriber Services

The accurate and reliable location information provided by the present invention can be used to provide many important services to the mobile device users.

Emergency Dispatching

In the event that a wireless device user places a call (e.g., a 911 call) to report an emergency situation, the location of the user can be automatically determined and quickly transmitted to the appropriate authorities to ensure a fast response. In particular, the location information derived from one or more LDAs or from an LDA hub is stored in a real-time location database that is accessible to an emergency dispatcher, e.g., via a computer network connection. Because the caller's location can be tracked in real-time, dispatchers and dispatched emergency vehicles can monitor the location of a user who is not stationary.

Location-Based Service Information

Location information also can be used for location-enhanced information services, e.g., for providing navigational directions and/or traffic condition information to a motorist, or to provide information to a caller about nearby restaurants, gas stations, automatic teller machines, parking lots, movie theatres, and so on. This application can be implemented, for example, by allowing an information vendor to access the real-time location database of callers. The caller location information can then be used to access a location-indexed database of services. The information vendor may be an automated system, e.g., a website or audio information system.

Vehicle Fleet Management

The locations of commercial vehicle fleets can be tracked in real time in order to assist in the management of the vehicles. For example, automatic smart vehicular scheduling can use real-time location information to optimize the use of vehicles based on vehicle locations and the locations of pick-ups or deliveries. The location information can also be used to optimize the routes taken by individual vehicles based on current traffic conditions, road condition, and road construction. Over the long term, location information can also be used to monitor vehicle use and schedule vehicle maintenance.

Tracking People and Objects

Location information also can be used for remotely monitoring the location of children, patients, or other individuals. The person need only wear a small micro-transmitter "tag" that periodically transmits a sufficiently powerful signal to be received by an LDA. A similar "tag" can be attached to objects such as automobiles to assist in locating them in the event that they are lost or stolen. In one possible implementation of this application, the location of the "tag" can be accessed by an authorized subscriber to the service via a website or by telephone.

WIRELESS PROVIDER SERVICES

A wireless communication provider can make use of location information to manage wireless networks individually and collectively. For example, location information can be used to assist in hand-off between cells, for automatic trunking, for channel borrowing, for channel capacity optimization, to more efficiently allocate cellular frequencies, and to increase the capacity of the network. The location information can also be used to actively monitor and/or manage the wireless traffic in a network, e.g., to help determine locations where calls are dropped, and to help determine where new base stations are needed. Location information also can be used for location-based billing of cellular calls and to help combat cellular fraud. It also can be used in conjunction with antenna selection techniques to improve individual cell efficiency and capacity. Since antennas at existing cellular base stations have differing directional responses, this technique allows more efficient assignment and use of frequency channels within presently existing cells. In particular, by using location information to pool channels among different sectors, the base station can reduce blocking and increase trunking efficiency.

In addition, location information provided by the present method can be used to improve the quality of and extend the range of existing base stations by beamforming in both receiving and transmission. For receiving, one can use the matrix **A** stored in the calibration table to compute the optimal beamformer. For transmission, one has to compute first the corresponding **A** matrix for the transmission frequency. This can be done as part of the calibration process by probing techniques, i.e., by using several different weight vectors and computing the received signal at the mobile. The matrix **A** can then be calculated from this data off-line.

Also, the location finding method can be used to implement location division multiple access (LDMA) to increase the capacity of cellular systems by allowing several phones to use the same frequency in the same base station service area. In contrast to switched beam techniques which divide the service area into large spatial sectors, LDMA divides the service area into small localized subcells. The subcells are based on the computation of signal signatures, such as the signal subspace. The shapes and sizes of the localized subcells are determined by the multipath reflectors in the environment. In particular, each subcell is characterized by a unique signal signature, so that transmitters in different subcells display distinct signal signatures. Accordingly, the present technique of LDMA often permits the isolation of interferers which might otherwise be in the same switched beam sector.

The present invention has an important advantage over spatial division multiple access (SDMA) techniques in that location-based computations can be done off-line once the

calibration database for the base station has been determined. Frequency assignment and beamforming can then be performed quickly in real time since a large amount of preprocessing has been performed in advance. Conventional SDMA techniques, in contrast, require complex computations to be performed in real time.

To implement this scheme, the beamforming in both the reception and transmission is computed from the whole set of **A** matrices corresponding to all the phones using the frequency. To compute the locations of all the users, the preferred embodiment is modified to incorporate techniques, such as those based on high order statistics, that can blindly estimate the array vectors in the presence of statistically independent interferers. This step should be carried out on every batch of 100 samples spanning a 1 ms sampling interval. Beamforming techniques such as this will improve signal to noise ratios, increase the overall capacity of the cellular network, and allow a higher density of base stations to be deployed. Network management techniques are used to coordinate nearby base stations to efficiently share frequencies based on the locations of a set of transmitters.

The foregoing system also provides a means for trouble shooting a base station. The array response matrix **A** can be used to continually monitor the performance of the array of antennas and/or equipment at the base station. For example, sudden and dramatic changes in the elements of the **A** matrix for all locations are likely due to hardware damage to the base station. An examination of the **A** matrices can be used to isolate and identify the damage. Smaller changes in **A** may indicate minor hardware changes in the base station and/or changes in the propagation environment. A comparison of such changes in the array response at one base station with those at another can be used to determine whether or not the changes are isolated to one station or common to all stations in the shared environment.

THIRD-PARTY SERVICES

The location information provided by the present invention can be used by various third-party entities in advantageous ways. For example, highway safety authorities can monitor metropolitan freeway traffic flow in real time, and obtain location-specific information about current traffic flow, congestion, likely accidents, etc. This information can be used to automatically display messages to motorists advising them to take alternate routes to avoid troubled areas, and/or to automatically dispatch police or fire vehicles to investigate likely traffic accidents. This traffic information can also be sent or made available directly to motorists whose locations indicate that they may be affected by the conditions.

CLAIMS

What is claimed is:

1. A method for location estimation in a wireless communication system comprising a mobile device and a location determination apparatus, the method comprising:

a) coherently receiving at the location determination apparatus a set of p signals using p receivers coupled to an antenna array comprising p antenna elements;

b) calculating at the location determination apparatus a signal signature for the mobile device from the coherently received set of p signals, wherein the signal signature characterizes a spatial channel between the mobile device and the location determination apparatus; and

c) selecting a set of likely locations from a predetermined set of calibrated locations corresponding to a predetermined set of calibrated signal signatures, wherein selecting the likely locations comprises matching the signal signature with similar calibrated signal signatures.

2. The method of claim 1 wherein the signal signature comprises multipath information of the spatial channel.

3. The method of claim 1 wherein calculating the signal signature comprises collecting a batch of p-dimensional signal vectors derived from the received signals, wherein the p-dimensional signal vectors represent signals originating at the mobile device.

4. The method of claim 3 wherein calculating the signal signature further comprises calculating a signal covariance matrix **R**, wherein the calculating comprises combining outer products of the p-dimensional signal vectors.

5. The method of claim 1 wherein calculating the signal signature comprises combining signal covariance matrices derived from outer products of the p-dimensional signal vectors.

6. The method of claim 5 wherein combining the signal covariance matrices comprises forming a linear combination of signal covariance matrices weighted by factors derived from an estimated velocity of the mobile device.

7. The method of claim 5 wherein the combining comprises estimating a velocity of the mobile device from a pair of recently measured covariance matrices.

8. The method of claim 1 wherein calculating the signal signature comprises comprises resolving each of the p signals into q multipath parts, and calculating q signal covariance matrices for the q multipath parts.

9. The method of claim 1 wherein calculating the signal signature comprises resolving each of the p signals into q multipath parts, estimating q relative temporal delay times of the q multipath parts, and forming a temporal delay signature from the q relative temporal delay times.

10. The method of claim 1 wherein calculating the signal signature comprises deriving p code correlations from the p signals and forming a code correlation signature from the p code correlations.

11. The method of claim 1 wherein the selecting comprises evaluating a function measuring the similarity between the signal signature and a calibrated signal signature.

12. The method of claim 11 wherein evaluating the function comprises computing a trace of a projection of a signal covariance matrix onto a calibrated covariance matrix subspace.

13. The method of claim 1 wherein the calibrated signal signatures comprise a signature chosen from the group consisting of a covariance matrix signature, a temporal delay signature, a code correlation signature, and an angular energy distribution signature.

14. The method of claim 1 wherein the selecting comprises calculating signature similarity functions for multiple signature types and combining the calculated functions.

15. The method of claim 1 wherein the calibrated signal signatures comprise a set of calibrated vectors $\mathbf{w}_k$, wherein each calibrated vector $\mathbf{w}_k$ measures a degree of similarity between a calibrated signal covariance matrix $\mathbf{R}_k$ and a collection of calibrated signal covariance matrices, and wherein the signal signature comprises a vector $\mathbf{w}$ measuring degree of similarity between a signal covariance matrix and the collection of calibrated signal covariance matrices.

16. The method of claim 15 wherein selecting comprises calculating the difference between the vector $\mathbf{w}$ and a calibrated vectors $\mathbf{w}_k$.

17. The method of claim 15 wherein the dimensions of $\mathbf{w}$ and $\mathbf{w}_k$ are both equal to p^2.

18. The method of claim 1 wherein the selecting comprises searching nodes of a tree-structure indexing the calibrated signatures.

19. The method of claim 18 wherein the searching comprises eliminating nodes of the tree-structure, and searching calibrated locations within remaining nodes.

20. The method of claim 1 wherein the selecting is performed by the location determination apparatus.

21. The method of claim 1 further comprising communicating the calculated signal signature to a hub, and wherein the selecting is performed at the hub, preferably using supplementary signal signatures communicated from additional location finding apparatuses.

22. The method of claim 1 further comprising modifying the set of likely locations based on a comparison of the likely locations with geographical information.

23. The method of claim 1 further comprising tracking subsequent sets of likely locations.

24. The method of claim 1 further comprising updating the predetermined set of calibrated signal signatures based on the signal signature and known geographic information.

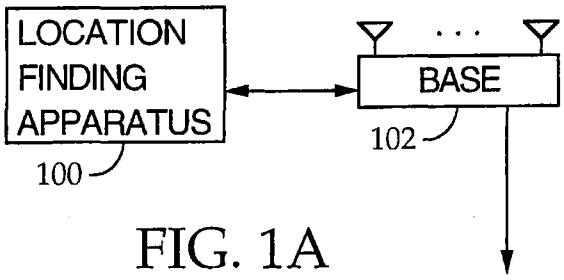


FIG. 1A

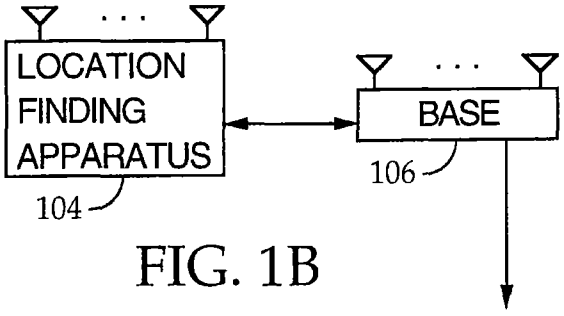


FIG. 1B

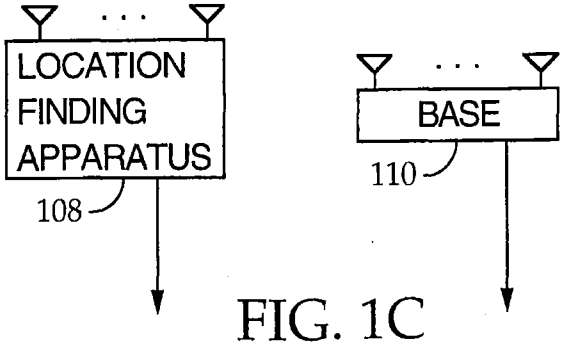


FIG. 1C

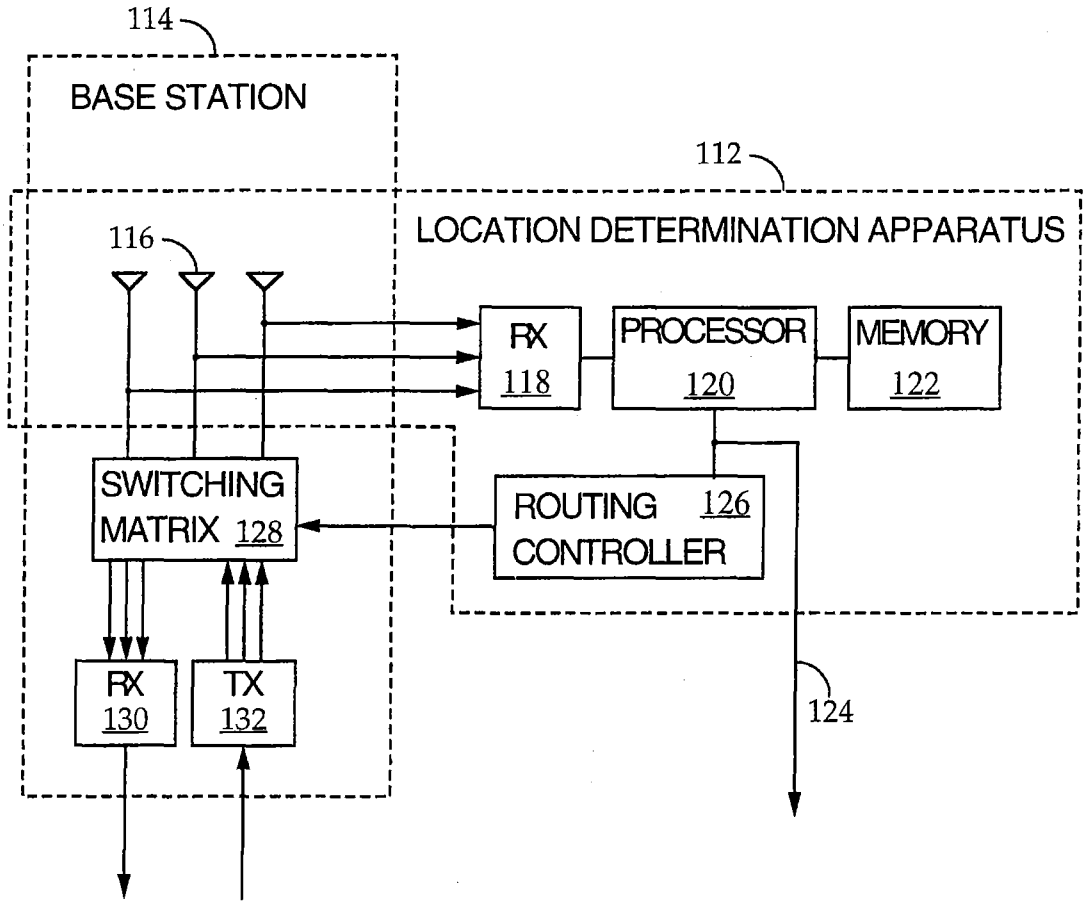

114
BASE STATION
112
LOCATION DETERMINATION APPARATUS
116
RX
118
PROCESSOR
120
MEMORY
122
SWITCHING
MATRIX 128
ROUTING 126
CONTROLLER
RX
130
TX
132
124

FIG. 2

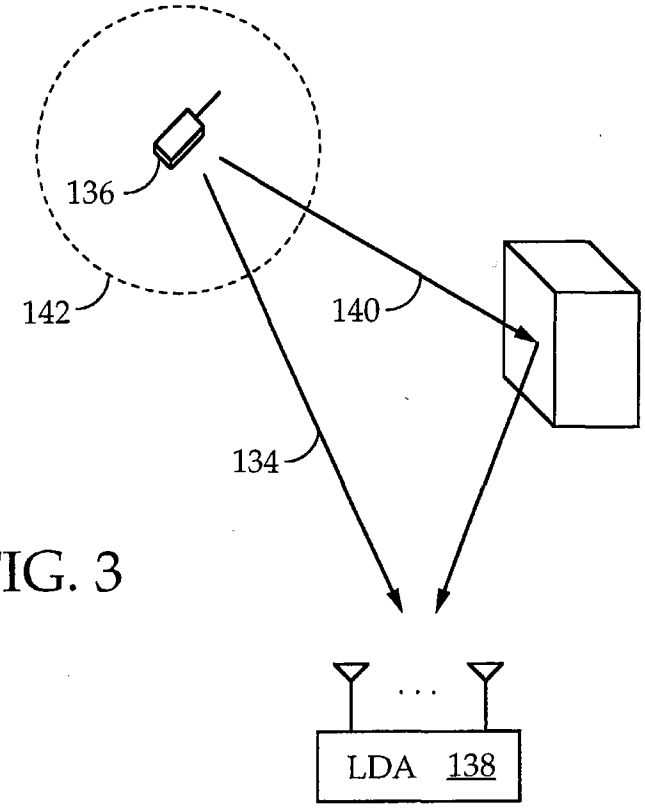


FIG. 3

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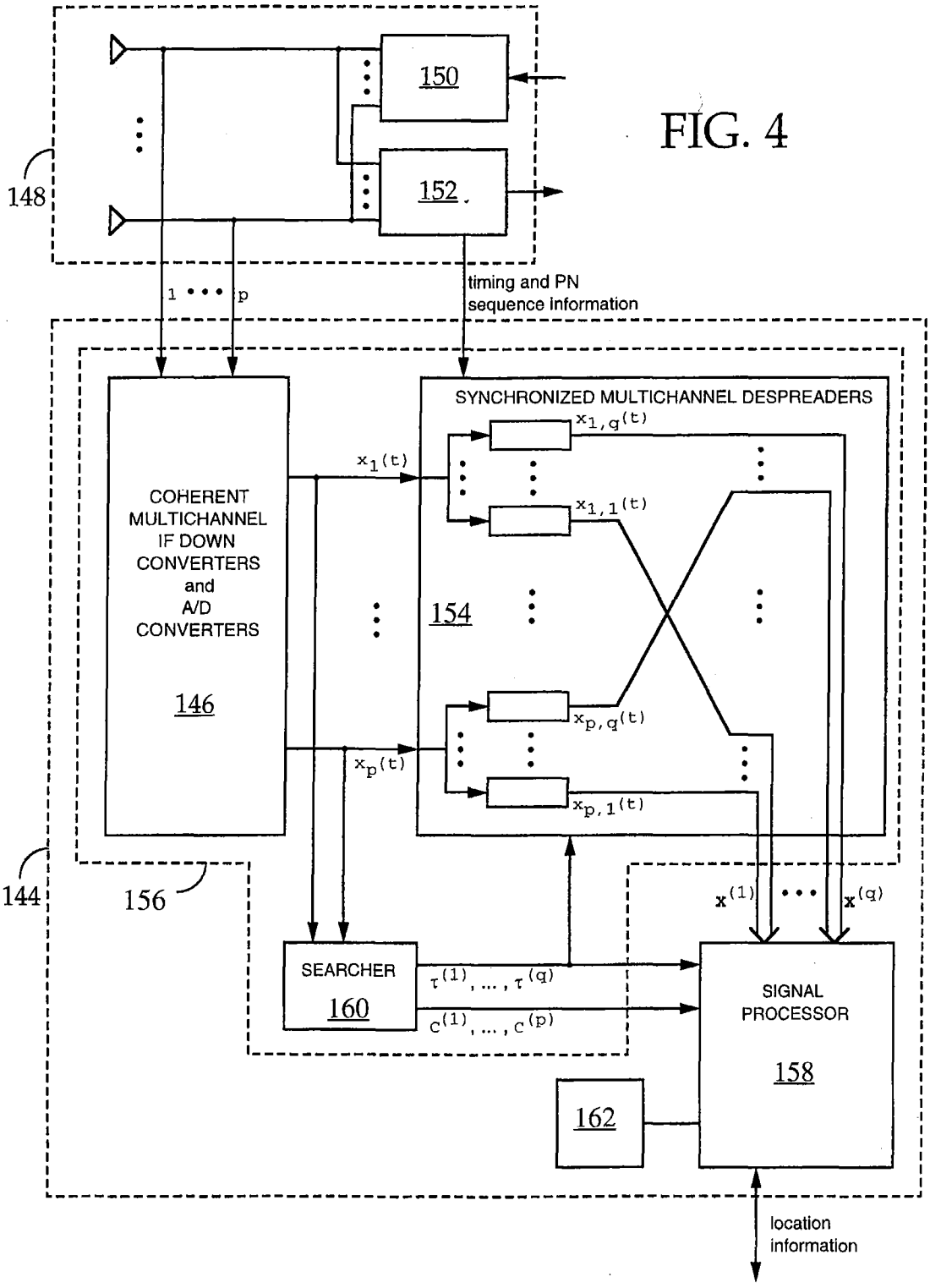
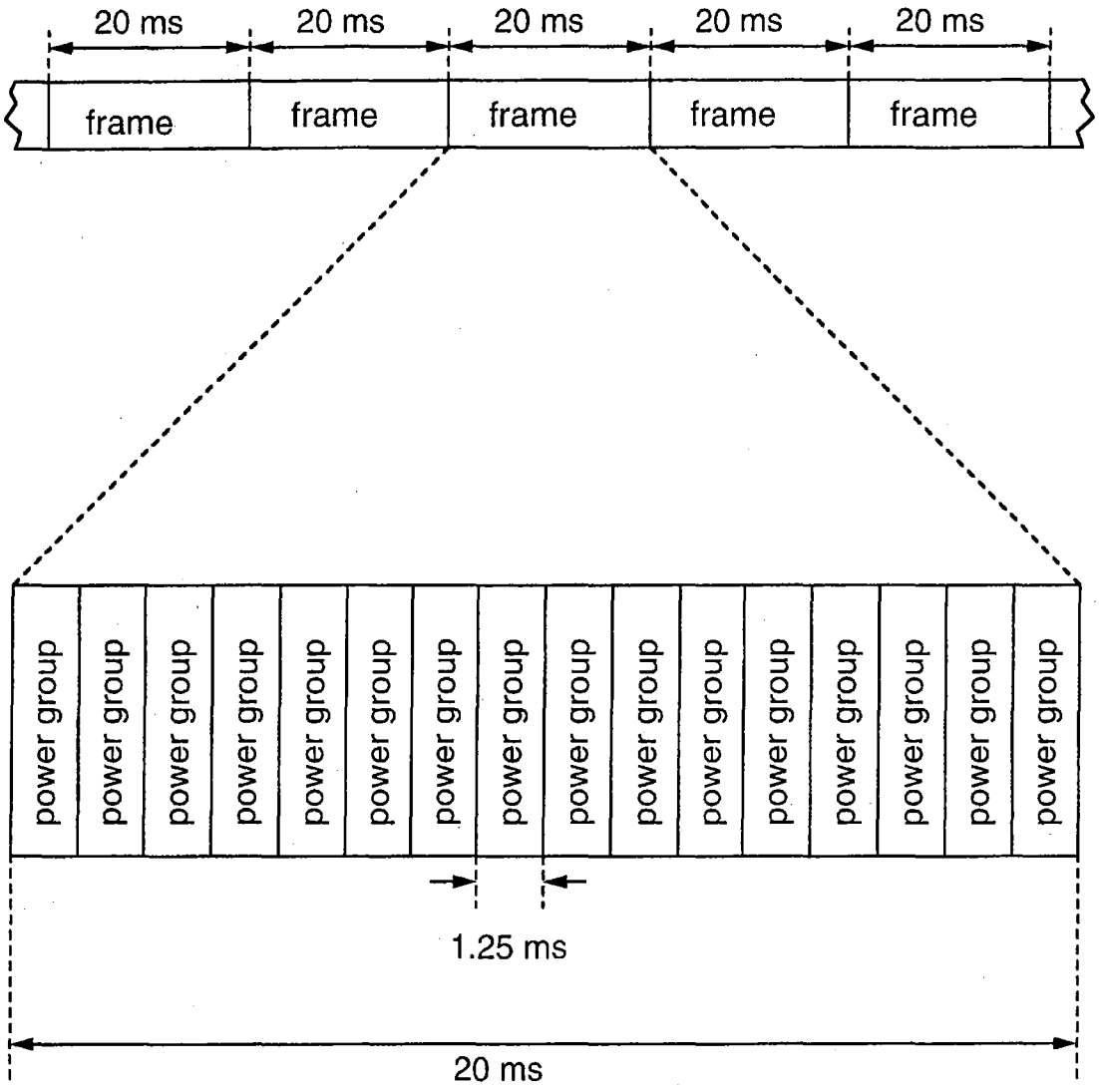

150
152
148
1 • • • p
timing and PN sequence information
SYNCHRONIZED MULTICHANNEL DESPREADERS
COHERENT MULTICHANNEL IF DOWN CONVERTERS and A/D CONVERTERS
146
154
$x_1(t)$
$x_p(t)$
$x_{1,q}(t)$
$x_{1,1}(t)$
$x_{p,q}(t)$
$x_{p,1}(t)$
144
156
SEARCHER
160
$\tau^{(1)}, \ldots, \tau^{(q)}$
$c^{(1)}, \ldots, c^{(p)}$
$x^{(1)}$ • • • $x^{(q)}$
SIGNAL PROCESSOR
158
162
location information

FIG. 4

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FIG. 5


20 ms
20 ms
20 ms
20 ms
20 ms
frame
frame
frame
frame
frame
power group
1.25 ms
20 ms

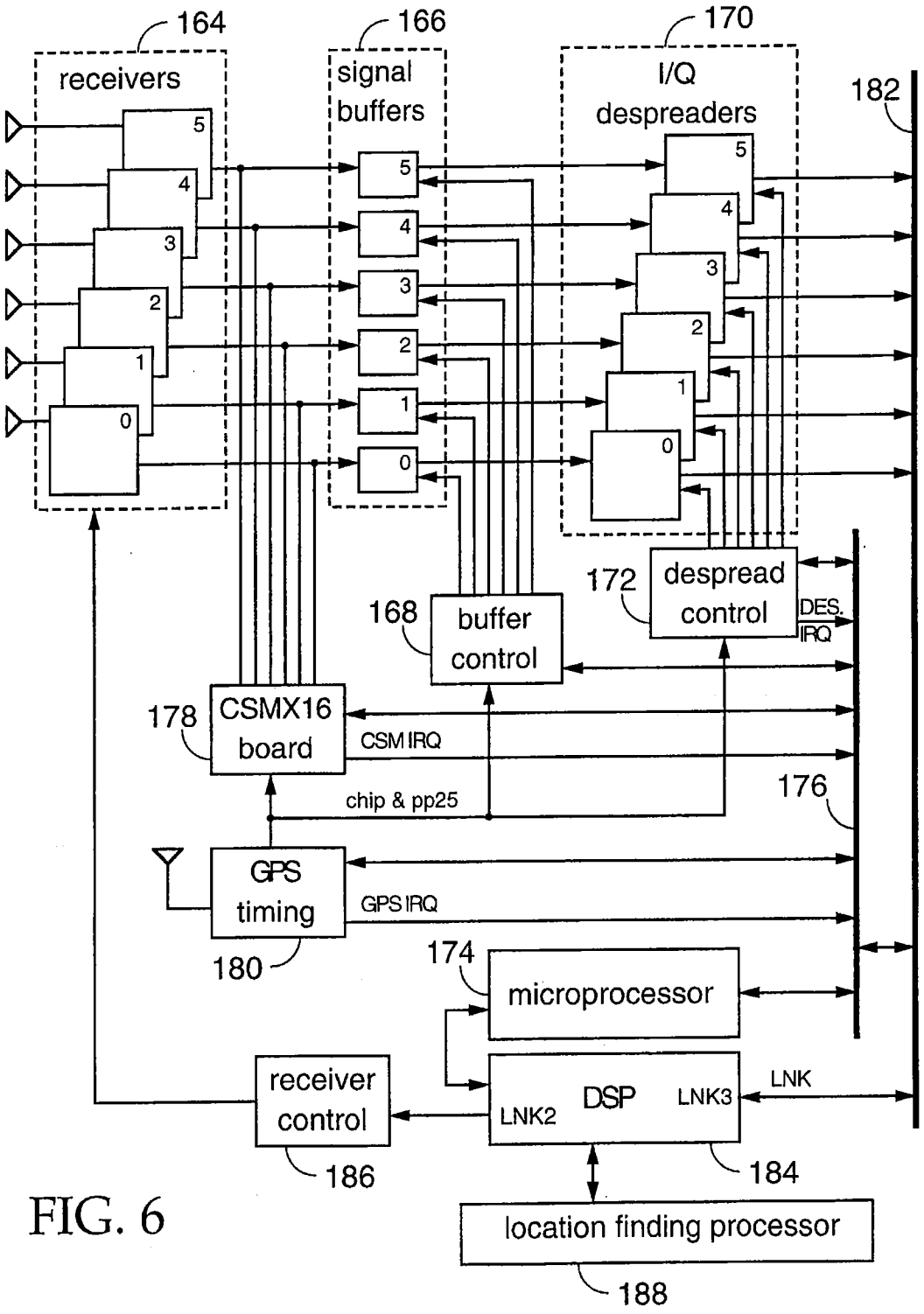

164
receivers
166
signal buffers
170
I/Q despreaders
182
5
4
3
2
1
0
172
despread control
DES. IRQ
168
buffer control
178
CSMX16 board
CSM IRQ
chip & pp25
176
GPS timing
GPS IRQ
180
174
microprocessor
receiver control
DSP
LNK2
LNK3
LNK
186
184
location finding processor
188

FIG. 6

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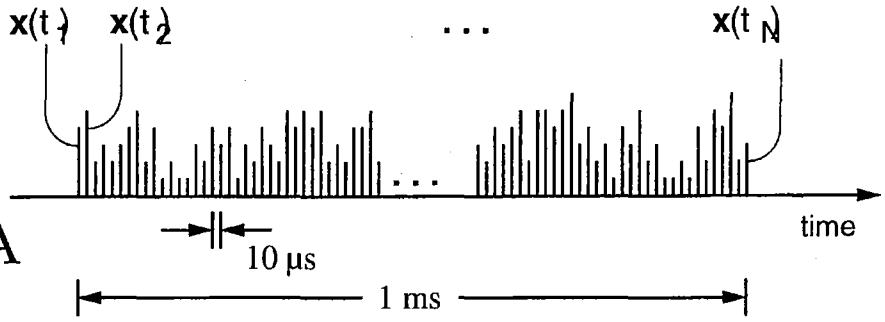


FIG. 7A

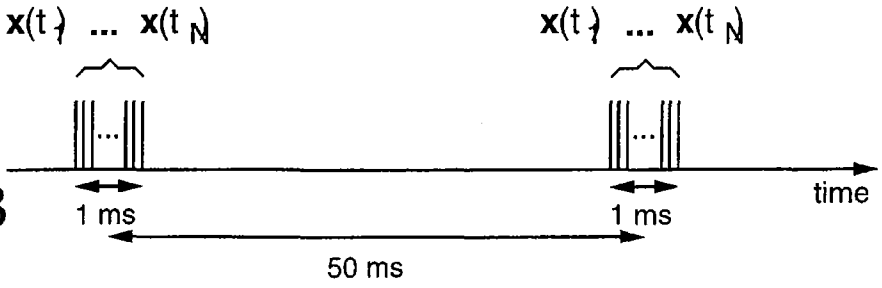


FIG. 7B

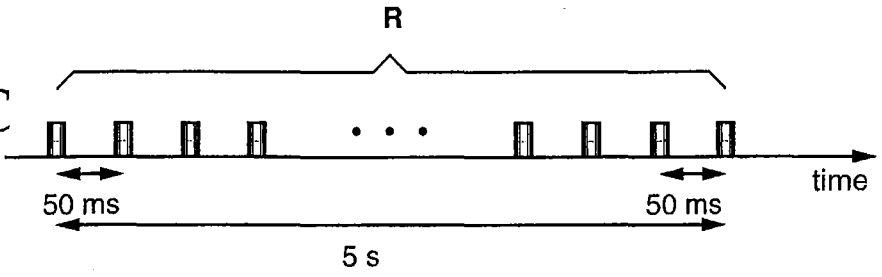


FIG. 7C

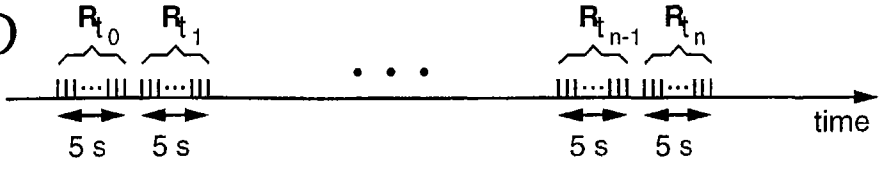


FIG. 7D

FIG. 8A

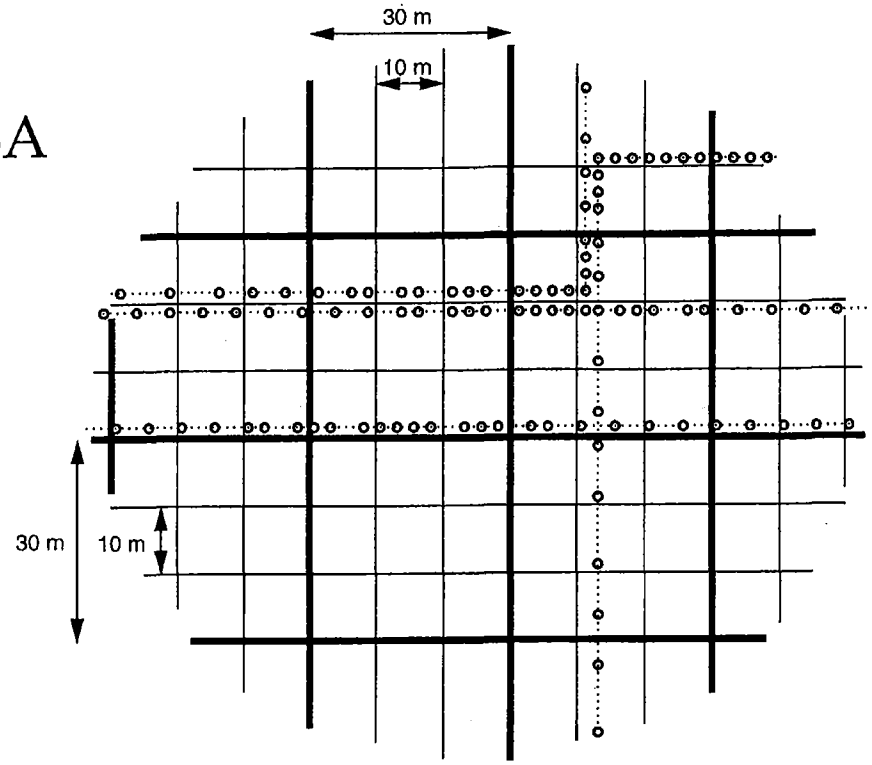
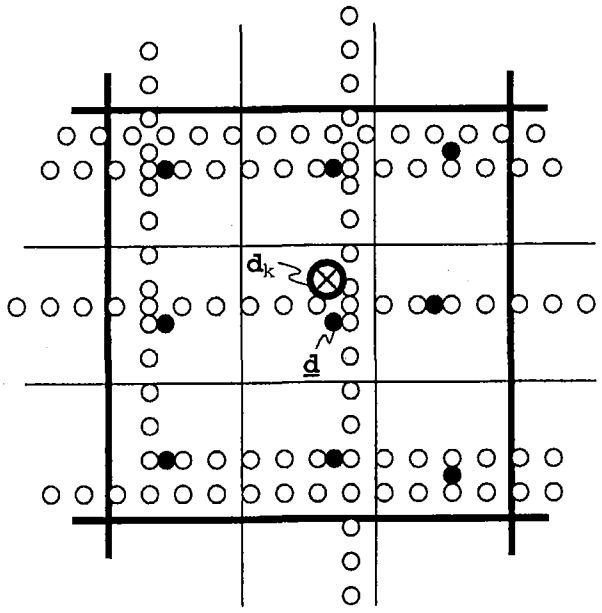


FIG. 8B



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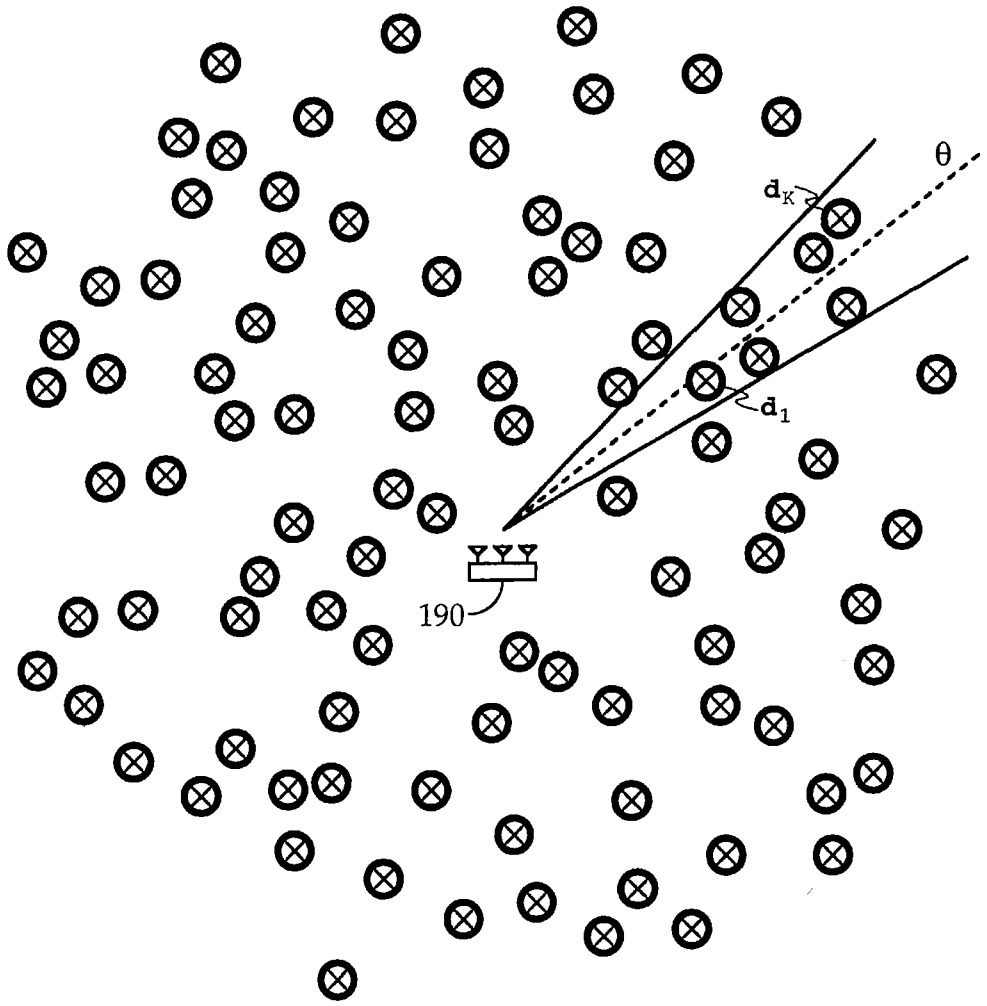


FIG. 9

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FIG. 10

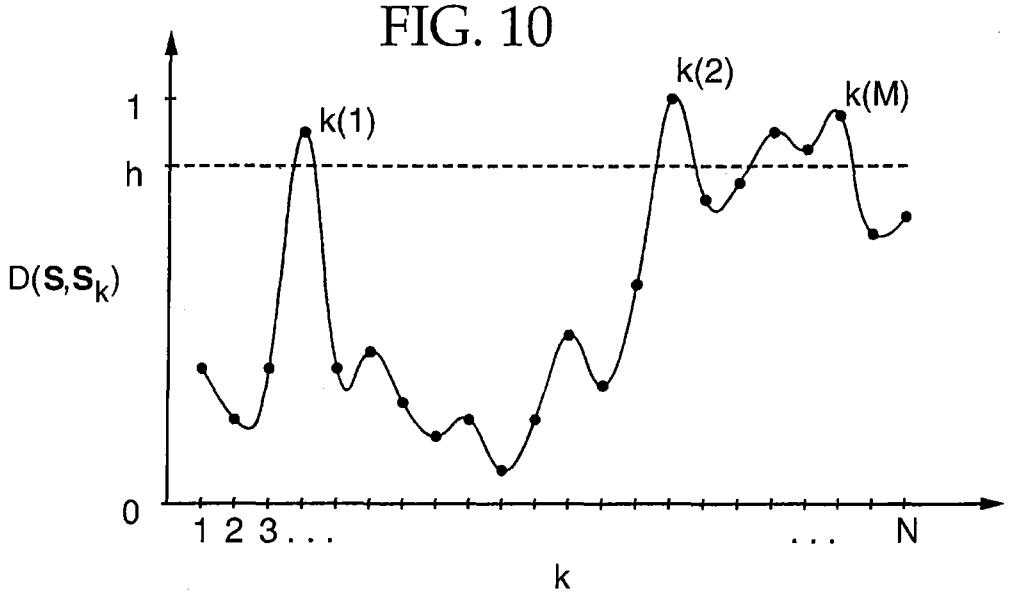
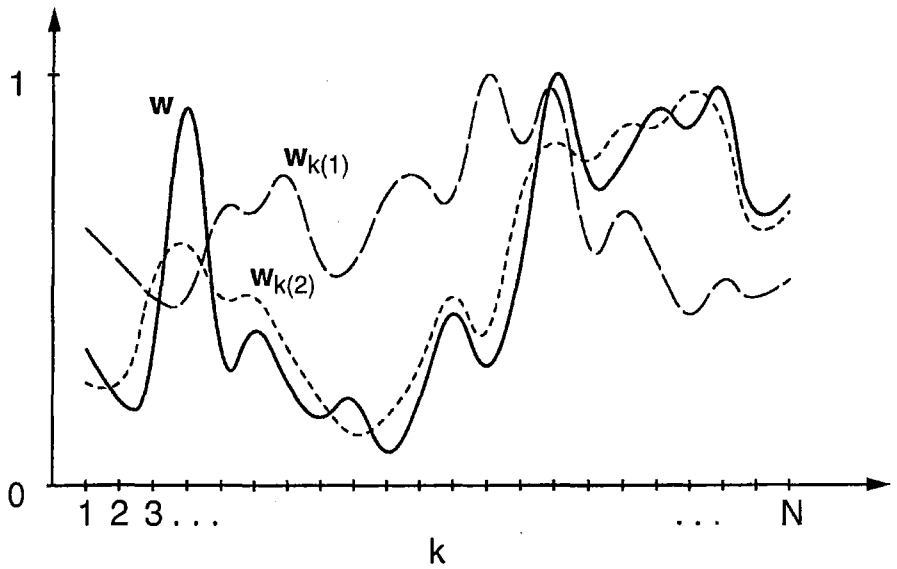


FIG. 11



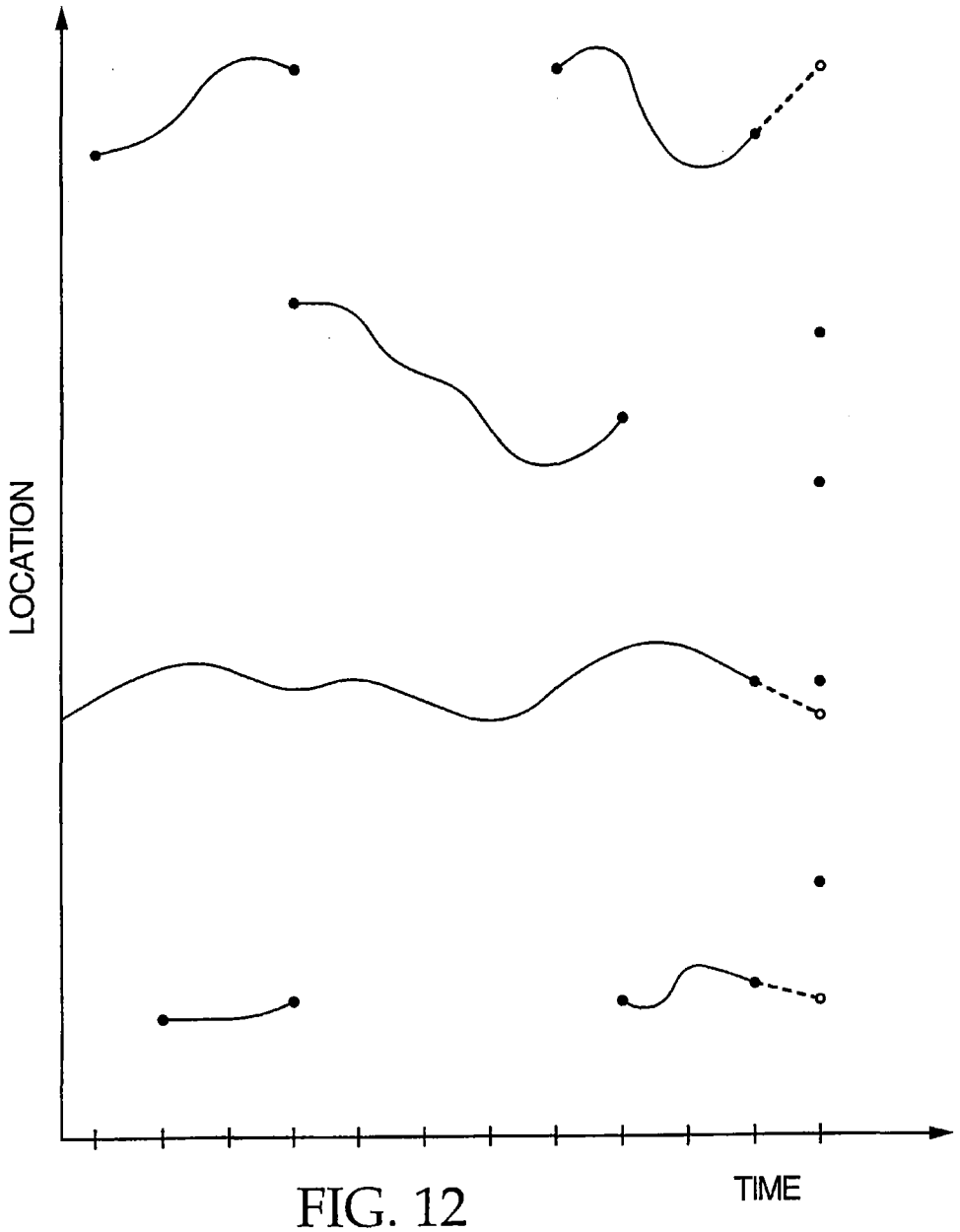


FIG. 12

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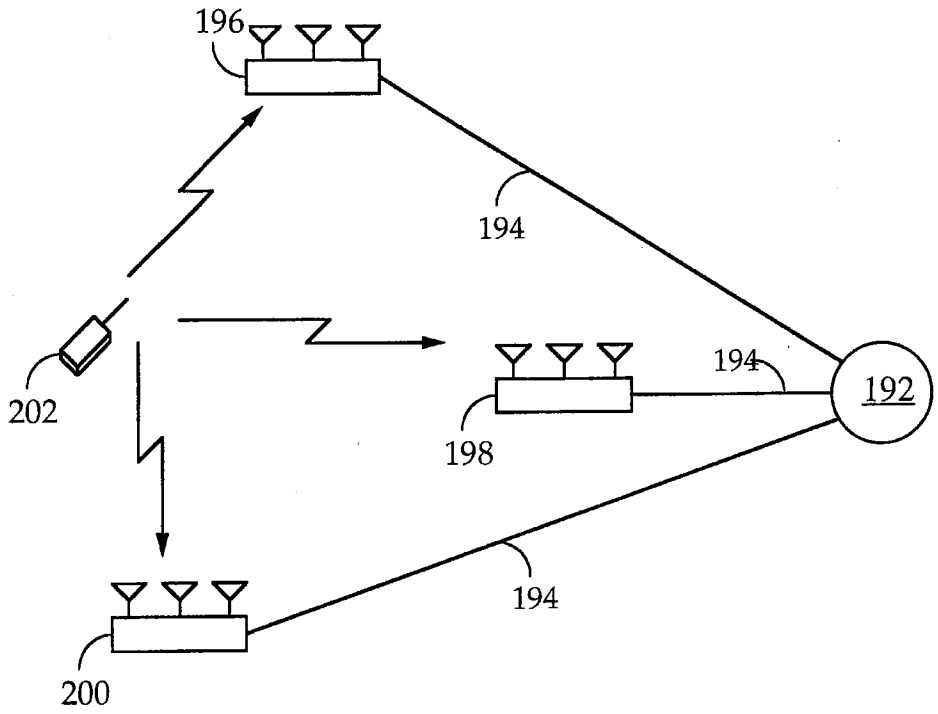


FIG. 13

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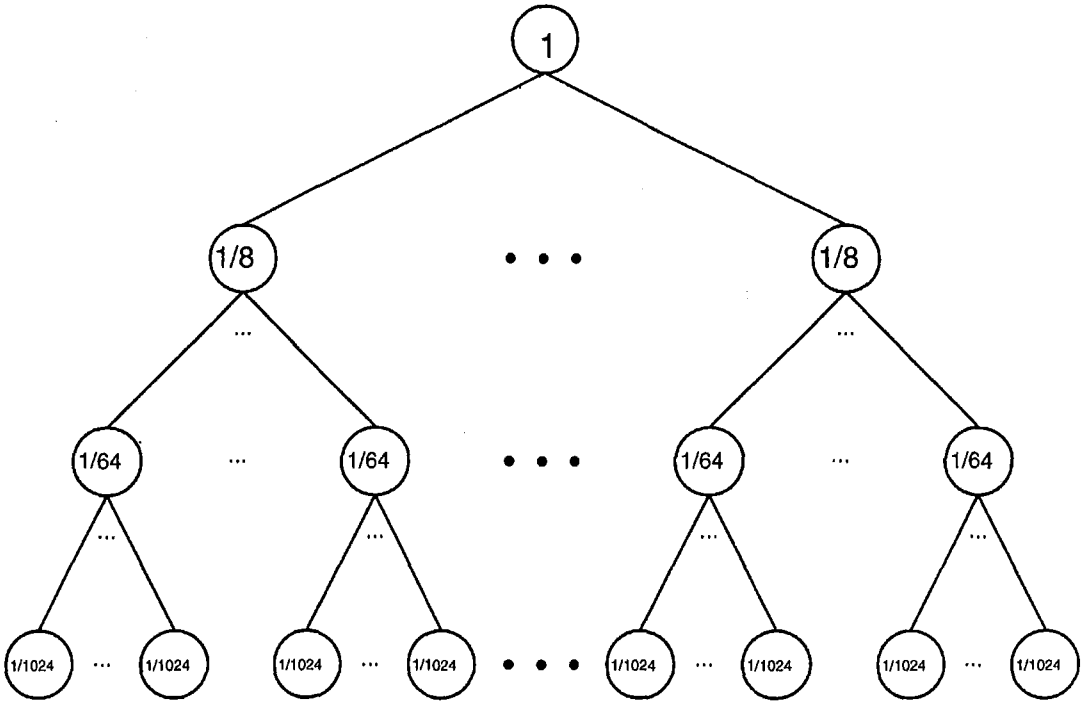

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1/64
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FIG. 14

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/24493

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : G01S 3/02
US CL : 342/457

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 342/457, 450, 451, 453; 455/456

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Please See Extra Sheet.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,717,406 A (SANDERFORD ET AL) 10 FEBRUARY 1998 (10/02/98) IN ITS ENTIRETY	1-24
X	US 5,394,158 A (CHIA) 28 FEBRUARY 1995 (28/02/95) IN ITS ENTIRETY	1-24
X	HASHEMI, Homayoun. "Pulse Ranging Radiolocation Technique and its Application to Channel Assignment in Digital Cellular Radio", 41st IEEE Vehicular Technology Conference, 1991, 675-680.	1-24
A	JENG, S.S. et al. "Measurements of Spatial Signature of an Antenna Array", 6th Int'l Symposium Personal Indoor and Mobile Radio communications. 1995. pp. 669-672	1-24

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
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"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 08 MARCH 2000	Date of mailing of the international search report 10 MAY 2000
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer GREGORY C. ISSING Telephone No. (703) 306-4156

Form PCT/ISA/210 (second sheet)(July 1992)*

B. FIELDS SEARCHED
Electronic data bases consulted (Name of data base and where practicable terms used):

IEEE DATABASE
SEARCH TERMS:(MULTIPATH, SIGNAL SIGNATURE, FINGERPRINT) AND (GEOLOCATION, LOCATION, POSITION) AND (CELLULAR,MOBILE)
BRS
SEARCH TERMS:SIMILAR TO ABOVE

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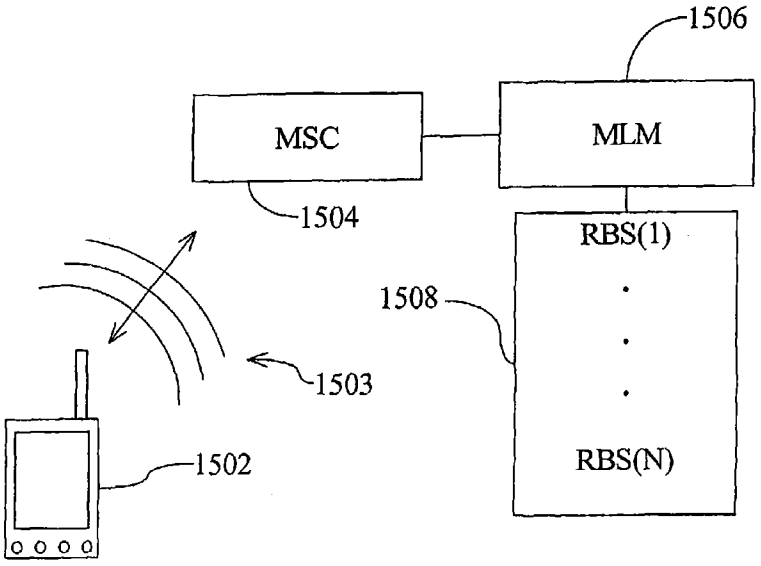
(74) Agent: **JONES, Michael, D.**; Klarquist Sparkman, LLP, One World Trade Center, Suite 1600, 121 SW Salmon Street, Portland, OR 97204 (US).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: METHODS AND APPARATUS FOR MOBILE STATION LOCATION ESTIMATION



(57) Abstract: Methods and apparatus for estimating mobile station location include receiving reported signal strengths or other attachment indicator values from a mobile station. The reported signal strengths are compared with characteristic received signal strength values in a coverage area of a mobile network. A mobile switching center determines if a location function is requested and initiates a location estimation process by a mobile location module (MLM). The MLM receives the reported signal strength contours associated with the attachment points. Based on a comparison of the reported attachment indicator values with characteristic values, the MLM provides a mobile location estimate.

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Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

METHODS AND APPARATUS FOR MOBILE STATION LOCATION ESTIMATION

Cross Reference to Related Applications

This application claims the benefit of U.S. Provisional Patent Application 60/281,147, filed April 3, 2001.

Field of the Invention

The present invention relates to methods and apparatus for determining the location of a mobile station in a wireless network.

Background

Mobile telephone systems, also called cellular telephone systems, are becoming increasingly popular. These systems are generally made up of cell sites that are configured to serve an associated coverage area that is referred to as a cell. The cell site is a location within a cell at which communication hardware such as antenna(s) and radio base stations are installed. A mobile station operating within a particular cell in the system communicates with the mobile telephone system through the associated cell site. The cell sites are in communication with a mobile switching center that connects the mobile telephone system to a land-line telephone network.

One reason for the popularity of cell phones is that they can be used for emergencies. For example, a motorist could use the mobile telephone to call for assistance in case of a disabled vehicle. Many areas provide a special emergency cellular telephone number. In other areas, users can call 911, just as they would from a conventional land-line phone.

One of the problems with using the mobile telephone for emergencies stems from the mobility of the telephone. Public service providers, such as police, do not know the location of the mobile telephone calling the emergency number. In addition, users who call the emergency number often cannot provide enough location information to allow the public service provider to find them. Thus, it is

desirable to provide a mobile telephone system that can determine the location of a mobile telephone and provide that information to public service providers.

Such a mobile telephone location service would be desirable in other contexts besides emergency responses. For example, a mobile telephone user who is lost may request location information from the mobile telephone system provider. The location information could be passed to the user from the system. Yet another user for such a system would be companies which operate fleets of vehicles. A home base for company operations could keep track of the locations of its vehicles by using a mobile telephone location service. Of course there are many other applications for such a service.

In known techniques for mobile telephone location, the distance between a mobile telephone and a mobile telephone system antenna in a cell site can be determined by analyzing the signal strength of a communication signal between the cell site antenna and the mobile telephone. If the distance between the mobile telephone and a number of cell site antennas is calculated, the approximate location of the mobile telephone can be determined by a geometric process such as triangulation.

U.S. Patent 4,891,650, describes a vehicle location system which determines an approximate vehicle location using a cellular telephone system. The location function is initiated when a vehicle transmits an alarm signal to nearby cell sites. The cell sites receiving this alarm signal analyze the received alarm signal to determine its signal strength. The cell sites then send signal strength information through the mobile telephone system to an alarm central station. The alarm central station then uses the signal strengths reported from various cells to determine an approximate location of the vehicle. A more accurate location is achieved by sending out actual tracking vehicles to the approximate location calculated by the central station. A disadvantage of this system is that each of the cell sites requires additional components, which will generate and send an appropriate signal strength report message to a mobile telecommunications switching office. The mobile telecommunications switching office also needs special functionality to send appropriate information to a central tracking station that determines an approximate location of the vehicle using the signal strengths.

U.S. Patent 5,218,367 describes a vehicle tracking system which uses signal strengths received from nearby cells to calculate an approximate vehicle location. In this system, a special purpose mobile telephone determines signal strengths being received from a nearby cell and generates and sends an appropriate alarm message, including signal strength information, to a central station via the mobile telephone system. The central station then uses this information to determine an approximate location of the vehicle. The system can improve upon the accuracy of the approximate location if the cells are divided into sectors and particular information about the antennas in these sectors is used. Once an approximate location is found, a more accurate location is achieved by sending out actual tracking vehicles to the approximate location calculated by the central station.

A technique described in U.S. Patent 4,891,650 requires additional components in each of the cell sites in order to generate and send appropriate signal strength report messages. Since there are many such cells in a mobile telephone system, such additional components are undesirable. Thus, there is a need for mobile telephone location system, which does not require additional components at each cell site. Other methods are described in U.S. Patent 5,724,660 and U.S. Patent 5,732,354.

Some of the location techniques described in the above patents do not calculate an accurate location of the mobile telephone. The accuracy of the location is improved by sending out actual tracking vehicles. However, the need for such vehicles makes such techniques very expensive. Improved methods and apparatus for mobile station location estimation are needed.

Summary

Mobile station location methods include determining a geographical location based on reported signal strength (RSS) values reported by a mobile station. The RSS values are compared with sets of RSS values obtained by, for example, signal strength measurements or signal strength computations, and stored in a memory. According to representative examples, methods include establishing latitude or longitude coordinates with a global positioning system processor associated with the mobile station. Reported RSS values are compared with predetermined RSS values

associated with the latitude and longitude coordinates. In additional examples, the predetermined sets of RSS values are revised based on GPS location coordinates reported by the mobile station.

Mobile station location processors include an input configured to receive attachment indicators associated with at least two points of attachment of the mobile station. A memory is configured to store sets of predetermined attachment indicators associated with the at least two points of attachment, and an estimation unit is configured to provide an estimate of the mobile station location based on a comparison of the received attachment indicators and at least one set of the at least two predetermined attachment indicators. According to additional examples, the received attachment indicator values are reported by the mobile station. In other examples, the attachment indicator values are reported by one or more points of attachment. In a representative example, the attachment indicator values are received signal strength values reported by the mobile station.

Mobile location modules include a processor configured to compare at least two reported received signal strength values with at least two predetermined received signal strength values associated with at least two geographical locations in a wireless network. The mobile location modules also include an output configured to deliver a mobile location estimate based on the comparison. According to representative examples, the processor is configured to determine a score associated with the comparison of the reported received signal strength values with the predetermined received signal strength values. In additional examples, the reported and received signal strength values relate to mobile-assisted hand-off.

Location units for estimating a geographic location of a mobile station include an input configured to receive attachment indicator values associated with a mobile station, and a processor configured to provide a mobile station location estimate based on predetermined attachment indicator contours associated with network attachment points. According to representative examples, the attachment indicator values are received signal strength values reported by the mobile station and the attachment indicator contours are received signal strength contours.

Methods of locating a mobile station include obtaining a set of received signal strength values associated with the mobile station and determining a mobile

station location based on a comparison of the received signal strengths with characteristic signal strength values. In representative examples, the mobile station location is determined by selecting a location associated with the characteristic signal strength values associated with a selected error score. In other examples, the methods include storing the characteristic signal strength values and retrieving the characteristic values from a memory.

Methods of locating a mobile station within a geographic service area include obtaining attachment indicator values for the mobile station. The mobile station attachment indicator values are associated with a series of attachment points and are compared with characteristic attachment indicator values associated with the series of attachment points to obtain a mobile station location estimate. According to additional representative examples, the methods include reporting the estimated mobile station location. In other examples, the attachment indicator values for the mobile station are received signal strength values associated with corresponding radio base stations and reported by the mobile station. In representative examples, the mobile station attachment indicator values and the characteristic attachment indicator values are compared by determining scores, and the estimated mobile station location is selected based on the scores.

Methods of locating a mobile station include obtaining at least one of a latitude and a longitude location estimate based on a global positioning system. An estimate of mobile station location is provided based on a comparison of mobile station attachment indicator values with characteristic attachment indicator values in a region associated with the latitude and longitude estimates.

Methods of estimating a mobile station location include receiving signal strength values reported by a mobile station and associated with a plurality of antennas. A first location area of the mobile station is calculated as a geographic coverage area of a serving cell site and a second location area of the mobile station is calculated based on a comparison of the reported received signal strength values with predetermined signal strength values associated with at least one location in the geographic coverage area. According to representative examples, the predetermined signal strength values are represented as signal strength contours, and the mobile

station location estimate is based on associating one or more signal strength contours with the reported received signal strength values.

Characteristic attachment indicator values can be determined based on a propagation characteristic between a geographic location and a point of attachment. In representative examples, the propagation characteristic can be propagation path slope, antenna pattern roll-off, or other value.

Networks configured to provide location estimates for a mobile station include a mobile location module that receives attachment indicator values associated with points of attachment. The network includes a database that includes characteristic attachment indicator values for geographic locations in a network service area. A mobile location estimate is provided based on a comparison of the received attachment indicator values and the characteristic attachment indicator values. In some examples, the received attachment indicator values are received signal strength values reported from the mobile station. In additional examples, the comparison is based on a calculated score associated with the characteristic attachment indicator values and the received attachment indicator values. In other examples, the characteristic attachment indicator values are configured as attachment indicator value contours, and the mobile station location estimate is based on these contours.

Computer readable media are provided that contain computer-executable instructions for determining mobile station location estimates. The media include computer-executable instructions configured to compare reported attachment indicator values with characteristic attachment indicator values associated with corresponding geographic locations. In some examples, instructions for determining the characteristic values are provided.

Methods of providing mobile location information include determining a mobile location based on a comparison of reported attachment indicator values with characteristic attachment indicator values associated with respective geographic locations. In some examples, the mobile location is reported to a service provider, and, in additional examples, the mobile location determination is repeated based on updated reported attachment indicator values to obtain an updated mobile location that is reported to the service provider.

These and other features are set forth below with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a geographic service area of a wireless network.

FIG. 2 is a block diagram illustrating a mobile telephone system.

FIG. 3 shows an example mobile-assisted hand-off (MAHO) list that includes received signal strengths.

FIG. 4 illustrates a Hata propagation loss model.

FIG. 5 illustrates a location area as an intersection of circles, wherein radii of the circles are overestimates of mobile station distances.

FIG. 6 illustrates a location area as an intersection of circles, wherein radii of the circles are underestimates of mobile station distances.

FIG. 7 illustrates a location point as an intersection of circles, wherein radii of the circles are accurate estimates.

FIG. 8 illustrates a method of reducing error components of computed distances.

FIG. 9 is a graph of latitude and longitude coordinates calculated by a GPS receiver/processor over a time interval.

FIG. 10 is a block diagram of a method of calculating a location of a mobile station.

FIG. 11 is a schematic block diagram of a wireless communication system.

FIG. 12 is a schematic diagram of a division of a geographical service area into zones.

FIG. 13 is a schematic diagram of an alternative division of a geographical service area into zones.

FIG. 14 is a schematic block diagram of a mobile station location module.

FIG. 15 is a schematic block diagram of a wireless network that includes a mobile station location module.

FIG. 16 is a schematic diagram illustrating received signal strength contours based on received signal strength values associated with cells of a wireless network.

FIG. 17 is a schematic block diagram illustrating a wireless network configured to provide mobile station locations to a emergency services provider.

DETAILED DESCRIPTION

FIG. 1 shows the geographic serving area 100 of a mobile telephone system. The serving area 100 is shown having 7 hexagonal cells numbered 1-7. Cell 7 is shown in the center, surrounded by adjacent cells 1-6. The serving area 100 of a mobile telephone system would typically contain more than 7 cells, however, for ease of reference, only 7 cells are shown in FIG. 1. Each cell 1-7 contains an antenna 101-107 which is used to transmit signals to and receive signals from mobile telephones such as a mobile telephone 120 within the mobile telephone system serving area 100.

A mobile telephone system 200 is shown in FIG. 2. Cell 7 is shown containing antenna 107 connected to a radio base station (RBS) 214. The mobile telephone 120 shown within cell 7 communicates with the mobile telephone system 200 via an air interface 202. For example, the mobile telephone 120 can be a digital mobile telephone that operates according to a North American time division multiple access (TDMA) system according an IS-55 standard, and an air interface according to an IS-54 or IS-136 standard. See, for example, TIA/EIA Interim Standard IS-55-A "Recommended Minimum Performance Standards of 800 MHz Mode Mobile Stations," September 1993; EIA/TIA Interim Standard IS-54-B "Cellular System Dual-Mode Mobile Station–Basestation Compatibility Standard," April 1992; EIA/TIA Interim Standard IS-136 "Cellular System Dual-Mode Mobile Station-Basestation: Digital Control Channel Compatibility Standard," April 1995; which are incorporated by reference herein. In addition, a global positioning system (GPS) receiver/processor unit 125 can be provided in or otherwise associated with the mobile telephone 120 which is to be located. This use of the GPS receiver/processor 125 in the mobile telephone 120 will be described in further detail below. Cells 1-7 include respective antennas connected to associated radio base stations (RBS) that are in communication with the mobile switching center (MSC) 220.

The cells 1-7 are assigned a plurality of voice channels for transmitting and receiving voice signals and respective control channels for transmitting and receiving control data signals. Referring to FIGS. 1-2, consider mobile telephone 120, which is operating in cell 7. The mobile telephone 120 is communicating over the air interface 202 with the mobile telephone system 200 via antenna 107 and RBS 214. Voice signals are communicated between the mobile telephone 120 and the antenna 107 via one of the cell's voice channels, and control data signals are communicated between mobile telephone 120 and the antenna 107 via the cell's control channel. In such a situation, cell 7 is the serving cell since the voice data is being communicated through that cell. In addition to the communication with the serving cell, the mobile telephone 120 also monitors the control channels of nearby cells. The mobile telephone 120, for mobile-assisted hand-off in accordance with the IS-54 and IS-136 standards, measures the signal strengths of these control channels of nearby cells. These control channel signal strength measurements are sent to the MSC 220 as described in further detail below. In addition, the mobile telephone 120 measures the signal strength of the voice signal it is receiving from the serving cell site antenna. This voice channel signal strength measurement is periodically sent by the mobile telephone 12 to the MSC 220 via the serving cell's reverse voice channel.

As the mobile telephone 120 travels within the geographic serving area 100, the signal strength of the voice channel signal between the antenna 107 and the mobile telephone 120 will vary. As the mobile telephone 120 enters another cell such as, for example, adjacent cell 5, the signal strength of the control channel signal from antenna 105 will become stronger than the signal strength of the voice channel signal from antenna 107. At this point, it is desirable for the mobile telephone 120 to terminate communication over the voice channel with cell 7 and to initiate communication via a voice channel of cell 5. This operation is called hand-off, and is used to change the serving cell while the mobile telephone 120 is traveling within the geographic serving area 100 so that the mobile telephone 120 maintains voice channel communication via the antenna with the strongest signal.

In mobile telephones based on the IS-54 and IS 136 air protocols, this hand-off operation is assisted by the mobile telephone itself. Such a function is called

mobile-assisted hand-off (MAHO). The mobile telephone 120 maintains a MAHO list, which contains the signal strengths of the signals that the mobile telephone 120 is receiving over the control channels of nearby cells. Each cell site has a pre-defined MAHO list. The MSC 220 stores these MAHO lists for each cell site and sends the appropriate list to the mobile telephone 120, depending on the serving cell site. These defined MAHO lists generally consist of the cells adjacent to the serving cell. For example, assuming that cell 7 is the serving cell, an example MAHO list 300 is shown in FIG. 3. The list of channels to measure and to include in the MAHO list is communicated to the mobile telephone 120 by the MSC 220. The list 300 contains an entry for each of the adjacent cells 1-6 in this illustration, with a corresponding signal strength (RSSI) which represents the signal strengths of the control channels broadcast by cells 1-6 as received by mobile telephone 120. Thus, $RSSI_1$ represents the control channel signal strength being received by the mobile telephone 120 from the antenna 101 in cell 1; $RSSI_2$ represents the control channel signal strength being received by the mobile telephone 120 from the antenna 102 in cell 2; etc.

MAHO measurements are periodically sent from the mobile telephone 120 to the MSC 220 via the serving cell's reverse voice channel. The contents of the MAHO list are determined by the IS-54 standard, and thus all digital mobile telephones, which comply with this, air protocol will maintain a MAHO list.

It is often desirable to determine a specific geographic location of a mobile telephone such as the mobile telephone 120 within the geographic serving area 100. A mobile location module (MLM) 230 can be included in the mobile telephone system 200 to provide a mobile station location. The MLM 230 includes a processor 232 and a memory 234. The MLM 230 is connected to the MSC 220, and the location function of the MLM 230 can be initiated by the MSC 220 as follows.

Upon initiation of a telephone call by the mobile telephone 120, the RBS 214 sends the MSC 220 the telephone number of the mobile telephone (the A number) and the telephone number of the telephone being called by the mobile telephone (the B number). The MSC 220 can be configured to perform an A/B number analysis to determine whether a location function is to be performed. For example, the MSC 220 can initiate the location function each time a mobile telephone dials 911. In

addition, the mobile telephone system provider can offer this location function as a service to its customers. In this situation, if the user of the mobile telephone 120 dials a certain number, the MSC 220 can initiate the location function and the location of the mobile telephone could be communicated to the mobile telephone user. Further, the MSC 220 can determine whether a location function is requested by referring to a user profile stored in the MSC 220. For example, a company, that uses a fleet of vehicles may want a location function performed each time a call is initiated from one of its mobile telephones. As seen by these examples, by performing an A/B number analysis, the MSC 220 can initiate a location function based on various criteria. One skilled in the art would recognize that various other A/B number analyses could be performed to determine whether initiation of the location function is requested. If the MSC 220 determines that a location function is requested, a location function in the MLM 230 is requested. Whether or not a location function is initiated, the voice portion of the signal can be sent to the appropriate destination. For example, if the mobile telephone 120 called a land line telephone, then the voice signal can be sent to the public switch telephone network (PSTN). Thus, calls that result in the initiation of a location function do not need to terminate at the MLM 230. Voice information may be transmitted to the appropriate location based upon the number dialed.

In one example, the location of a mobile telephone 120 within the geographic service area 100 can be determined by the MLM 230 as follows. The MSC 220 passes the following information to the MLM 230. The MAHO list 300 containing the $RSSI_{1\text{-}6}$ is sent by the mobile telephone 120. The cell site currently serving the mobile telephone 120 is identified. The signal strength of the voice channel signal from the serving cell site, represented as ($RSSI_V$), is measured and sent by the mobile telephone 120.

The MLM processor 232 then executes computer program code 238 stored in memory 234. The computer program code 238 describes the location algorithm to be performed by the processor 232. This algorithm is shown in the flow diagram of FIG. 10. The first step 1002 is to calculate two location zones, zone 1 and zone 2. Zone 1 is defined by the geographic coverage area of the cell currently serving the mobile telephone 120. For example, if the serving cell was cell 7 (see FIG. 1) then

zone 1 would be the geographic coverage area included in cell 7. Zone 2 is calculated by the MLM 230 as described below in conjunction with FIGS. 4-8.

The first step in calculating zone 2 is to evaluate $RSSI_V$ and $RSSI_{1-6}$ to determine the three strongest signal strengths. For the present example, assume that cell 7 is the serving cell and the strongest signal strengths are the voice channel signal strengths ($RSSI_V$) being communicated over antenna 107, the signal strength associated with the control channel for cell 2 ($RSSI_2$) being communicated over antenna 102, and the signal strength associated with the control channel for cell 4 ($RSSI_4$) being communicated over antenna 104. Using these signal strengths, it is possible to estimate the distance of the mobile telephone 120 from each of the antennas 102, 104, 107 using the following equation:

RSSI (dBm)=EIRP(dBm)-Propagation Loss(dB) (1)

In the above equation, RSSI is the known signal strength being received by a mobile telephone from an antenna. EIRP is the effective isotropic radiated power of the antenna, and it depends on the power of the transmitter (TxPower) and the gain of the antenna (Antenna Gain), such that EIRP (dBm)=TxPower(dBm)+Antenna Gain(dBi). For each antenna 102, 104, 107, the TxPower (dBm) and the Antenna Gain (dBi) are fixed constants and thus the EIRP for each of the antennas is a known value. See, for example, C.A. Belanis, Antenna Theory: Analysis and Design, John Wiley & Sons, New York, 1982.

The second term of equation (1), Propagation Loss, is modeled based upon the Hata model, which is illustrated in FIG. 4. The model is of the form:

Propagation Loss(dB)=A+B log d,

wherein A is the 1 km intercept point which depends on the height of the antenna and the frequency being transmitted and includes a component which is due to the antenna height above the ground. B is the propagation path slope, and d is the distance of the mobile telephone from the antenna (in kilometers). As shown in FIG. 4, EIRP(dBm)-A is the RSSI value of the line 402 at d=1 km, and B is the slope of the line at 402. For further information on the Hata model see, M. Hata, "Empirical Formula for Propagation Loss in Land Mobile Radio Services," IEEE Trans. Vehicular Tech. Vol. VT-29 (August 1980).

Thus, equation (1) becomes:

$$RSSI=EIRP-(A+B\log d) \quad (2)$$

Solving for distance d:

$$d=10^{\frac{1}{B}[EIRP-RSSI-A]} \quad (3)$$

In equation (3), EIRP is a known constant for each of the cell site antennas; the RSSI value is known based on measurements made by the mobile telephone 120 and the 1 km intercept point, A, is a known constant depending on the height of the antenna and the frequency being transmitted. Thus, the only unknown in equation (3) is the propagation path slope B. It is known that B is environment dependent and is generally bound as:

20 dB/dec (line of sight)$\leq$B $\leq$45 dB/dec (heavy urban).

Typically, propagation path slope is given in terms of terrain and building density. Typically categories are: Suburban: B=30, Urban: B=35, and Downtown: B=40. Thus, by estimating the value of B for each antenna, the distances d_2, d_4, and d_7 of the mobile telephone 120 from antennas 102, 104, 107 respectively, can be calculated as follows:

$$\log(d_2)=\frac{1}{B_2}[EIRP_2-RSSI_2-A_2]$$

$$\log(d_4)=\frac{1}{B_4}[EIRP_4-RSSI_2-A_4]$$

$$\log(d_7)=\frac{1}{B_7}[EIRP_7-RSSI_7-A_7],$$

wherein $EIRP_n$ is the effective isotropic radiated power of the antenna in cell n, A_n is the 1 km intercept point between the mobile telephone 120 and cell n, and B is the estimated propagation path slope of the environment in cell n.

After the distances d_2, d_4, and d_7 are calculated, a location area is determined by plotting the following circles, as illustrated in FIG. 5:

a circle 502 of radius d_2 centered at antenna 102;

a circle 504 of radius d_4 centered at antenna 104; and

a circle 507 of radius d_7 centered at antenna 107.

The intersection area 510 of circles 502, 504, 507 estimates the location of the mobile telephone 120 within the geographic serving area 100. Since the values or B_2, B_4 and B_7 are estimates, the resulting distances d_2, d_4 and d_7 will have a certain

error component based upon the estimate of B. The calculated distances d_2, will have other error components as well, based upon cell characteristics other than propagation path slope. Examples of such cell characteristics are the relative height of the mobile telephone to each cell site antenna and the gain reduction due to antenna pattern rolloff. The algorithm described herein does not take these other error components into account. In FIG. 5, d_2, d_4 and d_7 are overestimates of the distance of the mobile telephone 120 from each of the antennas 102, 104 and 107, and thus the resulting location can only be determined to be within area 510.

It is also possible that the resulting distances , d_2, d_4 and d_7 would be underestimates of the distance of the mobile telephone 120 from each of the antennas 102, 104 and 107. Such a case is illustrated in FIG. 6, in which the location estimate is within area 602. The area 602 is delimited by drawing the three lines 606, 607 and 608, which are tangent to the circles 616, 617 and 618 respectively. These three lines 606, 607 and 608 are adjusted such that they define a triangle of reduced area. The area defined by such a triangle is the location estimate area shown in FIG. 6 as area 602.

If the resulting distances d_2, d_4 and d_7 are accurate estimates of the distance of the mobile telephone 120 from each of the antennas 102, 104 and 107, then the drawn circles would intersect at a point. Such a case is illustrated in FIG. 7, in which the location estimate is shown as point 702.

Since the only variable in the distance equation is the propagation path slope B, it is possible to improve the accuracy of the location estimate by varying the estimates or B_2, B_4 and B_7 to reduce the error component of the calculated distances d_2, d_4 and d_7.

The basis for this technique is illustrated in FIG. 8. Lines which represent the distance between antennas 102, 104, and 107 are drawn. Line $L_{2\text{-}7}$ represents the distance between antennas 102 and 104. Line $L_{4\text{-}7}$ represents the distance between antennas 104 and 107. The lengths of lines $L_{2\text{-}4}$, $L_{2\text{-}7}$ and $L_{4\text{-}7}$ are known because the locations (in latitude and longitude coordinates) of the cell site antennas are known. As before, the lines d_2, d_4 and d_7 represent the calculated distances of the mobile telephone 120 from each of the antennas 102, 104 and 107, respectively. The angles

m, n, and o can be obtained as functions of the distances d_2, d_4, d_7 from the following expressions based on the law of cosines:

$$L_{2\text{-}4}=d_2^2+d_4^2-2d_2d_4\cos(m)$$

$$L_{2\text{-}7}= d_2^2+d_7^2-2d_2d_7\cos(o)$$

$$L_{4\text{-}7}=d_4^2+d_7^2-2d_4d_7\cos(n).$$

Referring again to FIG.8, the sum of the angles m, n, and o is 360 degrees so that $360 - (\angle m + \angle n + \angle o) = 0$.

The calculation of the distances d_2, d_4 and d_7 tends to be most accurate when each of these angles is positive and the sum of the angles is 360 degrees. The only variables in the calculations of d_2, d_4 and d_7 are the propagation path slopes B_2, B_4 and B_7, respectively, which values are generally between about 20 dB/dec and 45 dB/dec. Thus, the values d_2, d_4 and d_7 are calculated using equations 4, 5 and 6 while varying the propagation path slopes B_2, B_4 and B_7 between 20 dB/dec and 45 dB/dec. The resulting distances d_2, and d_4 and d_7 are then used to evaluate the sum of angles m, n, and o. The values of d_2, and d_4 and d_7 for which the sum is closest to 360 with all its terms positive gives values for d_2, and d_4 and d_7 with reduced error components.

When the distances d_2, d_4, and d_7 with reduced error components are found, the location area of the mobile telephone 120 is determined by plotting appropriate circles as described above. The geographic location (i.e. latitude and longitude) of antennas 102, 104, 107 in the geographic serving area 100 are known and, in one embodiment, are stored as cell site-information 236 in the memory 234 of the MLM 230. The MLM 230 uses these known cell site locations to determine the geographic location of the estimated location area by, for example, plotting the estimated location area on a map. This calculated location area is the zone 2 location. The MLM 230 can also include a database 250 configured to provide sets of RSS values corresponding to mobile station locations in the geographic service area of the network.

As discussed above, a GPS receiver/processor unit 125 can be used as a component in the mobile telephone 120 which is to be located. As is well known in the art, a GPS receiver/processor receives signals from satellites orbiting the earth and translates these signals into latitude and longitude coordinates of the position of

the GPS receiver/processor. A typical GPS receiver/processor is accurate to within approximately 50 feet. The MLM 230 uses information provided by the GPS receiver in the mobile telephone 120 to increase the accuracy of the geographic location estimate.

A known problem with GPS receivers is that location accuracy requires line of sight communication with multiple satellites and do not return accurate latitude and longitude coordinates if a line of sight to the satellite receivers is blocked. For example, GPS receivers typically do not report accurate coordinates when located inside a building or in wooded areas. This limitation can be compensated using the last GPS coordinate position which is within a predefined confidence level. This is accomplished by using a calculated average latitude and longitude position, along with a latitude and longitude error as follows.

FIG. 9 shows a graph of the latitude and longitude coordinates calculated by a GPS receiver/processor 125 over time intervals (t_{1-15}). At each time interval t_n, the GPS receiver/processor 125 calculates the current coordinates of the mobile telephone 120. At time t_n, the latitude coordinate is represented by Lat(t_n) and the longitude coordinate is represented by Long (t_n). The coordinates Lat(t_n) and Long (t_n) calculated by the GPS receiver/processor 125 will generally vary smoothly over time. However, of the line of sight to the satellites is blocked, for example if the mobile telephone 120 enters a building, the calculated coordinates will not be accurate. This is illustrated in FIG. 9 at intervals t_{8-12}.

The GPS receiver/processor 125 is configured to compute the average of the latitude and longitude coordinates over a predetermined sliding time window, where the average latitude and longitude for the window ending at time period t_n is represented as Lat_Avg(t_n) and Long_Avg(t_n) respectively. The length of the sliding time window is programmed into the GPS receiver/processor 125 and can vary depending on, for example, the desired accuracy and/or particular application. If this sliding time window is defined as N time periods, then the average latitude and a longitude coordinates Lat_Avg(t_n) and Long_Avg(t_n), respectively, for the time window ending at t_n is an average of N latitude coordinates and N longitude coordinates associated with times $t_{n-N+1}, \ldots, t_n$.

The values of Lat_Avg(t_n) and Long_Avg(t_n) can be continuously computed by the GPS receiver/processor 125 at successive time periods. For example, if the time period of the sliding time window N is set to 5 time periods, then the time window ending at time period t_8 is shown in FIG. 9 at 905. The values of Lat_Avg(t_8) and Long_Avg(t_8) would be calculated by the GPS receiver/processor 125 at time t_8 as averages of 5 values associated with times $t_4, \ldots, t_8$.

In addition to the average coordinates, the GPS receiver/processor 125 also calculates a peak error of the latitude and longitude coordinates during the time window. The peak error for the latitude coordinate for the time window ending at time t_n is represented as Error_Lat(t_n), and the peak error for the longitude coordinate for the time window ending at time t_n is represented as Error_Long(t_n). These peak errors are calculated by comparing the instantaneous latitude and longitude coordinates for each time period during the time window with the average coordinates of the time window as follows:

$$Error\_Lat(t_n)=max\{|Lat_{n-N+1}\ldots n-(Lat\_Avg(t_n))|\}$$

$$Error\_Long(t_n)=max\{|Long_{n-N+1}\ldots n-(Long\_Avg(t_n))|\}$$

For example, to calculate the peak error for the time window ending at time t_8, the calculation would be:

$$Error\_Lat(t_8)=\max\{|Lat_{4\ldots 8}-(Lat\_Avg(t_8))|\}$$

$$Error\_Long(t_8)=\max\{|Long_{4\ldots 8}-(Long\_Avg(t_8))|\}$$

Thus, the instantaneous latitude coordinates Lat(t_4), Lat(t_5), Lat(t_6), Lat(t_7), and Lat(t_8), are compared with Lat_Avg(t_8), and the largest deviation from the average latitude is the peak latitude error. Similarly, the instantaneous longitude coordinates Long(t_4), Long (t_5), Long (t_6), Long (t_7), and Long (t_8) are compared with Long_Avg(t_8), and the largest deviation from the average longitude is the peak longitude error. As an illustration, consider the time window 916 ending in time period t_{12}, in FIG. 9. The value of Lat_Avg(t_{12}) is represented by the line 910. The largest deviation from line 910 is the instantaneous latitude Lat(t_{10}) represented at point 914. Thus the peak error Error_Lat(t_{12}) during time window 916 is represented as the distance 912 between Lat(t_{10}) 914 and Lat_Avg(t_{12}) 910.

The GPS receiver/processor 125 uses the error values of Error_Lat(t_n) and Error_Long(t_n) to store the last reliable coordinates in the storage registers as

follows. These storage registers may be memory location in the GPS receiver/processor. Alternatively, these storage registers may be memory locations in a separate memory unit which is accessible by the GPS receiver/processor 125. At each time interval t_n, the GPS receiver/processor 125 compares the peak error values Error_Lat(t_n) and Error_Long(t_n) with programmed error thresholds Err_Thresh_Lat and Err_Thresh_Long. As with the programmable sliding time window, these thresholds can vary depending on the desired accuracy and/or particular application. These thresholds are defined such that if the peak error values Error_Lat(t_n) and Error_Long(t_n) are within the thresholds Err_Thresh_Lat and Err_Thresh_Long respectively, then it can be assumed that the instantaneous coordinate values Lat(t_n) and Long(t_n) are within acceptable reliability limits. At each time period t_n, if the peak errors of both the latitude and longitude are within the threshold values, then the instantaneous coordinate values are stored in memory registers Lat_reg and Long_reg respectively. If the peak errors for either the latitude and longitude are not within the threshold values, then the instantaneous coordinate values Lat(t_n) and Long(t_n) are not stored in memory registers Lat_reg and Long_reg respectively. This technique assures that the memory registers Lat_reg and Long_reg contain recent reliable latitude and longitude coordinates.

In addition to the information sent by the mobile telephone 120 described above, the following GPS information is sent over the air interface 202 to the mobile telephone system 200 during each time period t_n:

Lat(t_n) and Long(t_n);
Lat_reg and Long_reg;
Error_Lat(t_n) and Error_Long(t_n); and
Err_Thresh_Lat and Err_Thresh_Long.

The MSC 220 operates as described above to initiate the location function of the MLM 230 under certain conditions. The algorithm 238 stored in memory 234 of MLM 230 instructs the processor 232 to operate as described below in conjunction with FIG. 10. Thus, upon initiation of the location function, the MLM 230 operates according to the flow diagram of FIG. 10 to calculate the location of the mobile telephone 120.

As discussed above, zone 1 is defined by the geographic coverage area of the cell currently serving the mobile telephone 120 and zone 2 is the location area calculated by the MLM 230 as described above in conjunction with FIGS. 4-8. Zone 1 will generally define an area larger than zone 2. Referring to FIG. 10, in step 1004 the MLM 230 determines if the peak latitude and longitude error values for the current time window are within the predetermined threshold error values. If they are, then the instantaneous latitude and longitude coordinates Lat(t_n) and Long(t_n) are considered to be of acceptable accuracy and they are used for further processing in step1012. In step 1012 it is determined whether the instantaneous GPS coordinates define a location which is within zone 1. If not, then the MLM 230 returns the zone 2 location estimate with a moderate confident level in step 1010. If step 1012 determined that the instantaneous GPS coordinates define a location which is within zone 1, then in step 1020 it is determined whether the instantaneous GPS coordinates define a location which is within zone 2.. If they do, then the MLM 230 returns the instantaneous coordinates as the location estimate with a high confidence level in step 1024. If the instantaneous GPS coordinates do not define a location which is within zone 2, then the MLM 230 returns the instantaneous coordinates as the location estimate with a moderate confidence level in step 1018.

If in step 1004 the MLM 230 determines that the peak latitude and longitude error values for the current time window are not within the predetermined threshold error values, then the instantaneous latitude and longitude coordinates Lat(t_n) and Long(t_n) are considered not to be of acceptable accuracy, and the latitude and longitude values stored in the memory registers Lat_reg and Long_reg are used for further processing in step 1006. In step 1006 it is determined whether the GPS coordinates stored in the memory registers define a location which is within zone 1. If not, then the MLM 230 returns the zone 2 location estimate with a low confidence level in step 1008. If the GPS coordinates stored in the memory registers define a location which is within zone 1, then in step 1014 it is determined whether the GPS coordinates stored in the memory registers define a location which is within zone 2. If not, then the MLM 230 returns the memory register coordinates as the location estimate with a moderate confidence level in step 1016. If the GPS coordinates stored in the memory register define a location which is within zone 2, then the

MLM 230 returns the memory register coordinates as the location estimate with a high confidence level in step 1022.

Once the geographic location area is determined, the MLM 230 routes the information to the appropriate end user destination. The appropriate routing information 240, in one embodiment, is stored in memory 234 of the MLM 230. For example, if the location function was initiated because of a 911 call from the mobile telephone 120, the MLM 230 will route the location information to the appropriate public service provider. If the location function was initiated because the MSC determined that the cellular telephone number belonged to a fleet company, the location information would be sent to the appropriate fleet company. Further, the location information could be communicated to the mobile telephone 120 itself if the request for location information came from the user of the mobile telephone 120.

Power levels obtained by a mobile station and used in MAHO, or other sets of received signal strengths, power levels, or communication parameters can be used to locate a mobile station based on power contours or other predetermined power levels associated with an arrangement of cells. For example, as shown in FIG. 11, a mobile station 1102 transmits a set of received signal strength (RSS) values such as those illustrated in FIG. 2 to a network 1104 configured to deliver the reported RSS values to a mobile location module (MLM) 1106. The mobile location module 1106 includes a processor 1108 configured to receive the set of RSS values and identify a mobile station location based on sets of RSS values associated with a plurality of locations in a coverage area. As shown in FIG. 11, the sets of RSS values are stored in a database 1110. Typically the MLM 1106 is associated with a base station and the database 1110 includes sets of characteristic or predetermined RSS values associated the geographic area served by a particular base station. While cells are shown as contiguous and non-overlapping in FIG. 1, networks can include overlapping cells or geographic gaps between cells. Databases associated with several cells can include similar predetermined RSS values.

In a representative example, a network service area 1200 or a portion of a network service area such as a cell is divided into a service grid 1202 as shown in FIG. 12. The service grid 1202 is associated with a rectangular array of zones Z_{IJ} corresponding to coordinates (X_I, Y_J), respectively, where I, J are integers associated

with a number of rows and a number of columns, respectively. For convenience, a division into 16 rectangular zones is illustrated in FIG. 12, but a service area can be divided into fewer or more zones. Zones can be associated with a service area of one or more cells, or an entire network service area can be divided into a single set of zones. Zones can also be established based on nonrectangular grids such as triangular, square, hexagonal, curved, or other grids. In addition, the division can include a variety of regular and irregular shapes. The service area divisions can have different areas as well.

A mobile station location estimate can be obtained based on predetermined sets {RSS} of received signal strengths RSS by identifying a zone for which the reported RSS values match a set of RSS values associated with the zone. Matching can be determined based on computation of, for example, a sum of mean square differences between the reported RSS values (or some of these values) and the predetermined, stored zonal RSS values. While a mobile station typically reports several RSS values, zone matching can be based on computations using only selected RSS values. After a zone is selected, coordinates associated with the zone are provided as an estimate of mobile station location. Zone dimensions can be used to provide a location error estimate.

Another representative division of a network service area or a cell service area is illustrated in FIG. 13. Zones 1301-1312 are associated with perimeter coordinates (X,Y) that correspond to zone corners in the example of FIG. 13. For example, the zone 1301 is associated with perimeter coordinates (X1,Y1), (X2,Y1), (X1,Y2), and (X2,Y2) that correspond to sets {RSS(1,1)}, {RSS{2,1)}, {RSS(1,2)}, and {RSS(2,2)} of received signal strength values, respectively. A mobile station location estimate can be identified based on RSS values reported by a mobile station (reported RSS values, or RSS(mobile)). If a zone area is unacceptably large for a predetermined positional accuracy in a mobile station location estimate, mobile station location can be based on interpolation using the sets {RSS} of predetermined RSS values associated with one or more zones.

The mobile location module 1106 processes the set of reported received signal strengths {RSS(mobile)} to provide an estimate of mobile station location by associating the set {RSS(mobile)} with one or more of the sets {RSS} of received

signal strengths in the database 1110. An estimate of mobile station location corresponds to coordinates associated with the selected set of stored RSS values.

In an example, a mobile station location is estimated as described above based on, for example, triangulation using three RSS values. The triangulation procedure, with or with additional error corrections such as that described above, can be used to establish an initial mobile station location estimate (Xest, Yest). The mobile location module 1106 then compares reported RSS values with sets of RSS values associated with a grid such as the grids 1200, 1300, or with RSS values at one or more locations in a geographical area near the initial mobile station location estimate (Xext,Yest). Typically, these RSS values are stored in a database such as the database 1110 of FIG. 11. Based on the predetermined sets {RSS}, a second mobile location estimate is obtained.

With reference to FIG. 14, a mobile location module 1400 includes a database 1401 configured to store sets of RSS values associated with grid locations $1402_1, \ldots, 1402_G$. A processor 1404 is in communication with the database 1401 and is configured to receive data such as mobile-assisted hand-off data, typically a set of RSS values that are reported by a mobile station. The processor 1404 computes a score for all or selected RSS sets from the database 1401 based on the reported RSS values. The score values can be configured so that high values are associated with RSS values that do not correspond to a selected location while low scores indicate that the reported RSS values are similar to values of a selected location, or the score values can be otherwise configured. In a particular example, four grid locations associated with favorable score values are selected and stored in a memory 1406 and these grid values are communicated to an interpolator 1410 that provides interpolated location values at an output 1412. Typically, interpolation and score computation are produced with a microprocessor, workstation, an embedded processor, or special purpose processing hardware and software, so that the processor 1404 and the interpolator 1410 can be provided in the same hardware.

In some examples, a first mobile location estimate is based on the stored sets of RSS values and triangulation based estimation is not used, or triangulation based estimation is used in conjunction with RSS values. Alternatively, a GPS system associated with the mobile station can be used to establish a first mobile location

estimate (Xest, Yest) and stored sets of RSS values are used to produce a second mobile location estimate.

In other examples, a mobile location estimate is based on the sets of RSS values, and GPS, triangulation, or other methods are used to produce a second estimate based on the first estimate. As noted above, the sets {RSS} can include two or more power levels and typically include six or more RSS values, and mobile location estimates can be based on one or more of the RSS values while some RSS values are not used.

Comparison of reported RSS values with stored sets of RSS values in a database can be performed based on, for example, evaluation of a sum of squares of differences between the reported RSS values and stored RSS values associated with one or more geographical locations. Typically, one or more geographical locations (X,Y) associated with a minimum or a relatively small sums of squares are selected as mobile station location estimates. If more than one location is selected, additional methods such as triangulation based methods can be used to select among multiple location estimates. Alternatively, GPS based locations can be used to select a likely mobile station location. Although it is unlikely that a single estimate cannot be extracted from multiple location estimates, more than one mobile station location estimate can be reported to an emergency responder or other recipient.

According to some examples, mobile station locations are established by the a mobile network location module based on one or more series of received signal strength (RSS) contours obtained by, for example, measurements of received signal strength or calculated received signal strengths. With reference to FIG. 15, a wireless communication system 1500 includes a mobile station 1502 such a portable digital assistant or other mobile device that communicates via an air interface 1503 with a mobile switching center (MSC) 1504. The MSC 1504 is in communication with a mobile network location module (MLM) 1506 that is configured to estimate a mobile station location based on received signal strength (RSS) contours associated with radio base stations. The contours can be stored in a database 1508 as values RBS(1) . . . RBS(N) corresponding to respective radio base stations, wherein N is a number of radio base stations.

FIG. 16 illustrates representative cells 1602, 1604, 1606 and associated radio base stations (RBS) 1610, 1612, 1614, respectively. Received signal strength (RSS) contours 1620-1623 and 1630-1633 that are associated with, for example, cells 1602, 1604 are shown. In general, additional contours associated with other RSS values (i.e., additional radio base stations) are used but these contours are not shown in FIG. 16. The contours 1620-1623 and 1630-1633 are associated with locations for which received power levels from respective radio base stations are approximately equal. In an example, the mobile station is in communication via the cell 1602 (RBS 1610) and reports a received signal strength from RBS 1610 that is associated with the contour 1623. The mobile location module selects geographical locations associated with the contour 1623 as possible locations of the mobile station. Because the mobile station 1604 reports a set of RSS values, additional power contours associated with additional radio base stations can be used to locate the mobile station. For example, the mobile station reports an RSS value associated with the radio base station 1612. As an example, if this RSS value can be associated with the contour 1630, the mobile station location estimate can be improved and an estimated location is associated with regions 1650, 1652. This procedure can be repeated for additional RSS values and an estimated mobile station location can be reported based on the identified contours.

Contour spacing can be set based on an acceptable spatial resolution so that associating one or more contours with associated reported RSS values permits a mobile location estimate to have a predetermined spatial resolution. Alternatively, interpolation or other method can be used to increase spatial resolution and establish mobile locations between contours.

Mobile station location estimates based on received signal strength contours can be enhanced or verified using triangulation based methods, GPS based methods, or RSS pattern based methods. Typically the set of RSS values includes six or more received signal strength values but only one or more of these values can be used to establish a mobile location. In some examples, identification of a contour based on a first RSS value is used to establish a range of locations. In addition, a received voice power level RSS_V can be reported by the mobile station and used in preparation of mobile station location estimates in this or other methods.

While computation of an error score associated with a comparison of reported RSS values with predetermined sets of measured or calculated RSS values can be used to estimate mobile station location, such estimates can also be prepared based on signal strength patterns. For example, ratios of the reported RSS values can be compared with ratios of the predetermined RSS values. Alternatively, the predetermined RSS values and the set of reported RSS values can be correlated to identify a set of predetermined RSS values similar to the reported RSS values, and an associated location provided as a mobile station location estimate. Other pattern recognition methods can also be used.

FIG. 17 illustrates emergency services provided by a wireless network that is configured to report mobile station locations. A mobile station 1702, such as a cell phone, PDA, or other mobile or portable device voice, data, or voice/data device, reports one or more received signal strength values to a mobile switching center (MSC) 1706 using an air interface 1704. The mobile switching center 1704 delivers the reported RSS values to a mobile positioning center (MPC) 1708 that is in communication with a position determining processor (PDP) 1710. The mobile positioning center 1708 is also in communication with a public-safety answering point (PSAP) 1712 that is configured to communicate with an emergency services (911-selective) router 1714. The MSC 1706 is also in communication with the 911-selective router 1714.

In operation, the mobile station 1702 initiates an emergency services (911) request that is communicated via the air interface 1704 to the MSC 1706. The MSC 1706 sends a message to the MPC 1708 indicating that a 911 call has been placed and that the MSC 1706 is configured for mobile location services. The MPC 1708 returns routing instructions to the MSC 1706 so that the call is routed to the PSAP 1712 via the 911 selective router. The MPC 1708 queries the MSC 1706 for RSS values and requests that the mobile station report RSS values. The MSC 1706 forwards reported RSS values to the MPC 1708 and the PDP 1710 delivers a mobile location estimate to the MPC 1708. The PSAP 1712 queries the MPC 1708 for the mobile location that is communicated by the MPC 1708. As the emergency services request continues, additional requests for mobile location can be serviced so that

movement of the requestor can be traced. Based on these additional location estimates, other information such as direction of travel can be obtained.

While determining a location of a cell phone in a wireless network is important for providing emergency services based on an emergency services number such as 911 service, mobile location estimates can be included in other applications such as identification of a mobile location with respect to other users of a mobile network or determination of user location with respect to services such as dining, shopping, accommodations, entertainment, transportation, or other services. Such locations can be established without reference to dedicated positioning systems such as GPS and GPS hardware is unnecessary. Because GPS signals are relatively weak, location determination based on MAHO parameters permits location determination even in indoor or covered areas in which GPS signal reception is difficult or impossible. However, GPS can be used in association with MAHO based methods.

Location determination can also be similarly implemented in other networks that include mobile-assisted handoff. For example, wireless networks based on so-called BLUETOOTH technology, or on IEEE 802.11, can be configured so that mobile devices report received signal strengths. In addition, wireless networks using TDMA, CDMA, FDMA, or other protocols can be configured to implement mobile-assisted location services. Such networks can include control channels, voice channels, data channels, or other communication channels, and reported power levels in any of these channels can be used in mobile location.

Mobile station location methods and apparatus are described above with reference to selected communication standards, but in other examples additional systems are used. For example, systems based on the Global System for Mobile Communication (GSM), IS-95, IS-54, General Packet Radio Service (GPRS), the Digital Cordless European Telecommunication (DECT) service, or Cellular Digital Packet Data (CDPD) service, GERAN (GSM/EDGE) service, or combinations thereof can be provided. Location methods and apparatus can be configured for systems that provide wide area voice coverage, local voice coverage, wide area data services, local area data services, or combinations thereof.

Representative examples of handoff are described above with reference to handoff in voice networks based on base stations. In general, a connection between

a mobile or portable device and a network is made at so-called points of attachment. In cellular telephone networks, base stations generally serve as points of attachment while in wireless local area networks (WLANs), so-called access points serve as points of attachment. In some examples, a mobile device can connect to a network with base stations or access points. Received signal strength (RSS) values can be associated with network points of attachment, but other parameters such as path loss, symbol error rate, bit error rate, signal-to-interference ratio, carrier-to-interference ratio, block error rate, or other parameters can be used. For convenience, such parameters are referred to as attachment indicators.

In wireless networks in which a mobile station reports power levels periodically, mobile station location can be updated or tracked while voice or data communication is in progress, without interrupting communications. Accordingly, the movement of a mobile station can be tracked which can be especially important in supplying emergency services. In some TDMA systems, such received power levels are reported as often as once per second.

Signal strength contours and/or grids can be established in several ways. Because sophisticated radio frequency (RF) design software is available, RSS or other characteristic attachment indicator values can be calculated as a function of location of with spatial grids having dimensions of 50 m or less. A number of RF factors can be used in such a calculation including antenna height, antenna type, down-tilt, beam width, effective radiated power, and ground clutter. Such computations can include consideration of geographical factors such as surface topography and other factors. Such computed RSS values can be confirmed by field measurements and deficiencies in predicted values can be corrected or compensation based on field measurements. Alternatively, RSS values can be based on a series of measurements obtained by, for example, driving a vehicle in the geographical service area and recording RSS values. In other alternatives, some values are predicted based using RF design software while other values are measured. In addition, as RSS values are reported in association with actual GPS values, contour or grid values can be revised based on these measurements during network use, without use of dedicated hardware or additional support personnel.

Methods and apparatus are described above with reference to received signal strengths associated with one or more points of attachment to a network. In other examples, error rates, propagation delays, or other parameters can be associated with points of attachment and used to estimate locations. In addition, estimates are typically based on comparisons with signal strengths associated with three or more points of attachment, but in some examples, signal strengths associated with two points of attachment can be used. In some examples, attachment indicator values associated with attachment points are calculated or measured and stored in database. In other example, appropriate attachment indicator values are established as needed by, for example, computation based on propagation characteristics or interpolation based on stored values. Attachment indicator values associated with geographical locations can be referred to as characteristic attachment indicator values and such values can be stored, calculated, or measured.

Because mobile station location can be based on RSS values that are reported during normal network operation, such location methods tend to be reliable. In addition, any network failure that would impair mobile station location estimation is associated with other networks errors in routine network use so that such failures tend to be detected promptly. Other advantages of RSS level based mobile location determination is that the mobile station need not be a network subscriber, because RSS level reporting can be performed by non-subscribers. Thus, emergency services such as 911 calling are available to non-subscribers or to mobile stations that are not initialized, or that have no associated phone number.

Characteristic values associated with a network or a portion of a network can be stored in a memory. As used herein, memory includes random access memory (RAM), read-only memory (ROM), hard disks, floppy disks, magnetic tape, and other storage media.

Examples are described above with reference to representative mobile devices and wireless networks. These examples are illustrative, and these examples can be modified in arrangement and detail. We claim all that is encompassed by the appended claims.

We claim:

1. A mobile station location processor, comprising;

an input configured to receive attachment indicators associated with at least two points of attachment of the mobile station;

a memory configured to store sets of predetermined attachment indicators associated with the at least two points of attachment; and

an estimation unit configured to provide an estimate of the mobile station location based on a comparison of the received attachment indicators and at least one set of the at least two predetermined attachment indicators.

2. The mobile station location processor of claim 1, wherein the estimation unit is configured to provide the estimate of the mobile station location based on a comparison of the received attachment indicator values and the sets of attachment indicator values associated with the at least two points of attachment.

3. The mobile station location processor of claim 2, wherein the received attachment indicator values are reported by the mobile station.

4. The mobile station location processor of claim 3, wherein the attachment indicator values are received signal strength values.

5. The mobile station location processor of claim 1, wherein the attachment indicator values are received signal strength values reported by the mobile station.

6. A mobile location module, comprising:

a processor configured to compare at least two reported received signal strength values with received signal strength values associated with at least two geographical locations in a wireless network; and

an output configured to deliver a mobile location estimate based on the comparison.

7. The mobile location module of claim 6, wherein the processor is configured to determine a score associated with the comparison of the reported received signal strength values with the predetermined received signal strengths.

8. The mobile location module of claim 6, wherein the reported and received signal strength values related to mobile-assisted handoff.

9. A location unit for estimating a location of a mobile station, comprising:

an input configured to receive attachment indicator values associated with the mobile station; and

a processor configured to provide a mobile station location estimate based on predetermined attachment indicator contours associated with network attachment points.

10. The location unit of claim 9, wherein the attachment indicator values are received signal strength values reported by the mobile station and the attachment indicator contours are received signal strength contours.

11. A method of locating a mobile station, comprising:

obtaining a set of received signal strengths associated with the mobile station;

determining a mobile station location based on a comparison of the received signal strengths with predetermined signal strengths.

12. The method of claim 11, further comprising:

determining an error score based on the received signal strengths and the predetermined signal strengths;

wherein the mobile station location is determined by selecting a location associated with selected error score.

13. The method of claim 11, further comprising storing the predetermined signal strengths.

14. A method of locating a mobile station within a geographic service area, comprising:

obtaining attachment indicator values associated with a series of attachment points for the mobile station and; and

comparing the mobile station attachment indicator values with predetermined attachment indicator values associated with the series of attachment points to obtain a mobile station location estimate.

15. The method of claim 14, further comprising reporting the estimated mobile station location estimate.

16. The method of claim 14, wherein the attachment indicator values for the mobile station are reported by the mobile station.

17. The method of claim 16, wherein the attachment indicator values are received signal strength values associated with corresponding radio base stations.

18. The method of claim 14, wherein the attachment indicator values are received signal strength values associated with corresponding radio base stations.

19. The method of claim 14, wherein the mobile station attachment indicator values and the predetermined attachment indicator values are compared by determining a score associated with the predetermined attachment indicator values, and the estimated mobile station location is selected based on the associated score.

20. A method of locating a mobile station, comprising:

obtaining at least one of a latitude and a longitude location estimate based on a global positioning system; and

providing an estimate of mobile station location based on a comparison of mobile station attachment indicator values with predetermined attachment indicator values in a region associated with the latitude and longitude estimates.

21. A method of estimating a mobile station location, comprising:

receiving signal strength values associated with signals received by a mobile station from a plurality of antennas;

calculating a first location area of the mobile station as a geographic coverage area of a serving cell site; and

calculating a second location area of the mobile station based on a comparison of the received signal strength values with predetermined signal strength values associated with at least one location in the coverage area.

22. The method of claim 21, further comprising calculating the characteristic attachment indicator values based on at least one propagation characteristic.

23. The method of claim 22, wherein the at least one propagation characteristic is selected from a group consisting of transmitted power, propagation path slope, and antenna pattern roll-off.

24. A network configured to provide location estimates for a mobile station, comprising:

a processor configured to produce the location estimates based on characteristic attachment indicator values of the network and reported attachment indicator values associated with the mobile station; and

an output configured to deliver the location estimates.

25. The network of claim 24, further comprising a database that includes the characteristic attachment indicator values.

26. The network of claim 24, wherein the processor is configured to determine characteristic attachment indicator values based on at least one propagation characteristic.

27. A method of requesting services from a public-safety answering point (PSAP) with a mobile station, comprising:

delivering a message from the mobile station to the PSAP; and

providing the PSAP an estimate of mobile station location based on a comparison of mobile station attachment indicator values and characteristic attachment indicator values.

28. A method of providing a location estimate for a non-subscribing mobile station in a network, comprising:

receiving a series of attachment indicator values from the mobile station; and

estimating a mobile station location based on characteristic attachment indicator values associated with the network.

29. A method of determining characteristic attachment indicator values for at least a portion of a wireless network, comprising:

measuring the characteristic attachment indicator values; and

storing the characteristic attachment indicator values in a database.

30. The method of claim 29, further comprising associating at least one global positioning system coordinate with the measured characteristic attachment indicator values.

31. A method or revising a database of network characteristic attachment indicator values, comprising:

estimating a location of a mobile station based on a comparison of attachment indicator values reported by the mobile station with the characteristic attachment indicator values;

obtaining an associated global positioning system (GPS) location estimate from the mobile station; and

revising at least one characteristic attachment indicator value based on a comparison of the mobile station location estimate and the GPS location estimate.

FIG. 1

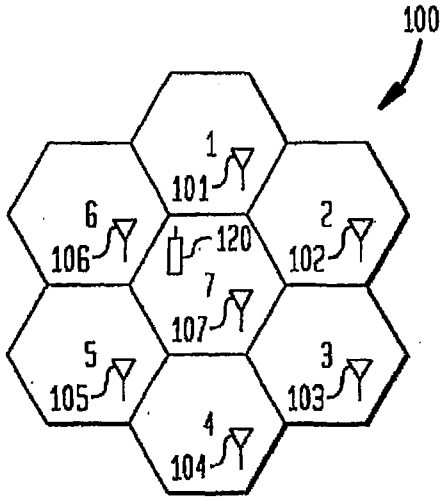


FIG. 3

300

CELL	SS
1	$RSSI_1$
2	$RSSI_2$
3	$RSSI_3$
4	$RSSI_4$
5	$RSSI_5$
6	$RSSI_6$

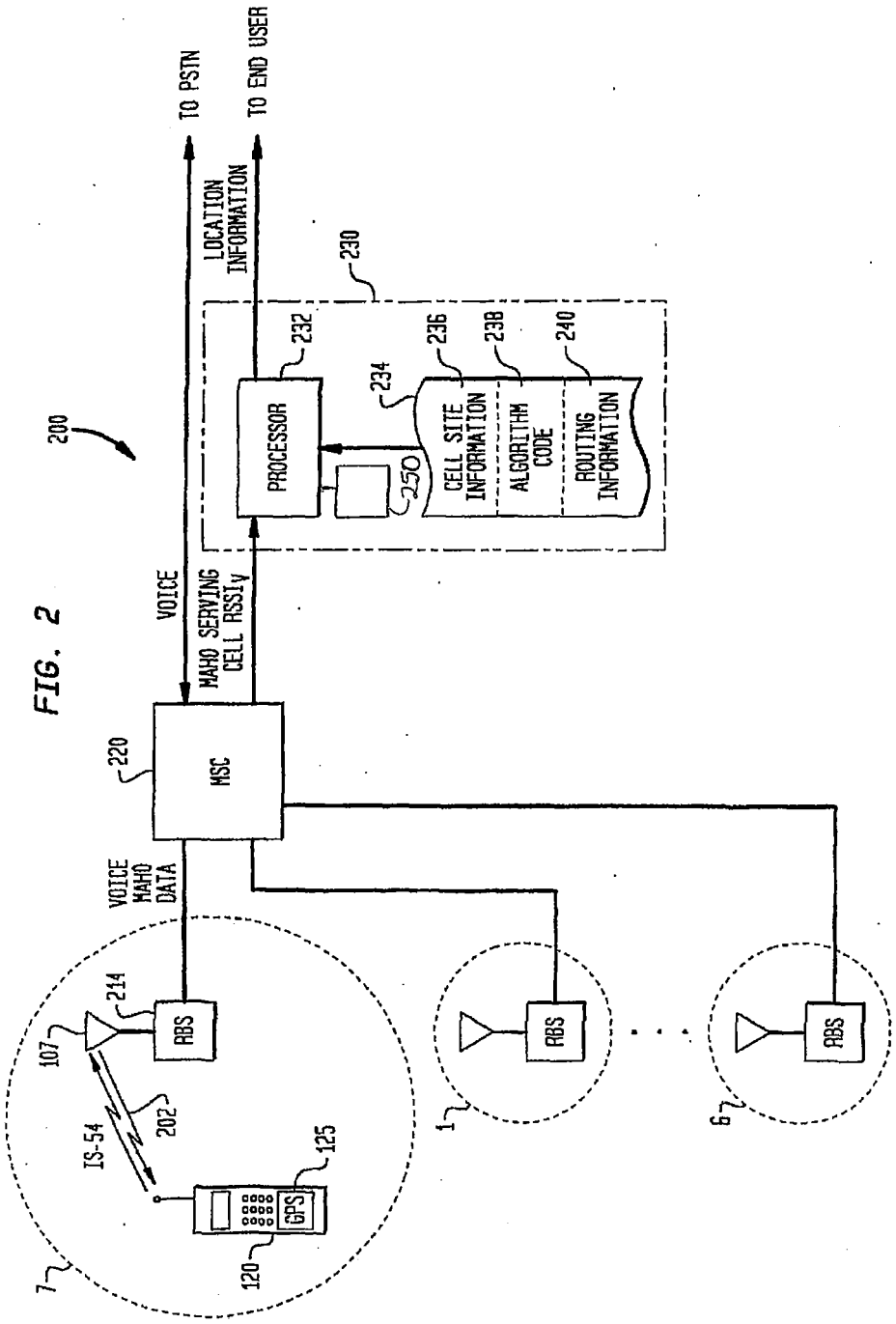

200
TO PSTN
TO END USER
LOCATION INFORMATION
230
232
PROCESSOR
234
236
CELL SITE INFORMATION
238
ALGORITHM CODE
240
ROUTING INFORMATION
250
VOICE
MAHO SERVING CELL RSSI
220
MSC
VOICE MAHO DATA
214
RBS
107
IS-54
202
125
GPS
120
7
1
6

FIG. 2

FIG. 4

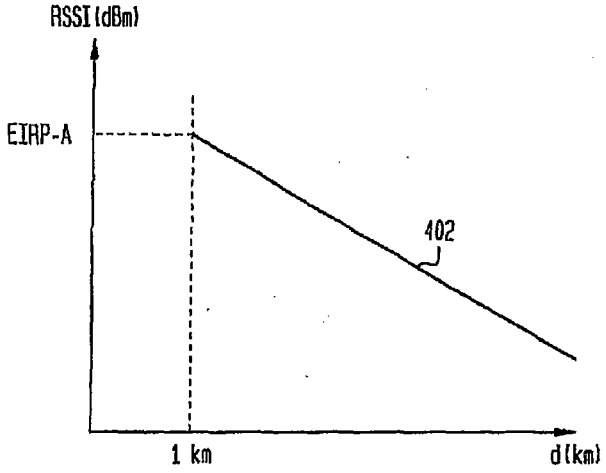


FIG. 5

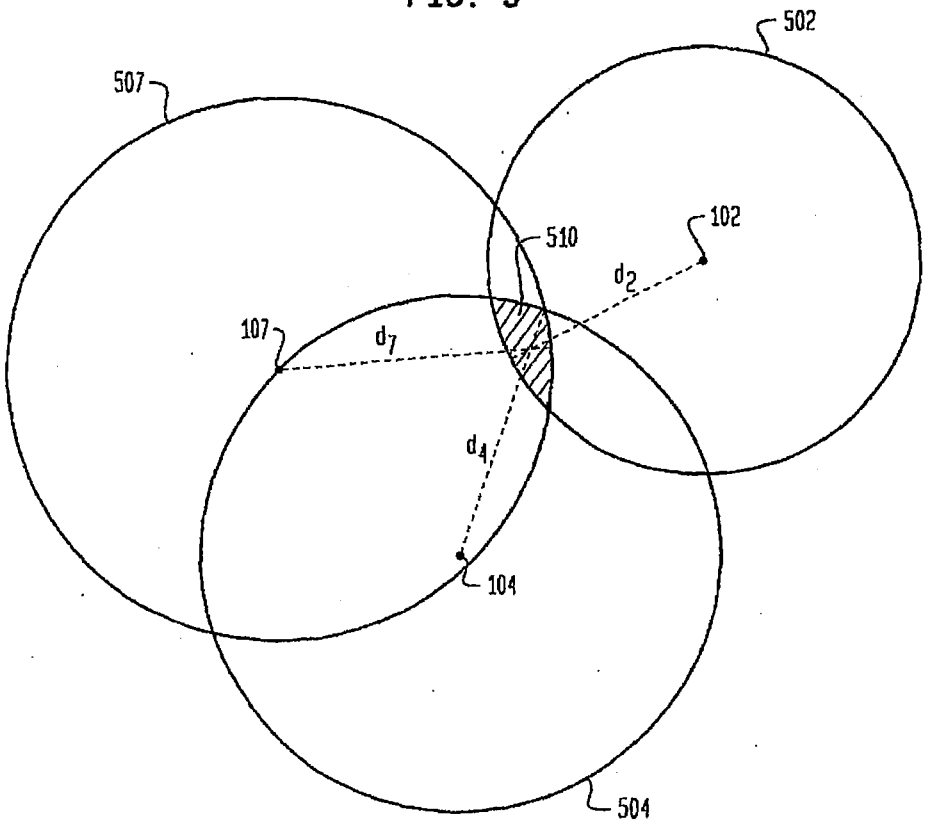


FIG. 6

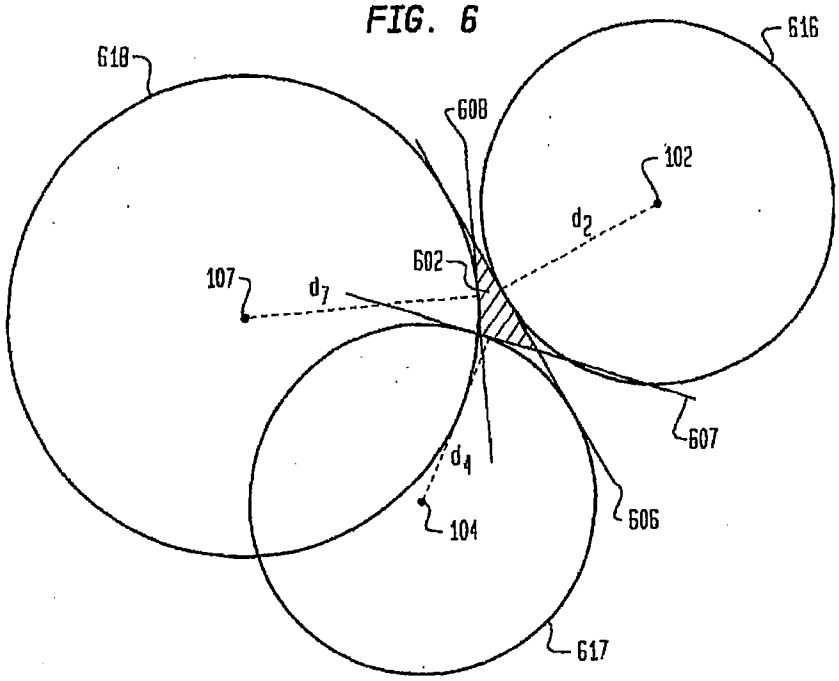

618
616
608
102
d_2
602
107
d_7
607
d_4
606
104
617

FIG. 7

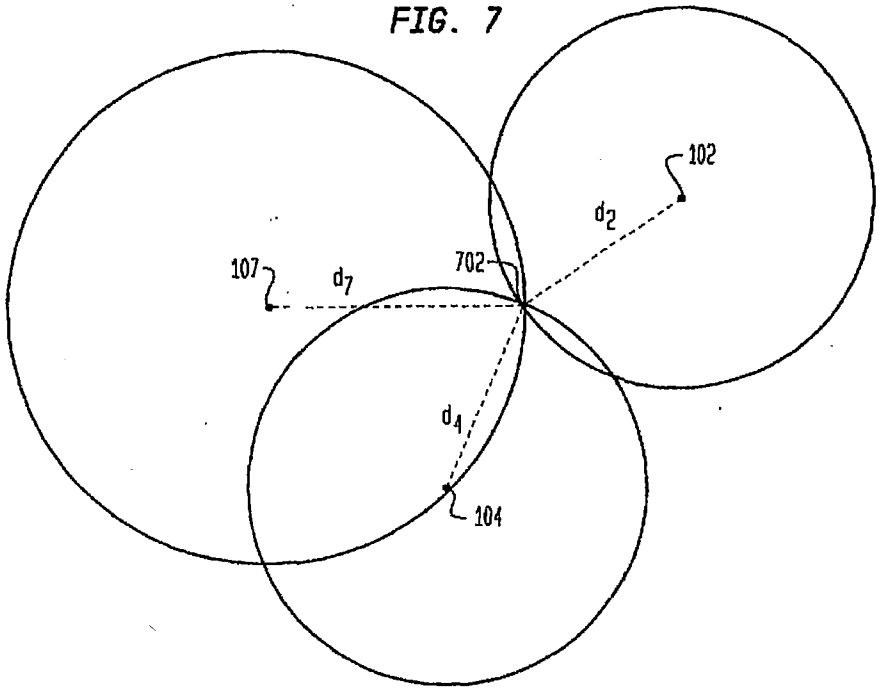

102
d_2
107
d_7
702
d_4
104

FIG. 8

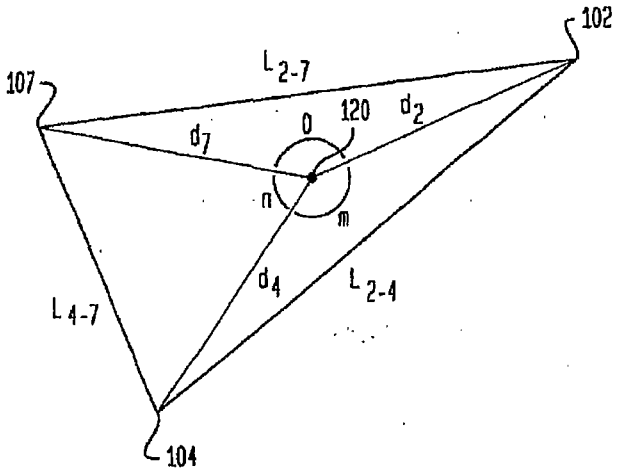

102
107
L_{2-7}
d_7
0
120
d_2
n
m
d_4
L_{2-4}
L_{4-7}
104

FIG. 9

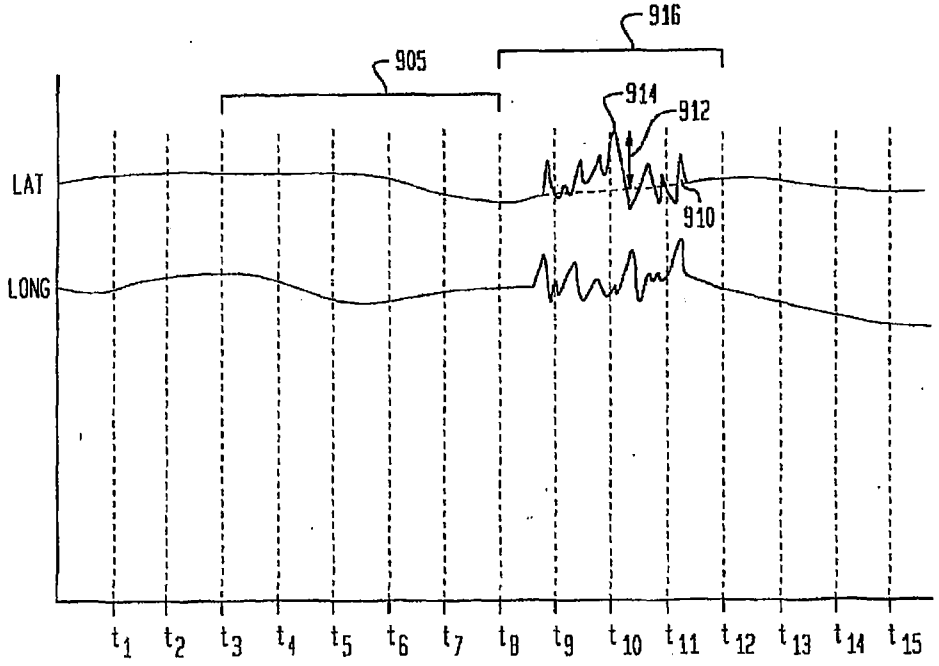

916
905
914
912
910
LAT
LONG
t_1 t_2 t_3 t_4 t_5 t_6 t_7 t_8 t_9 t_{10} t_{11} t_{12} t_{13} t_{14} t_{15}

FIG. 10

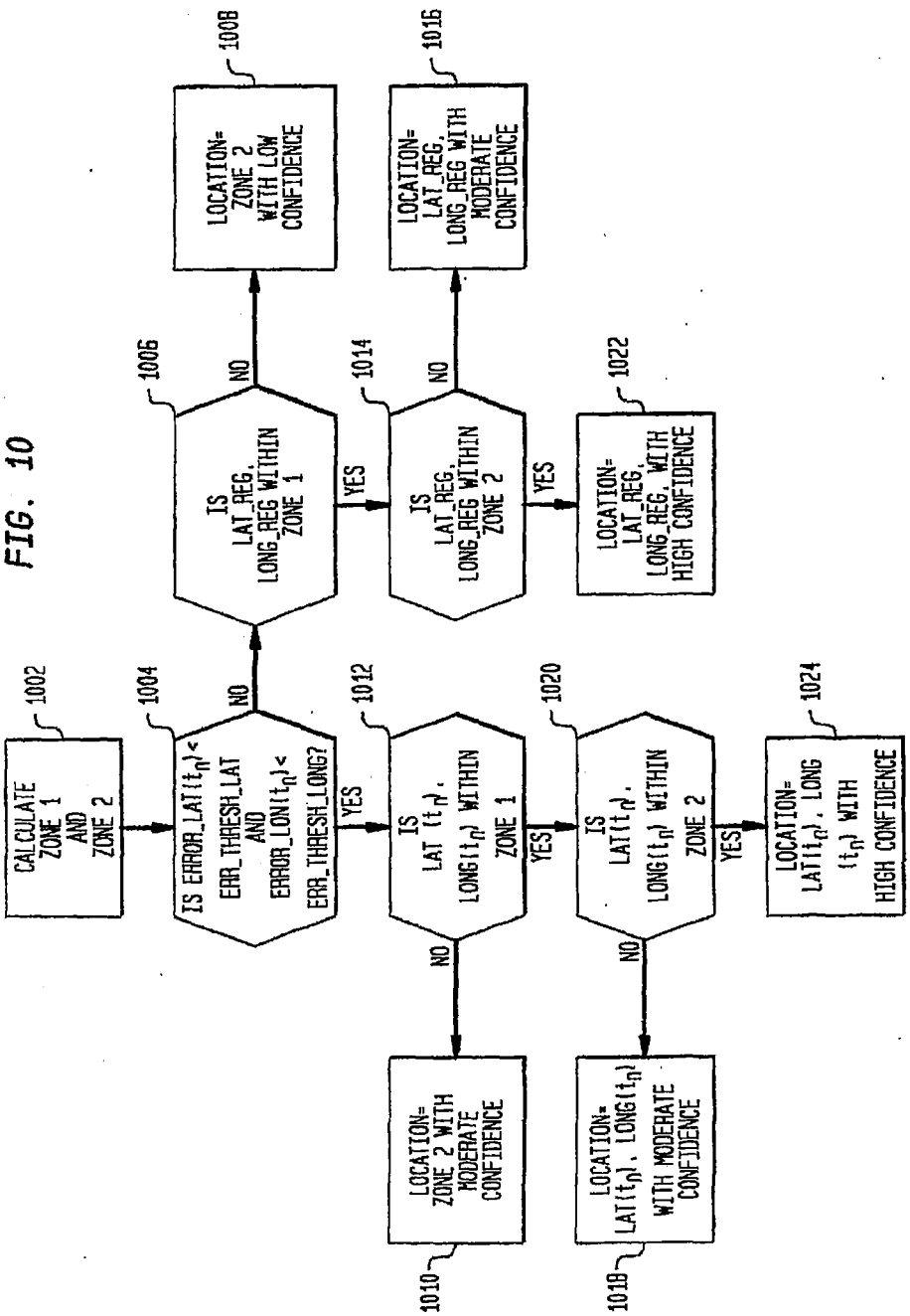
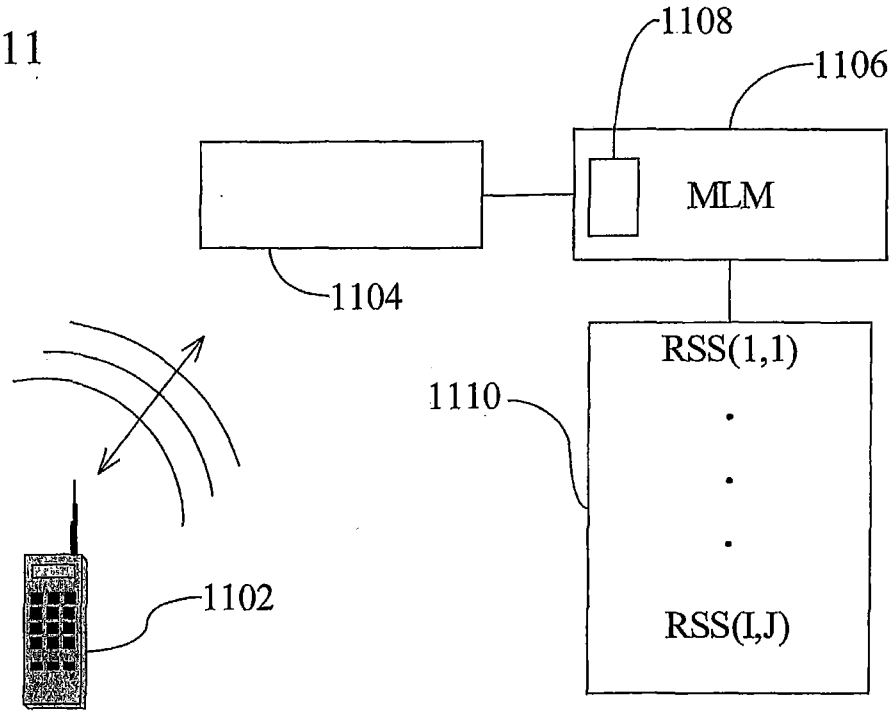

1002
CALCULATE ZONE 1 AND ZONE 2
1004
IS ERROR_LAT(t_n)< ERR_THRESH_LAT AND ERROR_LON(t_n)< ERR_THRESH_LONG?
NO
YES
1006
IS LAT_REG, LONG_REG WITHIN ZONE 1
NO
YES
1008
LOCATION= ZONE 2 WITH LOW CONFIDENCE
1012
IS LAT (t_n), LONG(t_n) WITHIN ZONE 1
NO
YES
1010
LOCATION= ZONE 2 WITH MODERATE CONFIDENCE
1014
IS LAT_REG, LONG_REG WITHIN ZONE 2
NO
YES
1016
LOCATION= LAT_REG, LONG_REG WITH MODERATE CONFIDENCE
1020
IS LAT(t_n), LONG(t_n) WITHIN ZONE 2
NO
YES
1018
LOCATION= LAT(t_n), LONG(t_n) WITH MODERATE CONFIDENCE
1022
LOCATION= LAT_REG, LONG_REG, WITH HIGH CONFIDENCE
1024
LOCATION= LAT(t_n), LONG (t_n) WITH HIGH CONFIDENCE

FIG. 11


1108
1106
MLM
1104
RSS(1,1)
1110
RSS(I,J)
1102

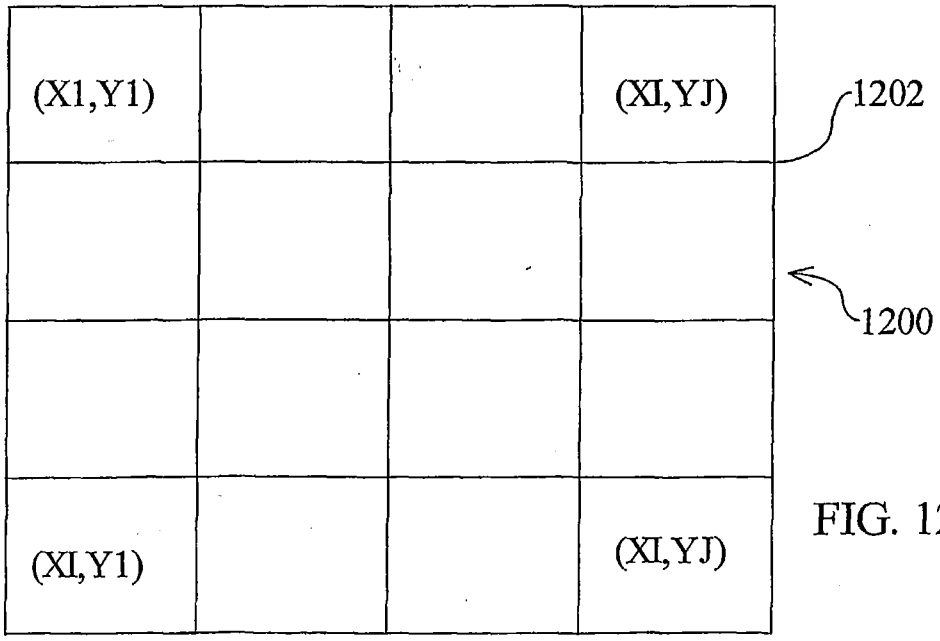

(X1,Y1)
(XI,YJ)
1202
1200
(XI,Y1)
(XI,YJ)

FIG. 12

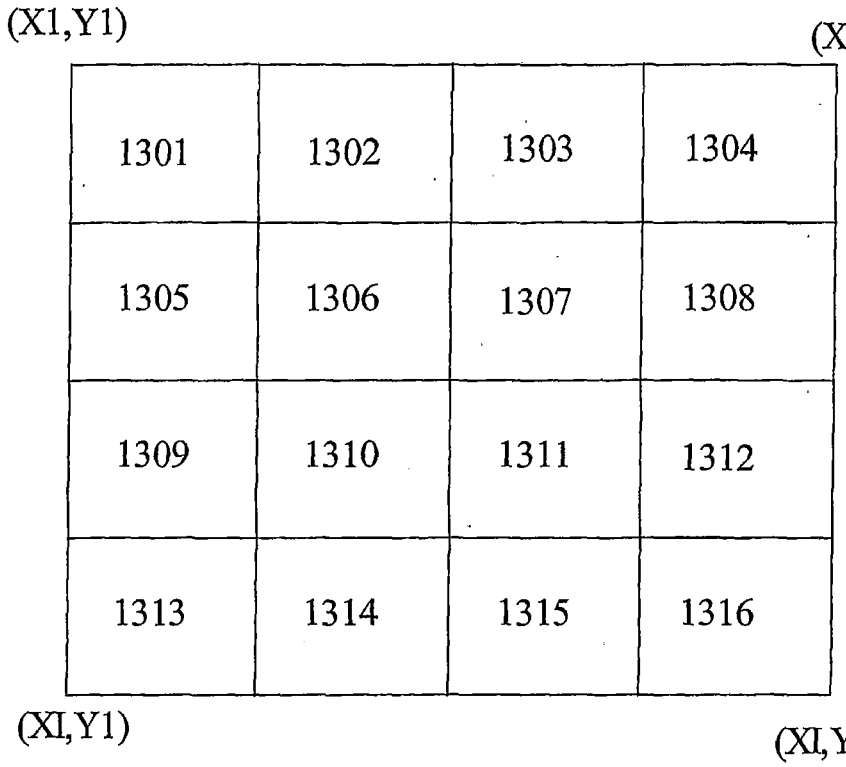
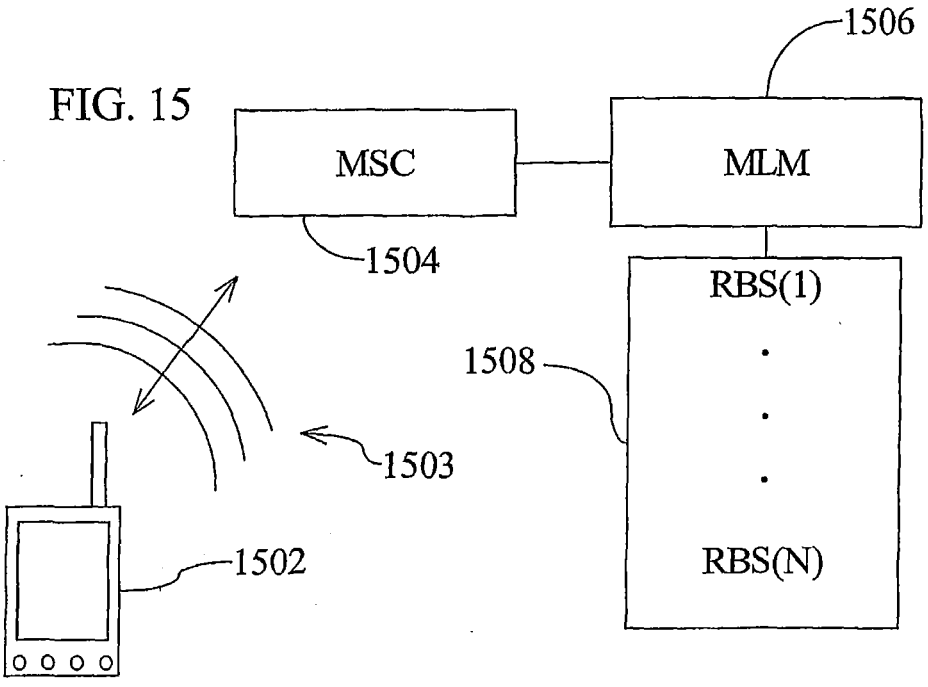

(X1,Y1)
(X1,YJ)
1301
1302
1303
1304
1305
1306
1307
1308
1309
1310
1311
1312
1313
1314
1315
1316
1300
(XI,Y1)
(XI,YJ)

FIG. 13

FIG. 15


1506
MSC
MLM
1504
RBS(1)
1508
1503
1502
RBS(N)

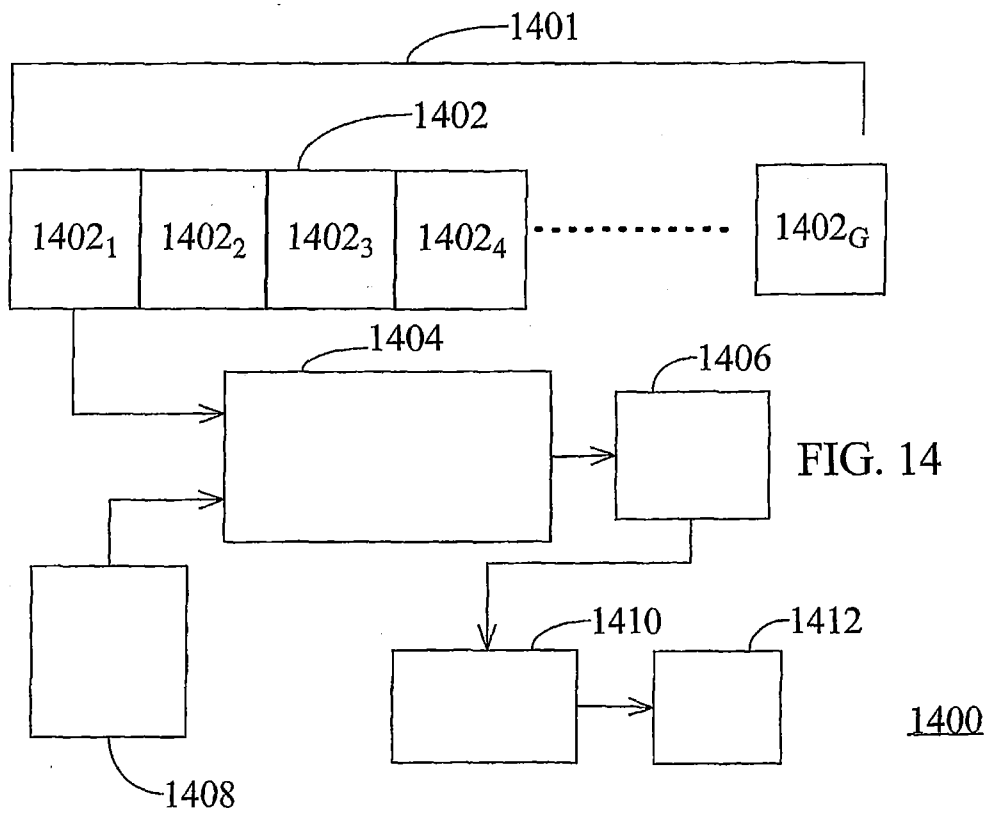

1401
1402
1402$_1$
1402$_2$
1402$_3$
1402$_4$
1402$_G$
1404
1406
1408
1410
1412
1400

FIG. 14

FIG. 16

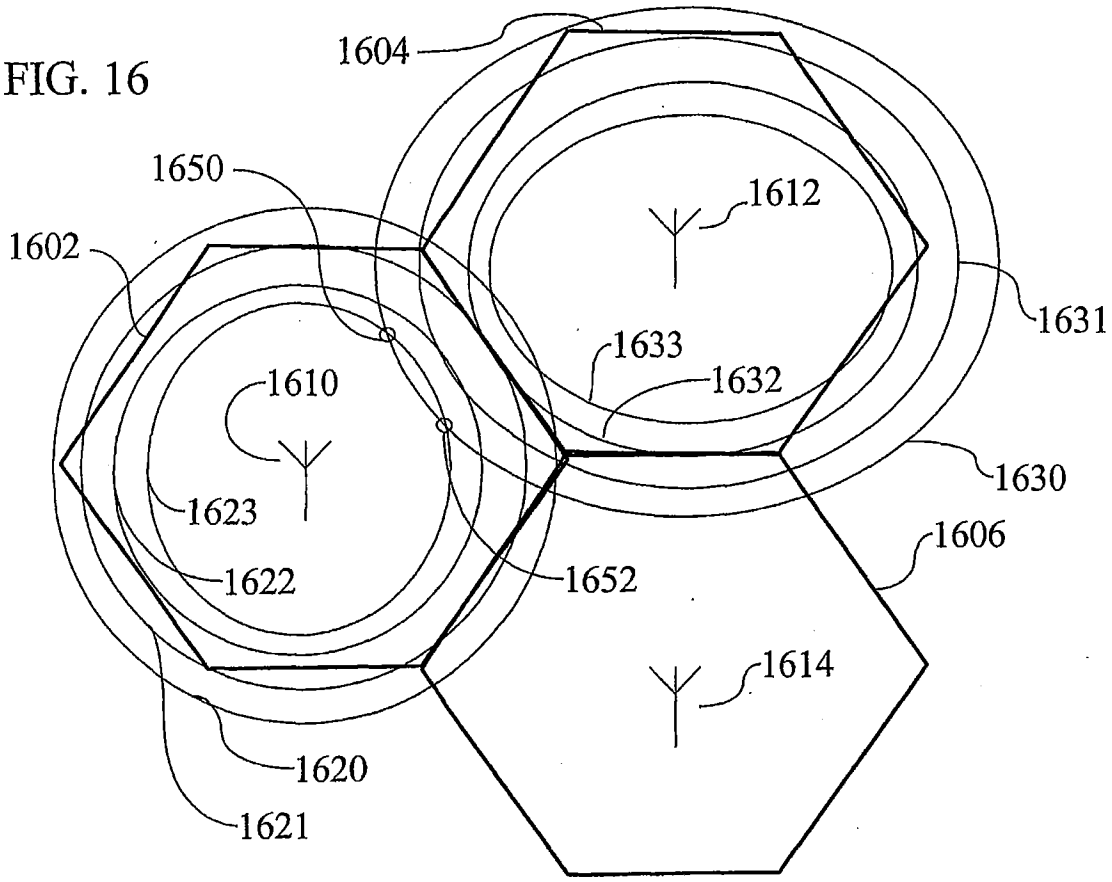
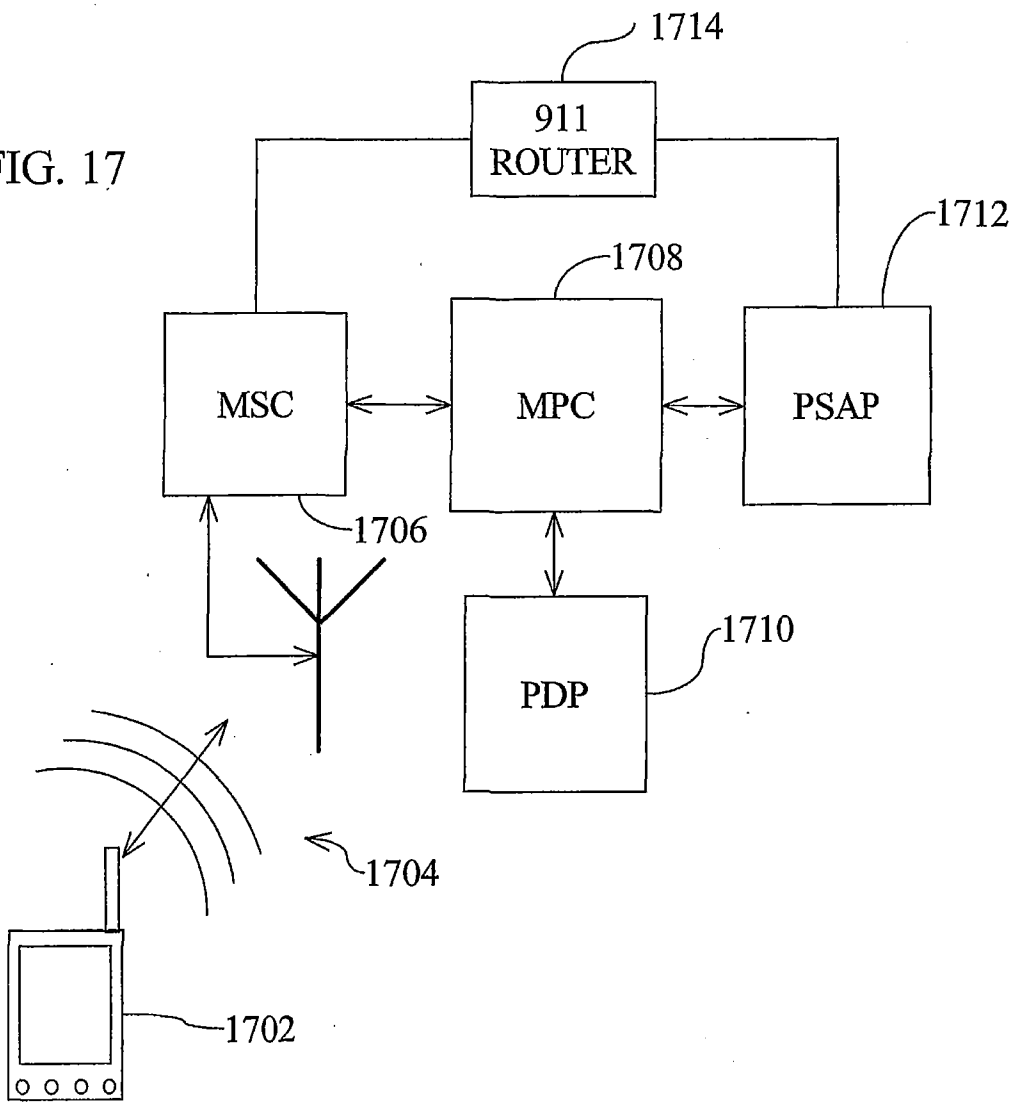

1604
1650
1602
1612
1631
1633
1632
1610
1630
1623
1606
1622
1652
1614
1620
1621

FIG. 17


1714
911
ROUTER
1712
1708
MSC
MPC
PSAP
1706
1710
PDP
1704
1702

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European Patent Office
Office européen des brevets

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(54) Calibration of a device location measurement system that utilizes radio signal strengths

(57) An architecture for minimizing calibration effort in an IEEE 802.11 device location measurement system. The calibration technique is based upon a regression function that produces adequately accurate location information as a function of signal strength regardless of gaps in the calibration data or minimally available data. The algorithm takes a set of signal strengths from known room locations in a building and generates a function giving (x,y) as a function of signal strength, which function may then be used for the estimation of new locations. Radial basis functions, which are simple to express and compute, are used for regression. The fact that the algorithm maps signal strength to continuous location makes it possible to skip rooms during calibration, yet still evaluate the location in those rooms.

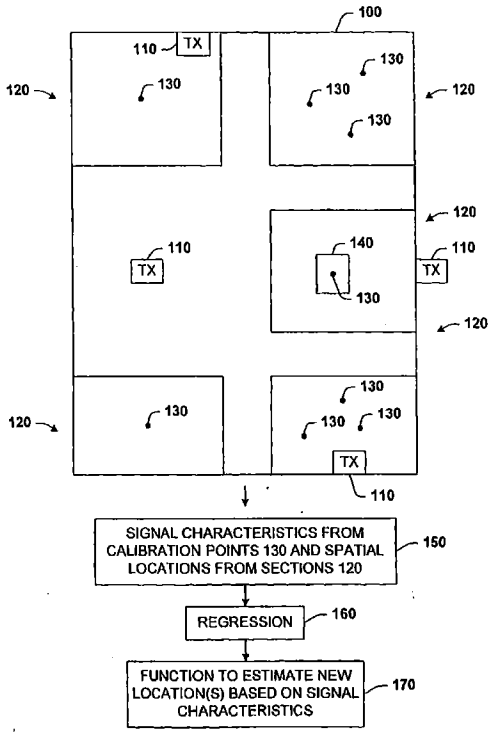


FIG. 1

EP 1 471 688 A2

Description

TECHNICAL FIELD

[0001] This invention is related to IEEE 802.11 devices, and more specifically, to locating wireless devices using wireless signal strengths.

BACKGROUND OF THE INVENTION

[0002] Knowledge of locations of users and devices inside a building is an important prerequisite for location-based services and aspects of ubiquitous computing. One promising approach to determining location is through triangulation by measuring IEEE 802.11 wireless signal strengths of wireless devices. One of the most attractive features of an IEEE 802.11 location-based system is that it does not require any extra infrastructure beyond a wireless network that already exists in many buildings. This is in contrast to other person-tracking systems that employ active/passive badges and cameras, which in turn require installation and maintenance of extra equipment.

[0003] Using an 802.11 wireless client as a location sensor (*e.g.*, a portable computer as a receiver) is becoming increasingly popular way of enabling location-based services. Triangulation of signal strengths from multiple access points (APs) may be used to pinpoint location of the receiving device down to a few meters. However, this level of accuracy comes at a price of requiring tedious and time-consuming manual labor in order to obtain spatially high-density calibration data of signal strengths as a function of location.

[0004] Knowing radio signal strength measurements on a network client from a few different APs, researchers have shown how to compute location down to a few meters. This type of location measurement is especially attractive because it uses existing devices of a building and its users, and because it functions indoors where global positioning system (GPS) and cell phone location signals often break down. However, the accuracy of such systems usually depends on a meticulous calibration procedure that consists of physically moving a wireless client receiver to many disparate known locations, and different orientations, inside the building. It is often be impracticable to expect anyone to spend resources on such work - when presented with such prospect as part of a new product, software product planners often balk, complaining that system administrators are reluctant to even keep locations of printers updated, much less create and maintain a high-resolution table of IEEE 802.11 signal strengths.

[0005] One alternative to manual calibration is to analytically predict signal strengths based on a floor plan of a building, physical simulation of radio frequency (RF) propagation, and knowledge of the locations of wireless access points. It was discovered, for the chosen simulation method, that physically simulating signal strengths increased median location error by approximately 46% (from 2.94 meters to 4.3 meters) over values obtained by manual calibration. Moreover, a good physical simulation usually requires a more detailed model of the building than is normally available.

[0006] In the realm of IEEE 802.11 locations, one published work was based on the RADAR system, an in-building RF-based location and tracking system. RADAR worked based on a table of indoor locations and corresponding signal strengths. Using a manually calibrated table, the nearest neighbor algorithm gave a median spatial error of approximately 2.94 meters. Another table based on simulated radio wave propagation allowed the avoidance of most of the calibration work at the cost of increasing the median error to 4.3 meters. The RADAR work also looked at the problem of reducing calibration effort. It was found that reducing the number of calibration points from seventy to forty had only a small negative impact on accuracy. In follow-on work, RADAR was enhanced to use a Viterbi-like algorithm on short paths through the building. This further reduced the median error to approximately 2.37 meters.

[0007] As part of Carnegie Mellon's Andrew system, a limited study of an IEEE 802.11 location system was performed using eight discrete locations in a hallway. A table of signal strength versus location was built. It was determined that upon returning to the eight locations, the system inferred the right location 87.5% of the time.

[0008] Another location service used signal-to-noise ratios, instead of the more commonly used raw signal strengths. The location algorithm was a Bayesian network, manually trained at discrete locations in two buildings. The Bayes formulation allowed the inclusion of *a priori* probabilities of a person's location, as well as transition probabilities between locations. In one test on twelve locations in a hallway, the service was capable of identifying the highest probability to the correct location 97% of the time, not counting the 15% of the time it was inconclusive.

[0009] In still another study, IEEE 802.11 was used to compute the location of wireless PocketPCs, both indoors and outdoors. Instead of manual calibration, a formula was used that approximated the distance to a wireless access point as a function of signal strength. Using a hill-climbing algorithm, the system computes location down to about ten meters (approximately thirty-five feet) using signal strengths from multiple access points.

[0010] In yet another study of an IEEE 802.11 location system, Bayesian reasoning and a hidden Markov model were used. Not only were signal strengths taken into account, but also the probability of seeing an access point from a given location. Like other work, it was based upon a manual calibration. The system explicitly modeled orientation and achieved a median spatial error of approximately one meter using calibration samples taken approximately every

1.5 meters in hallways. Although in terms of accuracy, this may be perhaps the best result, the study also acknowledges the problem of calibration effort, and suggests that calibrated locations could be automatically inferred by outfitting the calibrator with an accelerometer and magnetic compass.

[0011] Some of the conventional systems described hereinabove are explicitly working toward more accuracy, but at the expense of increased calibration effort.

SUMMARY OF THE INVENTION

[0012] The following presents a simplified summary of the invention in order to provide a basic understanding of some aspects of the invention. This summary is not an extensive overview of the invention. It is not intended to identify key/critical elements of the invention or to delineate the scope of the invention. Its sole purpose is to present some concepts of the invention in a simplified form as a prelude to the more detailed description that is presented later.

[0013] The present invention disclosed and claimed herein, in one aspect thereof, comprises an IEEE 802.11 location-based technique for coarsely calibrating a system used to determine a precise triangulated location in view of radio signal strengths at a given location. The calibration technique is based upon a regression function that produces adequately accurate location information as a function of signal strength regardless of gaps in the calibration data or minimally available data.

[0014] Since rooms are a natural spatial fiducials in buildings, and assuming that manual calibration is the principal method for some time, the architecture of the present invention discloses a new IEEE 802.11 location system based upon a relatively easy calibration procedure of recording signal strengths down to room resolution (*e.g.*, from an arbitrary point or set of points in each room of the building or from a more precise location within each room). The disclosed location algorithm is designed to work in spite of missing calibration data, that is, data that is unobtainable because a room, set of rooms, or even a building wing, may be inaccessible. The regression algorithm takes a set of signal strengths from known locations in a building and generates a function that maps signal strength to (x,*y*) location. This function may then be used to estimate new location(s). Radial basis functions, which are simple to express and compute, are used for regression.

[0015] The fact that the algorithm regresses on signal strength to provide location makes it possible to skip rooms during calibration, yet still evaluate locations in those rooms. This is more difficult with most conventional IEEE 802.11 location algorithms that instead must classify signal strengths into only previously seen locations. Although accuracy goes down with reduced calibration data, it goes down surprisingly little. The results quantify the tradeoff between accuracy and effort, and suggest a prescription for manually calibrating systems of this type.

[0016] One embodiment provides a more precise location measurement methodology, where calibration is accomplished by placing the receiver at one point at the location to be measured, and measuring signal properties based upon that single receiver location. The user selects the approximate location of the receiver on a map that shows the position of the receiver relative to the location to be measured. Additionally, an averaging function is provided that averages the last ten computed (x,y) locations to further reduce noise.

[0017] In a second embodiment that is less precise, the user moves the receiver around at the location, *e.g.*, in the room, while taking measurements at several calibration points. Thus the exact location of the receiver is not known. For purposes of calibration, the location of the receiver is taken as the (x,y) centroid of the room, no matter where in the room the receiver was located when the measurements were made.

[0018] To the accomplishment of the foregoing and related ends, certain illustrative aspects of the invention are described herein in connection with the following description and the annexed drawings. These aspects are indicative, however, of but a few of the various ways in which the principles of the invention may be employed and the present invention is intended to include all such aspects and their equivalents. Other advantages and novel features of the invention may become apparent from the following detailed description of the invention when considered in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019]

FIG. 1 illustrates the geometry of the calibration procedure for a system that determines new location(s) based on signal characteristics.

FIG. 2 illustrates a flow chart of the general calibration process of the present invention.

FIG. 3 illustrates a flow chart of a process for determining new location information.

FIG. 4 illustrates a more detailed flow chart of the process for determining the mapping from signal strengths to (x,y) location in accordance with the present invention.

FIG. 5 illustrates a layout of a typical office floor of rooms utilized for a sample application of the calibration process

of the present invention.

FIG. 6 illustrates an exemplary screenshot of a graphical user interface for facilitating signal strength logging of the calibration data.

FIG. 7 illustrates a block diagram of a computer operable to execute the disclosed architecture.

FIG. 8 illustrates a schematic block diagram of an exemplary computing environment in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0020] The present invention is now described with reference to the drawings, wherein like reference numerals are used to refer to like elements throughout. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It may be evident, however, that the present invention may be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form in order to facilitate describing the present invention.

[0021] As used in this application, the terms "component" and "system" are intended to refer to a computer-related entity, either hardware, a combination of hardware and software, software, or software in execution. For example, a component may be, but is not limited to being, a process running on a processor, a processor, an object, an executable, a thread of execution, a program, and/or a computer. By way of illustration, both an application running on a server and the server can be a component. One or more components may reside within a process and/or thread of execution and a component may be localized on one computer and/or distributed between two or more computers.

[0022] As used herein, the term "inference" refers generally to the process of reasoning about or inferring states of the system, environment, and/or user from a set of observations as captured *via* events and/or data. Inference can be employed to identify a specific context or action, or can generate a probability distribution over states, for example. The inference can be probabilistic-that is, the computation of a probability distribution over states of interest based on a consideration of data and events. Inference can also refer to techniques employed for composing higher-level events from a set of events and/or data. Such inference results in the construction of new events or actions from a set of observed events and/or stored event data, whether or not the events are correlated in close temporal proximity, and whether the events and data come from one or several event and data sources.

[0023] The disclosed calibration architecture supports the premise that calibration efforts can be significantly reduced with only a minor reduction in spatial accuracy. This effectively diminishes one of the most daunting practical barriers to wider adoption of an IEEE 802.11 location-based measurement technique.

[0024] Referring now to FIG. 1, there is illustrated geometry of the calibration procedure for a system of the present invention that determines new location(s) based on signal characteristics. These new location(s) are expected to be within a region 100. Region 100 may be a building, a floor of a building, or any other region that has coverage by one or more transmitters 110. The transmitters 110 may be located internal and external to the region 100. In order for the location system to be able to determine at least an (x,y) location, there must be at least three transmitters 1 10 whose signal characteristics can be measured in the region 100. These transmitters 110 may be, but are not required to be, for example, access point (AP) transceivers disposed on a network. However, for purposes of this description, the phrase "transmitting device" and the term "transmitter(s)" should be understood to include any device that may or may not be disposed on a network and that transmits a signal.

[0025] Region 100 is divided into sections 120, which sections 120 may include, for example, rooms, hallways, or lounges in a building, and thus may be of variable size. Alternatively, the sections 120 may be particular locations within rooms. The transmitters 110 are not necessarily located in the sections 120. Furthermore, there can be additional areas of region 100 that are not divided into sections 120.

[0026] The sections 120 may contain one or more calibration points 130. During calibration, a receiver 140 is placed sequentially at every calibration point 130. For each calibration point 130, one or more signal characteristics of every receivable transmitter 110 are recorded. In one embodiment, the transmitters 110 are transceivers that are compliant with an IEEE 802.11 standard and the signal characteristics are the signal strengths of the transmitters 110, measured at the calibration point 130. Also, for each calibration point 130, the identity of the corresponding section 120 is recorded. The identity of the corresponding section 120 can be indicated, for example, by a user selecting a section from a map. The spatial location of all sections 120 are also required for calibration. These spatial locations can be the centroid of the spatial extent of each section 120.

[0027] In another embodiment, there is only one calibration point 130 for each section 120. The calibration point 130 is located at a known location inside each section 120. The signal characteristics are then measured multiple times, while the receiver 140 is rotated in place at the single calibration point 130. The spatial location of section 120 is taken to be the spatial location of the calibration point 130.

[0028] In yet another embodiment, there are multiple calibration points 130 for each section 120. These calibration points 130 are chosen to be scattered throughout the section 120. The signal characteristics may be measured one

or more times for each calibration point 130. The spatial location of section 120 is taken to be the centroid of the section 120.

[0029] With any of the embodiments, the signal characteristics are measured by receiver 140 at all calibration points 130 and the spatial locations from all sections 120 are gathered, at act 150. Regression is then performed upon this data, at act 160. Regression operates on the gathered data to produce a regression function, as indicated at an act 170, which can be used subsequently to estimate new location(s) throughout the region 100 based on newly measured signal characteristics. These new location(s) are not constrained to lie on the calibration points 130. Indeed, they are not even constrained to lie within sections 120; they can occur at locations that are inaccessible at the time of calibration.

[0030] Referring now to FIG. 2, there is illustrated a flow diagram of a general calibration process in accordance with the present invention. While, for purposes of simplicity of explanation, the methodology of FIG. 2, and any subsequent methodologies in, e.g., the form of flow charts, are shown and described herein as a series of acts, it is to be understood and appreciated that the present invention is not limited by the order of acts, as some acts may, in accordance with the present invention, occur in different orders and/or concurrently with other acts from that shown and described herein. For example, those skilled in the art will understand and appreciate that a methodology could alternatively be represented as a series of interrelated states or events, such as in a state diagram. Moreover, not all illustrated acts may be required to implement a methodology in accordance with the present invention.

[0031] At 200, the receiver is brought to a calibration point 130. At 202, the spatial location of the receiver is then recorded. Note that recording of the spatial location information need not be performed at each calibration point, but may be recorded only once during calibration of a section 120. The receiver then measures and records signal strengths of one or more transmitters of the location, as indicated at 204. At 206, if the signal strengths at more calibration points 130 must be measured, flow returns to 200 to bring the receiver to that next calibration point 130, and continue the measurement and recording process for that calibration point 130. If no other calibration point 130 must be measured, flow proceeds from 206 to 208, to create a regression function. This regression function is trained via regression. The training set comprises the signal strengths measured at calibration points 130 and the spatial locations of sections 120. The regression function is then determined that provides position in (x,y) coordinates as a function of signal strengths over the entire region 100. Alternatively, the regression function may provide (x,y,z) coordinates, if the region 100 extends over multiple floors of a building.

[0032] Referring now to FIG. 3 there is illustrated a flow diagram of a process for determining new location(s). At 300, a receiver is brought to a general area of the new location. This location may be one that was previously visited or a location that is being visited for the first time. Signal strengths are then measured and recorded, as indicated at 302. The signals may be received from any transmitters associated with region 100. At 304, the regression function is employed to estimate new location(s) within region 100, based on the signal strengths measured by the receiver at 302. The process then reaches a Stop block.

THE ALGORITHM

[0033] Referring now to FIG. 4, there is illustrated a more detailed flow diagram of the process for determining mapping from signal strengths to (x,y) location in accordance with the present invention. At 400, signal strength vectors from every section 120 are clustered into K clusters. At 402, all signal strength vectors are separated into a training set and a test set of vectors. At 404, an untried value of sigma (σ) is chosen. At 406, a kernel matrix is created from the training set. At 408, the linear system is solved for coefficients of alpha (α) and beta (β). At 410, the values of sigma (σ), alpha (α), and beta (β) are saved. At 412, sigma (σ), alpha (α), and beta (β) are evaluated on the test set utilizing Equations (2) and (3). At 414, it is determined if the last sigma (σ) has been reached. If NO, flow proceeds back to the input of 404 to choose another untried sigma (σ). If YES, flow is to 416 to save the best sigma (σ), alpha (α), and beta (β).

[0034] Following is a detailed description of the algorithm and associated equations.

[0035] In order to facilitate understanding of the mathematics discussed *infra*, each set of calibration signal strength readings is designated with a vector $\mathbf{s}_i$, where i indexes over substantially all calibration vectors in substantially all the room locations. Each calibration vector has a corresponding (x_i, y_i) giving the location from which it was taken. This may be the centroid of the spatial extent of section 120 or wherever the receiver is placed. Each signal strength vector $\mathbf{s}_i$ has a plurality of elements, one element for each transmitter receivable in region 100. The elements in $\mathbf{s}_i$ corresponding to transmitters that were not sensed at the calibration point 130 were given a value of one less than the minimum signal strength seen for the whole experiment. The signal strengths are returned from a WRAPI (Wireless Research Application Programming Interface) library as integers in units of dBm, where dBm = 10 $\log_{10}$ (milliwatts).

[0036] Many conventional IEEE 802.11-based location studies have formulated the task of location measurement as a classification problem, where the goal is to classify the signal strength vector into a discrete set of locations. This includes the probabilistic formulations where the classification result is given as a set of probabilities over all the possible locations. However, the classification formulation is unsuitable for a goal of completely skipping certain rooms during the calibration phase. If a trained classifier has never seen a certain room, it will not ever classify data as coming from

that room.

[0037] Instead, the present invention uses regression to form the regression function that maps signal strength vector (s) into locations. Thus, the present invention can map a signal strength vector into a new location that has never been calibrated. If classification (rather than regression) is still desired, a post-processing check can be made to determine which room, if any, contains the estimated location.

[0038] Following is a description of how the signal strengths measured in accordance with the embodiments of FIG. 1 are used to generate the regression function that gives location as a function of the signal strength vector, after which the number of calibration vectors is reduced in a principled way to see how reducing the amount of calibration data affects the accuracy of location measurement.

[0039] Regression fits a function to the calibration vectors $\mathbf{s}_i$ and the corresponding room coordinates (x_i,y_i). The present invention utilizes kernel regression, which estimates new location(s) via the formula

$$x(\mathbf{s}) = c_x + \sum_{j=0}^{M-1} \alpha_j K\left(\left\|\mathbf{s} - \mathbf{s}_j^*\right\|\right), \text{ and}$$
$$y(\mathbf{s}) = c_y + \sum_{j=0}^{M-1} \beta_j K\left(\left\|\mathbf{s} - \mathbf{s}_j^*\right\|\right); \qquad (1)$$

where $K(r)$ is a chosen kernel function, S^*_j are the chosen kernel function centers, and α_j and β_j are the computed weights based on calibration data. The Euclidean distance r between an observed signal strength vector $\mathbf{s}$ and a stored signal strength vector $\mathbf{s}^*_j$ is shown by $\|\mathbf{s}\text{- }\mathbf{s}^*_j\|$. The offset (c_x,c_y) can be computed in a number of ways, as is known in the art of machine learning. In one embodiment, the offset is simply the centroid of the training data, *i.e.,*

$$(c_x,c_y) = \frac{1}{N}\left(\sum_{i=0}^{N-1} x_i, \sum_{i=0}^{N-1} y_i\right); \qquad (2)$$

where N is the number of calibration vectors (in the application provided herein, the number is 28,114).

[0040] In the embodiment of FIG. 1, the kernel function is chosen to be an isotropic Gaussian kernel function:

$$K(r) = \exp\left(-\frac{r^2}{2\sigma^2}\right). \qquad (3)$$

where σ is the radius, and r is the Euclidean distance $\|\mathbf{s}\text{-}\mathbf{s}^*_j\|$.

[0041] This choice of kernel function also requires a choice of scale parameter sigma (σ), which is described below. Additionally, the choice of the M kernel centers $\mathbf{s}^*_j$ is also described below.

[0042] The present invention uses a least-squares fit to compute the weights α_j and β_j based on the calibration data. To compute the α_j (for the x coordinate), the squared error is minimized between the calibration data and $x(\mathbf{s}_i)$, which is,

$$err = \sum_{i=0}^{N-1}\left(x_i - c_x - \sum_{j=0}^{M-1} \alpha_j K_{ij}\right)^2, \qquad (4)$$

where

$$K_{ij} = K\left(\left\|\mathbf{s}_i - \mathbf{s}_j^*\right\|\right).$$

Minimizing with respect to α_j gives a linear equation that can be solved for the vector $\mathbf{a} = (\alpha_0, \alpha_1,...,\alpha_{M-2}, \alpha_{M-1})^T$:

$$K^T K a = K^T X \quad (5)$$

Here K is an N x M matrix of K_{ij}, and $\mathbf{x} = (x_0 - C_x, x_1 - C_x, - - -, x_{N-2} - c_x, x_{N-1} - c_x)^T$. Analogously, β_j is obtained from $K^T K\beta = K^T\mathbf{y}$.

[0043] Note that $K^T K$ has size M x M, where M is a chosen number of stored signal strength vectors. $K^T K$ is a kernel matrix. One possible choice is to let each calibration point $\mathbf{s}_j$ serve as a stored signal strength vectors, giving $M = N$. Solving Equation (5) with M larger than 27,000 (as is used in the embodiment of FIG. 1) would be extremely computationally intensive. In addition, the regression function produced when $M = N$ may not smoothly generalize between calibration points 130. Instead, the signal strength calibration vectors were clustered in each location, and the cluster centers were used as kernel centers. Using a standard k-means algorithm, computing $k = 5$ signal strength clusters in each room, results in less than 700 kernel centers to represent all 118 rooms on the test floor.

[0044] If the uncertainty of the location of calibration points 130 is known, each term in Equation (4) may be weighted by the inverse of the variance of the uncertainty for its corresponding calibration point. In the art, this is known as heteroscedastic regression.

[0045] The only remaining choice was for the scale parameter σ. A simple linear search was performed over possible values of σ. For each candidate σ, the weights a and β were computed first using 70% of the calibration data. The candidates were evaluated using the remaining disjoint 30%. The system picked the σ that gave the least rms distance error in (x,y). In spite of the 70/30 split for computing σ, 100% of the calibration data was used to cluster for the kernel centers.

[0046] As previously indicated, an optional step is to average together the results of the last several locations to reduce noise. The last ten (x,y) results were averaged together.

[0047] As mentioned previously, a second set of test vectors were taken a few days separated from the training data. Using the embodiment where one calibration point 130 is taken per section 120, the second set numbered 25,457 readings to serve as test data. When testing this data, the kernel regression method yielded an rms error of approximately 3.75 meters. Computation of the rms error is known in the art, and thus not shown here.

APPLICATION EXAMPLES

[0048] As indicated above, the location algorithm of the present invention works based on regression of signal strength training data taken from known room locations.

[0049] Referring now to FIG. 5, there is illustrated a layout of a typical office floor 500 of rooms 502 utilized for a sample application of the calibration process of the present invention. The floor 500 includes 132 rooms 502 of which 118 were accessible. The area of the floor 500 is approximately 2,680 square meters. The floor was taken to be region 100. The building maps of the floors were extracted both as polygon representations and bitmaps. The coordinates of all maps were expressed in actual floor coordinates in meters. The algorithm was evaluated on the one floor 500 with the 118 different rooms.

[0050] To study the problem of calibration effort, the amount of calibration data was reduced as if less time was spent in each room and as if certain rooms had been skipped. The 118 rooms were split into 137 sections, since in larger rooms, e.g., conference rooms, more receiver locations were used. The receiver locations were noted by making the location selection utilizing the map via the interface of FIG. 6, described hereinbelow. The results indicated a calibration location for every 19.5 square meters. For calibration, each accessible section was entered with a wirelessly connected receiver, *e.g.*, the portable PC, running the logging program. The logging program used the WRAPI interface to obtain signal strengths from all the visible IEEE 802.11 transmitters. The receiver measured signals for approximately sixty seconds in each location. Additionally, the receiver was oriented in a number of different ways to factor out orientation effects. A scan rate of 3.4 Hz was used providing approximately 200 scans for each location. Each scan yielded the set of signal strengths and the MAC (Media Access Controller) addresses of the wireless access points. On average, the wireless communication interface could "see" 3.9 AP's at any given time. As previously indicated, the first set of signal strength readings numbered 27,796, and the second set, taken a few days later to serve as test data, numbered

25,457.

[0051] As a way of reducing noise and increasing accuracy, a running average filter was applied to the computed location vectors. The filter was ten samples long, which induced a delay of approximately 2.9 seconds at the scan rate of 3.4 Hz.

[0052] To test the effect of reduced time, the first *s* seconds of calibration data were processed with the same training algorithm, and then tested with the entire test set. Accuracy does not suffer significantly even when the time spent in each location is only ten seconds. At ten seconds, the rms error had only increased by approximately 12% (or 0.45 meters) from the rms error at sixty seconds. At a data rate of 3.4 Hz, ten seconds of data yielded only thirty-four signal strength vectors. This indicates that it is not necessary to spend much time at each location during calibration.

[0053] The effect of reducing the number of calibration locations from the original full set of 137 locations down to 10% of the original was tested. To choose k locations from the original calibration set, a k-means clustering algorithm was run on the original locations to make *k* clusters. The *k* original locations nearest the *k* cluster centroids were chosen as those for calibration. As determined, the rms error grows as the number of locations decreases. However, even at 50%, the rms error has only grown by 20% (0.74 meters), and at 20%, has grown by 42% (1.59 meters). At 10% of the original locations, the rms error is 9.19 meters, which is an increase of 145% (5.44 meters) over the best result at 100%. Therefore, this shows that there is a significantly diminishing return for moving to a denser set of calibration points. This experiment also suggests a way to choose calibration points in a space by starting with a dense set, for example, at the centroid of every room, and use k-means to cluster the set into a representative sub-sample.

[0054] Furthermore, both the time spent at each location and the number of locations can be significantly reduced with only a minor degradation in accuracy. For example, spending thirty seconds in 40% of the locations increases the rms error by only approximately 21 % (from 3.75 meters to 4.55 meters), yet reduces the calibration effort by much more than half.

[0055] Referring now to FIG. 6, there is illustrated an exemplary screenshot of a graphical user interface (GUI) 600 for facilitating signal strength logging of the calibration data. The GUI 600 facilitates the display of a floor graphical representation 602 of the floor 500, and rooms thereof. The user indicates the location of the receiver by selecting a room from the floor representation 602 via a mouse, keyboard, or other conventional input device. Additionally, there is presented a signal strength subwindow 604 for presenting a signal strength indicator plot 605 that displays a representation of the measured signal strengths from nearby transmitters. For example, a first bar 606 includes a first color or fill pattern that indicates the signal was received from a transmitter on the current floor being calibrated. Associated with the bar 606 is data 608 that indicates the signal strength data, the floor on which the room is located, and the room number of the transmitter (i.e., 113/3/3327). In this particular example, the transmitter was in building number (113), room number 3327 (also denoted graphically at 610) of the third floor (3).

[0056] A second bar identification 612 may be used to indicate measurements received from transmitters on floors other than the current floor being calibrated. The bar 612 is associated with room 113/4/4327, which is a room 4327 on the fourth floor of building 113. It is to be appreciated that the GUI can be programmed to provide a wide variety of graphical responses to measure signals, including flashing bars, and text, audio output signals, etc., commonly available for providing such interface features.

[0057] The interface 600 also includes a Location Input subwindow 614 that allows the user to zoom in on a floor map via a Map Zoom subwindow, and choose a floor for calibration via a Floor Chooser subwindow.

[0058] The interface 600 further includes a Scan Control subwindow 616 for selecting the scan rate (in Hertz) for signal detection. The user can also direct logging of the data to a location on the receiving device via a Logging path field 618. The user may also select a remote network storage location by entering the corresponding network path in the path filed 618. Once entered, all data is automatically stored in the designated file location.

[0059] At first glance, an rms error of approximately 3.75 meters for the location system seems much worse than previous conventional studies obtaining a median error of approximately 2.94 meters in a first conventional experiment or approximately one meter for a second conventional experiment. However, both of these conventional systems required much more calibration effort. The first conventional experiment covered hallway outside of about fifty-four rooms with seventy calibration points. The second conventional experiment covered the hallway with calibration points approximately 1.5 meters (five feet) apart. In contrast, the disclosed examples used one calibration point per room on rooms with an average center-to-center spacing of approximately 2.85 meters. The other efforts also took much more care in making sure the locations of the calibration points were known. While the above first and second conventional experiments show what is achievable with a careful calibration, the disclosed methodology illustrates what is achievable with a practical one.

[0060] One barrier to deploying an IEEE 802.11-based location system is the calibration effort. In the disclosed example, approximately four hours were spent calibrating 118 rooms on one floor of the building. It is desirable to know if this amount of calibration is really necessary. In particular, it is desirable to evaluate the effect of reducing the time spent in each room and reducing the number of rooms visited. By training on subsets of the original training data, the effects of reducing the time and number of rooms was simulated.

[0061] In summary, calibration for IEEE 802.11-based location can be very tedious. In the disclosed application example, one floor of an office building was calibrated down to room resolution, which approximates what could be expected for a large-scale deployment of an IEEE 802.11 location system. Using radial basis functions to interpolate location as a function of signal strength, an rms error of approximately 3.75 meters was achieved on rooms whose mean spacing was approximately 3.27 meters. By formulating the problem as one of interpolation, it is possible to make the calibration process easier by skipping a significant fraction of the rooms. Additionally, it is unnecessary to spend much time in each room, as more time beyond a short minimum does not improve accuracy very much.

[0062] In an alternative implementation, instead of measuring the strength of multiple transmitters from a single receiver at various calibration locations, the disclosed invention is equally applicable to determining the location of a transmitter by fixing a number of receivers at known locations and measuring the strength of a single transmitter at various calibration locations. The latter would be applicable to the case where the transmitter is a source of audio (*e.g.*, a human), while the receiver is a set of audio microphones.

[0063] In a further alternative embodiment, calibration and regression need not operate on signal strength. Various signal properties can be used, such as phase, autocorrelation, or spectrum. Regression can apply equally well to these alternative signal properties, even if each property itself is not a scalar. The input to a kernel regression system would then consist of a vector that comprises multiple vectors of signal properties, appended together.

[0064] Referring now to FIG. 7, there is illustrated a block diagram of a computer operable to execute the disclosed architecture. In order to provide additional context for various aspects of the present invention, FIG. 7 and the following discussion are intended to provide a brief, general description of a suitable computing environment 700 in which the various aspects of the present invention may be implemented. While the invention has been described above in the general context of computer-executable instructions that may run on one or more computers, those skilled in the art will recognize that the invention also may be implemented in combination with other program modules and/or as a combination of hardware and software. Generally, program modules include routines, programs, components, data structures, etc., that perform particular tasks or implement particular abstract data types. Moreover, those skilled in the art will appreciate that the inventive methods may be practiced with other computer system configurations, including single-processor or multiprocessor computer systems, minicomputers, mainframe computers, as well as personal computers, hand-held computing devices, microprocessor-based or programmable consumer electronics, and the like, each of which may be operatively coupled to one or more associated devices. The illustrated aspects of the invention may also be practiced in distributed computing environments where certain tasks are performed by remote processing devices that are linked through a communications network. In a distributed computing environment, program modules may be located in both local and remote memory storage devices.

[0065] With reference again to FIG. 7, there is illustrated an exemplary environment 700 for implementing various aspects of the invention includes a computer 702, the computer 702 including a processing unit 704, a system memory 706 and a system bus 708. The system bus 708 couples system components including, but not limited to the system memory 706 to the processing unit 704. The processing unit 704 may be any of various commercially available processors. Dual microprocessors and other multi-processor architectures also can be employed as the processing unit 704.

[0066] The system bus 708 can be any of several types of bus structure including a memory bus or memory controller, a peripheral bus and a local bus using any of a variety of commercially available bus architectures. The system memory 706 includes read only memory (ROM) 710 and random access memory (RAM) 712. A basic input/output system (BIOS), containing the basic routines that help to transfer information between elements within the computer 702, such as during start-up, is stored in the ROM 710.

[0067] The computer 702 further includes a hard disk drive 714, a magnetic disk drive 716, (*e.g.*, to read from or write to a removable disk 718) and an optical disk drive 720, (*e.g.*, reading a CD-ROM disk 722 or to read from or write to other optical media). The hard disk drive 714, magnetic disk drive 716 and optical disk drive 720 can be connected to the system bus 708 by a hard disk drive interface 724, a magnetic disk drive interface 726 and an optical drive interface 728, respectively. The drives and their associated computer-readable media provide nonvolatile storage of data, data structures, computer-executable instructions, and so forth. For the computer 702, the drives and media accommodate the storage of broadcast programming in a suitable digital format. Although the description of computer-readable media above refers to a hard disk, a removable magnetic disk and a CD, it should be appreciated by those skilled in the art that other types of media which are readable by a computer, such as zip drives, magnetic cassettes, flash memory cards, digital video disks, cartridges, and the like, may also be used in the exemplary operating environment, and further that any such media may contain computer-executable instructions for performing the methods of the present invention.

[0068] A number of program modules can be stored in the drives and RAM 712, including an operating system 730, one or more application programs 732, other program modules 734 and program data 736. It is appreciated that the present invention can be implemented with various commercially available operating systems or combinations of operating systems.

[0069] A user can enter commands and information into the computer 702 through a keyboard 738 and a pointing

device, such as a mouse 740. Other input devices (not shown) may include a microphone, an IR remote control, a joystick, a game pad, a satellite dish, a scanner, or the like. These and other input devices are often connected to the processing unit 704 through a serial port interface 742 that is coupled to the system bus 708, but may be connected by other interfaces, such as a parallel port, a game port, a universal serial bus ("USB"), an IR interface, etc. A monitor 744 or other type of display device is also connected to the system bus 708 *via* an interface, such as a video adapter 746. In addition to the monitor 744, a computer typically includes other peripheral output devices (not shown), such as speakers, printers etc.

[0070] The computer 702 may operate in a networked environment using logical connections to one or more remote computers, such as a remote computer(s) 748. The remote computer(s) 748 may be a workstation, a server computer, a router, a personal computer, portable computer, microprocessor-based entertainment appliance, a peer device or other common network node, and typically includes many or all of the elements described relative to the computer 702, although, for purposes of brevity, only a memory storage device 750 is illustrated. The logical connections depicted include a local area network (LAN) 752 and a wide area network (WAN) 754. Such networking environments are commonplace in offices, enterprise-wide computer networks, intranets and the Internet.

[0071] When used in a LAN networking environment, the computer 702 is connected to the local area network 752 through a network interface or adapter 756. The adaptor 756 may facilitate wired or wireless communication to the LAN 752, which may also include a wireless access point disposed thereon for communicating with the wireless adaptor 756. When used in a WAN networking environment, the computer 702 typically includes a modem 758, or is connected to a communications server on the LAN, or has other means for establishing communications over the WAN 754, such as the Internet. The modem 758, which may be internal or external, is connected to the system bus 708 *via* the serial port interface 742. In a networked environment, program modules depicted relative to the computer 702, or portions thereof, may be stored in the remote memory storage device 750. It will be appreciated that the network connections shown are exemplary and other means of establishing a communications link between the computers may be used.

[0072] Referring now to FIG. 8, there is illustrated a schematic block diagram of an exemplary computing environment 800 in accordance with the present invention. The system 800 includes one or more client(s) 802. The client(s) 802 can be hardware and/or software (*e.g.*, threads, processes, computing devices). The client(s) 802 can house cookie (s) and/or associated contextual information by employing the present invention, for example. The system 800 also includes one or more server(s) 804. The server(s) 804 can also be hardware and/or software (*e.g.*, threads, processes, computing devices). The servers 804 can house threads to perform transformations by employing the present invention, for example. One possible communication between a client 802 and a server 804 may be in the form of a data packet adapted to be transmitted between two or more computer processes. The data packet may include a cookie and/or associated contextual information, for example. The system 800 includes a communication framework 806 that can be employed to facilitate communications between the client(s) 802 and the server(s) 804. Communications may be facilitated via a wired (including optical fiber) and/or wireless technology. The client(s) 802 are operably connected to one or more client data store(s) 808 that can be employed to store information local to the client(s) 802 (*e.g.*, cookie (s) and/or associated contextual information). Similarly, the server(s) 804 are operably connected to one or more server data store(s) 810 that can be employed to store information local to the servers 804.

[0073] What has been described above includes examples of the present invention. It is, of course, not possible to describe every conceivable combination of components or methodologies for purposes of describing the present invention, but one of ordinary skill in the art may recognize that many further combinations and permutations of the present invention are possible. Accordingly, the present invention is intended to embrace all such alterations, modifications and variations that fall within the spirit and scope of the appended claims. Furthermore, to the extent that the term "includes" is used in either the detailed description or the claims, such term is intended to be inclusive in a manner similar to the term "comprising" as "comprising" is interpreted when employed as a transitional word in a claim.

Claims

1. A method of calibrating a system used to determine new location(s) depending on observed signal properties, comprising:

   measuring signal properties related to identified locations; and
   generating a regression function based at least in part upon the signal properties, the function estimating new location(s) as a function of observed signal properties.

2. The method of claim 1, the regression function comprising a plurality of kernel functions, each kernel function computing the difference between a vector of observed signal properties and a vector of stored signal properties.

3. The method of claim 2, the kernel functions being isotropic Gaussian kernel functions.

4. The method of claim 2, the vectors of stored properties are computed by clustering a plurality of vectors of measured signal properties.

5. The method of claim 2, the regression function further comprising weights and a scale parameter such that each kernel function depends on the scale parameter, the scale parameter determined by further,

selecting a plurality of the scale parameter values;
for each scale parameter value, fitting the weights to a first subset of the signal properties using the scale parameter value;
evaluating the regression function using the fitted weights on a second subset of the signal properties, the second subset being disjoint from the first subset;
selecting a best scale parameter where the regression function obtains the least location error on the second subset of the signal properties; and
storing the best scale parameter and corresponding weights.

6. The method of claim 1, the regression function comprising weights, and the act of generating the regression function comprises fitting the regression function to the measured signal properties by adjusting the weights.

7. The method of claim 6, the weights adjusted according to a least-squares fitting procedure.

8. The method of claim 6, the weights adjusted by computing a kernel matrix.

9. The method of claim 6, the weights adjusted based upon an estimate of location uncertainty associated with each identified location.

10. The method of claim 6, the weights comprising a plurality of weights for computing an x location and a plurality of weights for computing a y location.

11. The method of claim 1, the regression function further comprises additional parameters that are computed from a centroid of the identified locations.

12. The method of claim 1, the signal properties are of wireless radio signals transmitted from wireless transceivers, and the signal properties comprise signal strengths.

13. The method of claim 12, the wireless transceivers operating in accordance with an IEEE 802.11 standard.

14. The method of claim 1, wherein a subset of the new location(s) are inaccessible at the time of calibration, the inaccessible locations including at least one of a room, a plurality of rooms distributed throughout a floor, and a plurality of rooms proximately located on a floor.

15. A method of calibrating a wireless device location measurement system, comprising:

accessing at least one wireless transmitting device;
logging signal strength data for each of wireless transmitting device; and
generating a regression function based upon the signal strength data, the regression function utilized to estimate new location(s).

16. The method of claim 15, the signal strength data logged from a plurality of different locations within range of the transmitting device.

17. A location system that observes signal properties to determine a new location(s), comprising:

means for measuring signal properties related to identified locations; and
means for generating a regression function based at least in part upon the signal properties, the function estimating new location(s) as a function of observed signal properties.

18. A location system that uses observed signal properties to determine new location(s), comprising:

a measuring component for measuring signal properties related to identified locations; and
a regression component for generating a regression function based at least in part upon the signal properties, the function estimating new location(s) based upon observed signal property data.

19. The system of claim 18, the regression function comprising a plurality of kernel functions, each kernel function computing the difference between a vector of observed signal properties and a vector of stored signal properties.

20. The system of claim 19, the kernel functions being isotropic Gaussian kernel functions.

21. The system of claim 19, wherein the vector of stored properties is computed by clustering a plurality of vectors of measured signal properties.

22. The system of claim 18, the regression function comprising weights, and the regression component comprising a fitting component for fitting the regression function to the measured signal properties by adjusting the weights.

23. The system of claim 22, the fitting component comprising a least-squares fitting component.

24. The system of claim 22, the fitting component comprising a component for computing a kernel matrix.

25. The system of claim 22, the fitting component receives as input an estimate of the location uncertainty associated with each identified location.

26. The system of claim 22, the weights comprising a plurality of weights for computing an x location and a plurality of weights for computing a y location.

27. The system of claim 22, the regression function further comprising additional parameters that are computed from the centroid of the identified locations.

28. The system of claim 19, the signals are wireless signals transmitted from wireless transceivers, and the signal properties comprise signal strengths.

29. The system of claim 28, the wireless transceivers operate in accordance with an IEEE 802.11 standard.

30. The system of claim 18, further comprising a subset of the new location(s) that are inaccessible at the time of calibration, the inaccessible locations including at least one of a room, a plurality of rooms distributed throughout a floor, and a plurality of rooms proximately location on a floor.

31. A computer implementing the system of claim 18.

32. A user interface for calibrating a system that observes signals properties to estimate new location(s), comprising:

a user input component for receiving user preference information associated with at least the location; and
a presentation component for presenting a representation of the signal properties and for facilitating input of user preference information.

33. The interface of claim 32, further comprising a floor layout of individual representations of the locations, wherein the location representations are selectable.

34. The interface of claim 32, further comprising a plotting capability for plotting the signal properties associated with the selected location and an unselected location.

35. The interface of claim 32, the user input component comprising at least one of:

means for selecting a building associated with the locations;
means for selecting a floor in the building;
means for selecting one of the locations; and

means for selecting a scan rate for sampling the signal properties.

36. The interface of claim 32, further comprising means to display a color and/or a pattern corresponding to a state of the user preference information.

37. A computer for calibrating a system that uses signal properties to estimate new location(s), comprising:

means for measuring the signal properties related to identified locations; and
means for regressing, the regressing means generating a regression function based at least in part on the measured signal properties, the regression function used to estimate new location(s).

38. The computer of claim 37, the means for regressing further comprising means for clustering the signal properties for use by the regression algorithm.

39. The computer of claim 37, the means for regressing further comprising means to separate the measured signal properties into a training set and a test set.

40. The computer of claim 37, the means for regressing further comprising means for generating a kernel matrix from the training set.

41. The computer of claim 37, the measured signal properties comprising signal strengths.

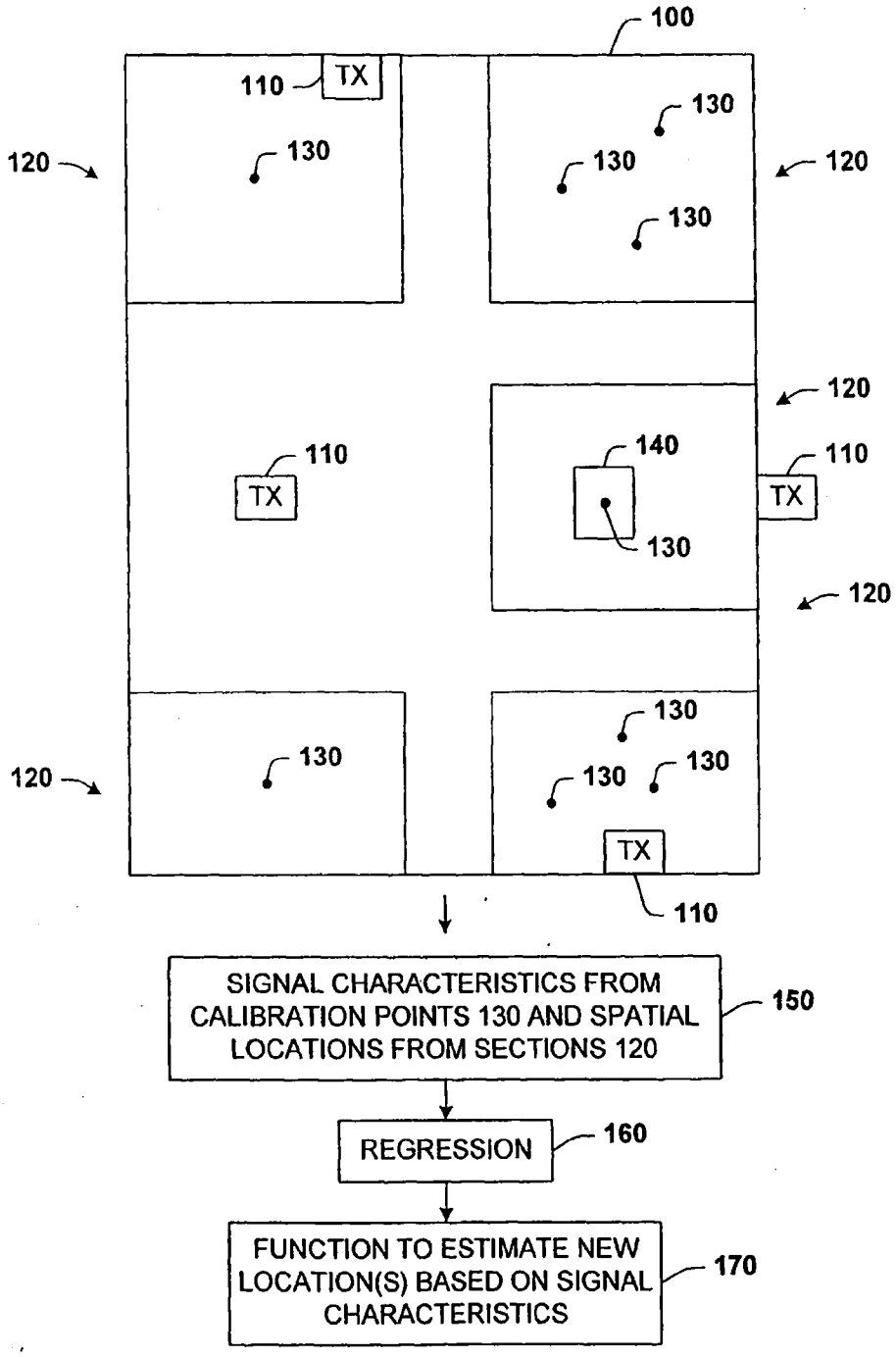

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SIGNAL CHARACTERISTICS FROM CALIBRATION POINTS 130 AND SPATIAL LOCATIONS FROM SECTIONS 120
150
REGRESSION
160
FUNCTION TO ESTIMATE NEW LOCATION(S) BASED ON SIGNAL CHARACTERISTICS
170

FIG. 1

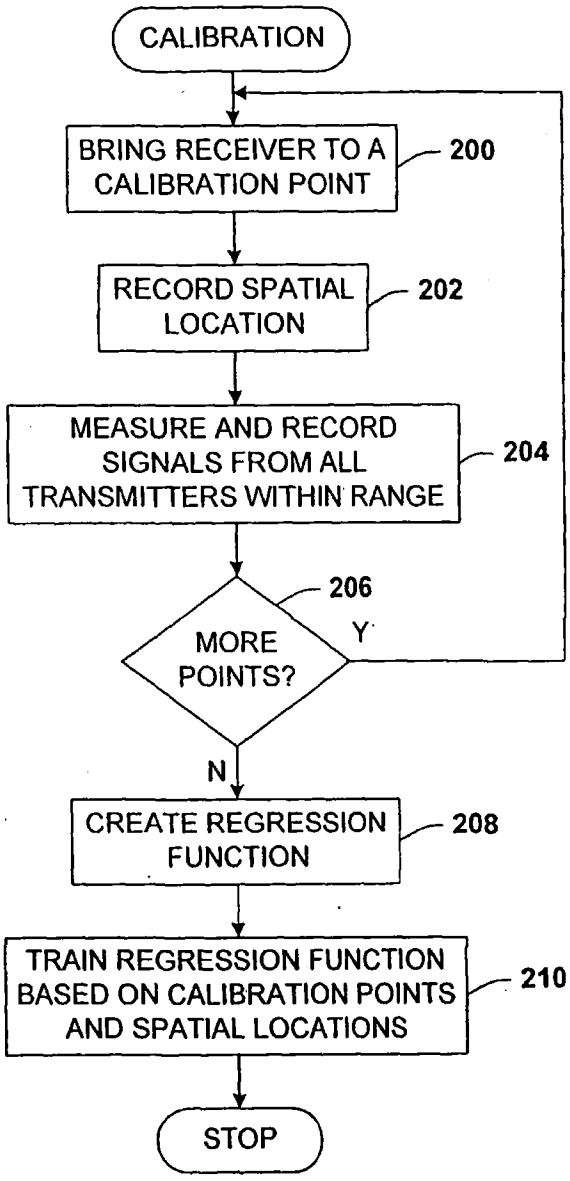

CALIBRATION
BRING RECEIVER TO A CALIBRATION POINT
200
RECORD SPATIAL LOCATION
202
MEASURE AND RECORD SIGNALS FROM ALL TRANSMITTERS WITHIN RANGE
204
206
MORE POINTS?
Y
N
CREATE REGRESSION FUNCTION
208
TRAIN REGRESSION FUNCTION BASED ON CALIBRATION POINTS AND SPATIAL LOCATIONS
210
STOP

FIG. 2

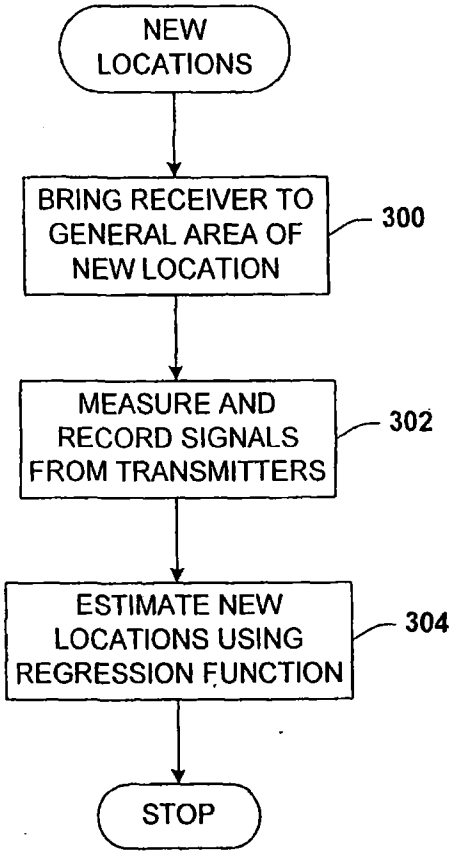

NEW LOCATIONS
BRING RECEIVER TO GENERAL AREA OF NEW LOCATION
300
MEASURE AND RECORD SIGNALS FROM TRANSMITTERS
302
ESTIMATE NEW LOCATIONS USING REGRESSION FUNCTION
304
STOP

FIG. 3

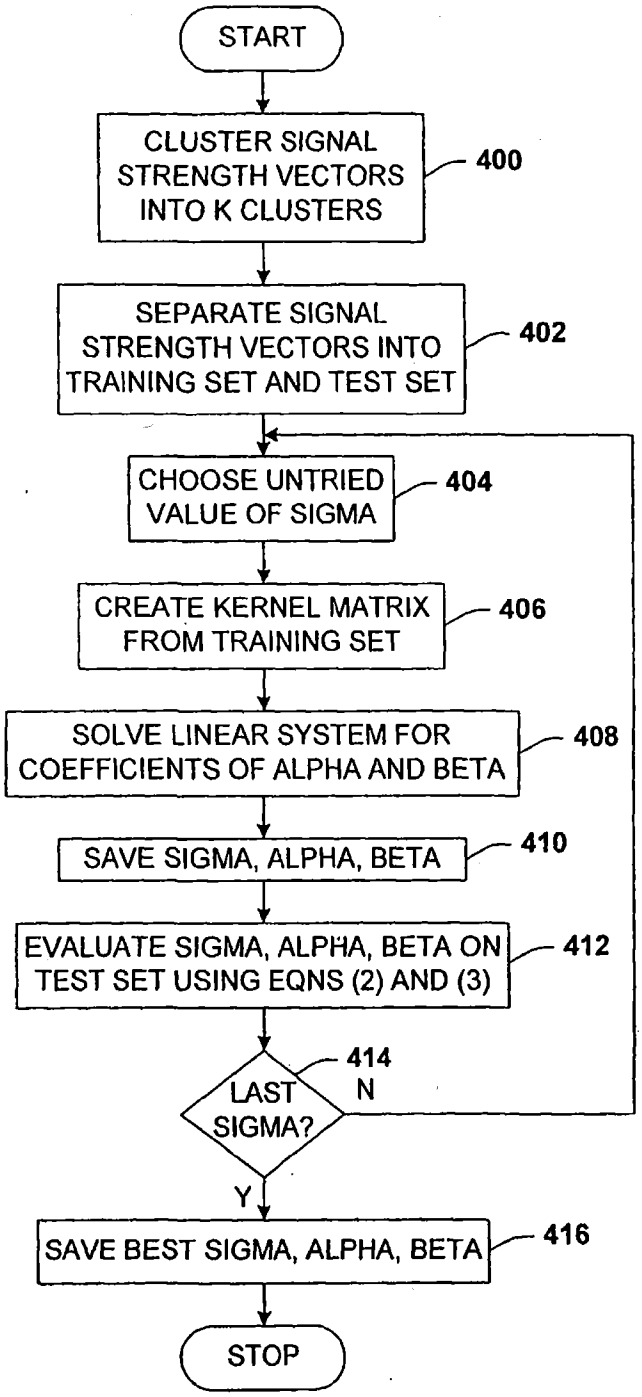

START
CLUSTER SIGNAL STRENGTH VECTORS INTO K CLUSTERS
400
SEPARATE SIGNAL STRENGTH VECTORS INTO TRAINING SET AND TEST SET
402
CHOOSE UNTRIED VALUE OF SIGMA
404
CREATE KERNEL MATRIX FROM TRAINING SET
406
SOLVE LINEAR SYSTEM FOR COEFFICIENTS OF ALPHA AND BETA
408
SAVE SIGMA, ALPHA, BETA
410
EVALUATE SIGMA, ALPHA, BETA ON TEST SET USING EQNS (2) AND (3)
412
LAST SIGMA?
414
N
Y
SAVE BEST SIGMA, ALPHA, BETA
416
STOP

FIG. 4

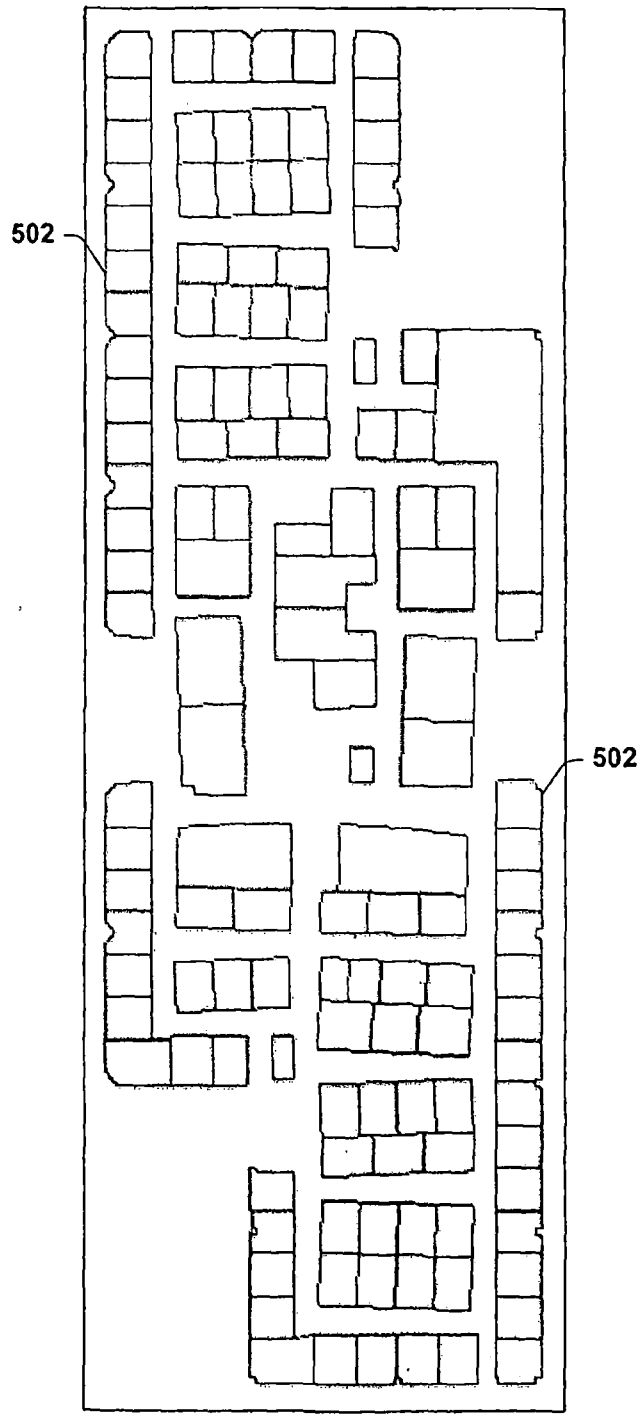


FIG. 5

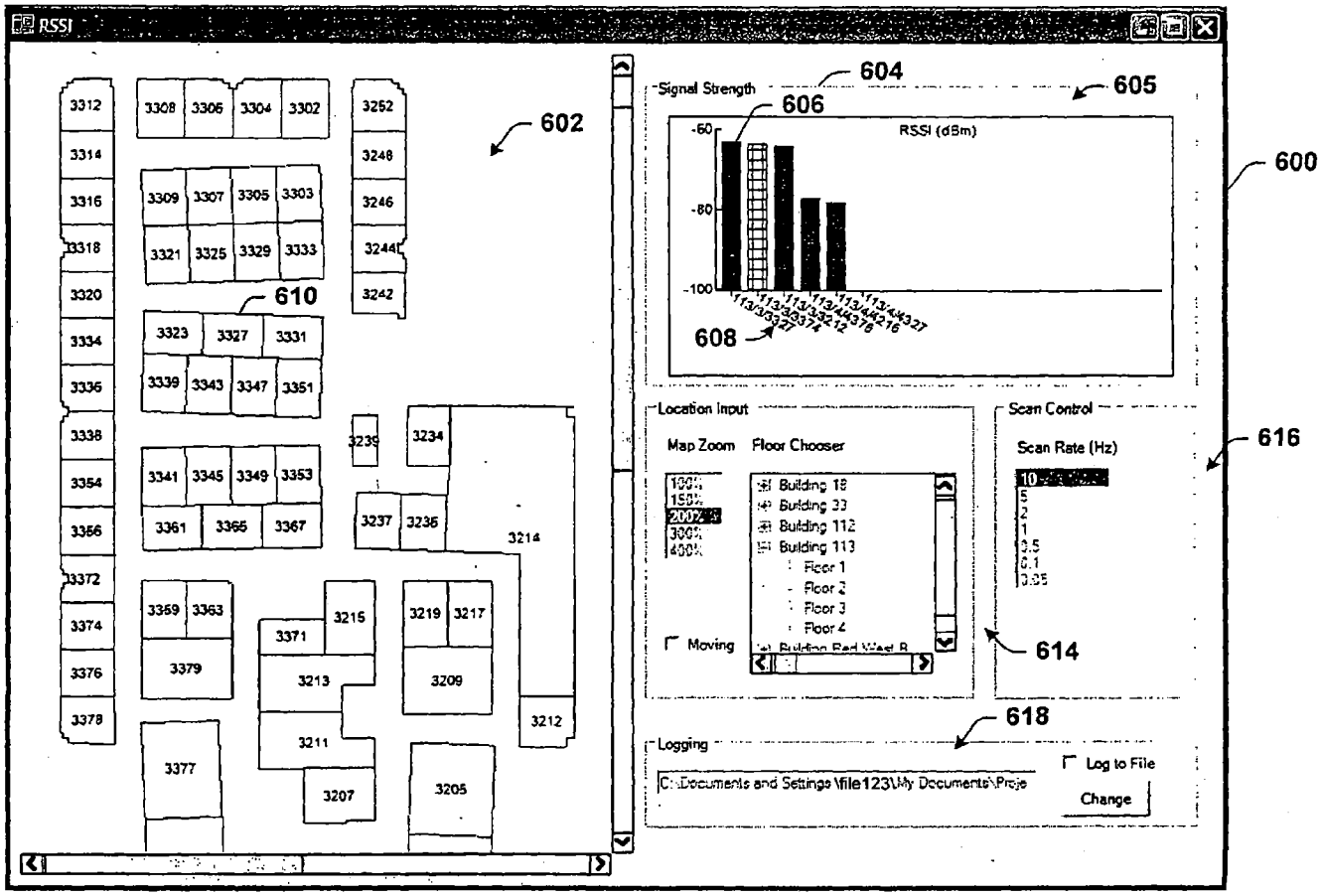

RSSI
602
604
605
606
600
610
608
616
614
618
Signal Strength
RSSI (dBm)
-60
-80
-100
Location Input
Map Zoom
Floor Chooser
Building 18
Building 33
Building 112
Building 113
Floor 1
Floor 2
Floor 3
Floor 4
Moving
Scan Control
Scan Rate (Hz)
Logging
Log to File
Change
3312
3314
3316
3318
3320
3334
3336
3338
3354
3356
3372
3374
3376
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3242

FIG. 6

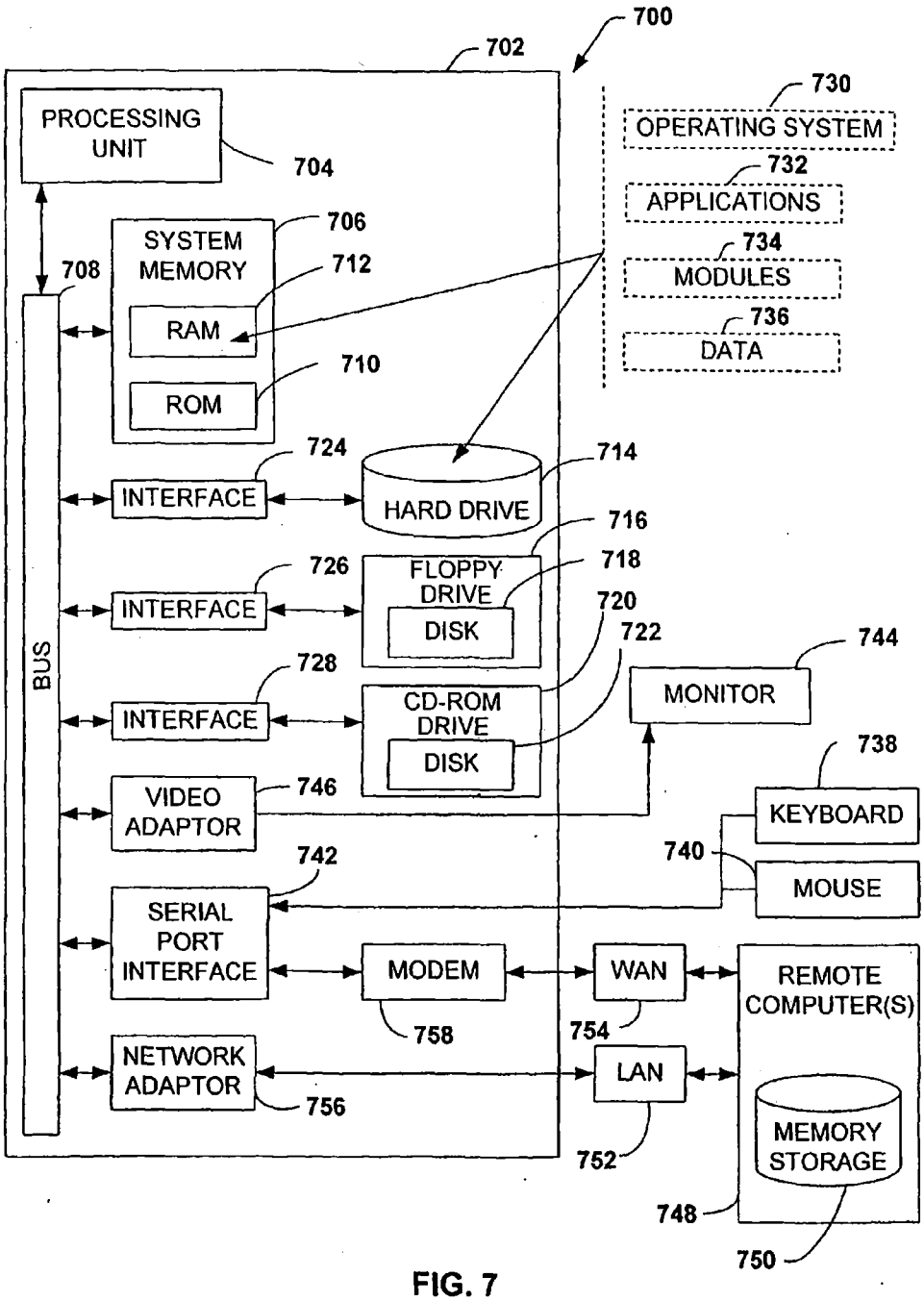

700
702
PROCESSING UNIT
704
730
OPERATING SYSTEM
732
APPLICATIONS
734
MODULES
736
DATA
706
SYSTEM MEMORY
708
712
RAM
710
ROM
724
INTERFACE
HARD DRIVE
714
716
726
FLOPPY DRIVE
718
INTERFACE
DISK
720
722
744
728
MONITOR
INTERFACE
CD-ROM DRIVE
738
DISK
BUS
746
VIDEO ADAPTOR
KEYBOARD
740
742
MOUSE
SERIAL PORT INTERFACE
MODEM
WAN
REMOTE COMPUTER(S)
758
754
NETWORK ADAPTOR
LAN
756
MEMORY STORAGE
752
748
750

FIG. 7

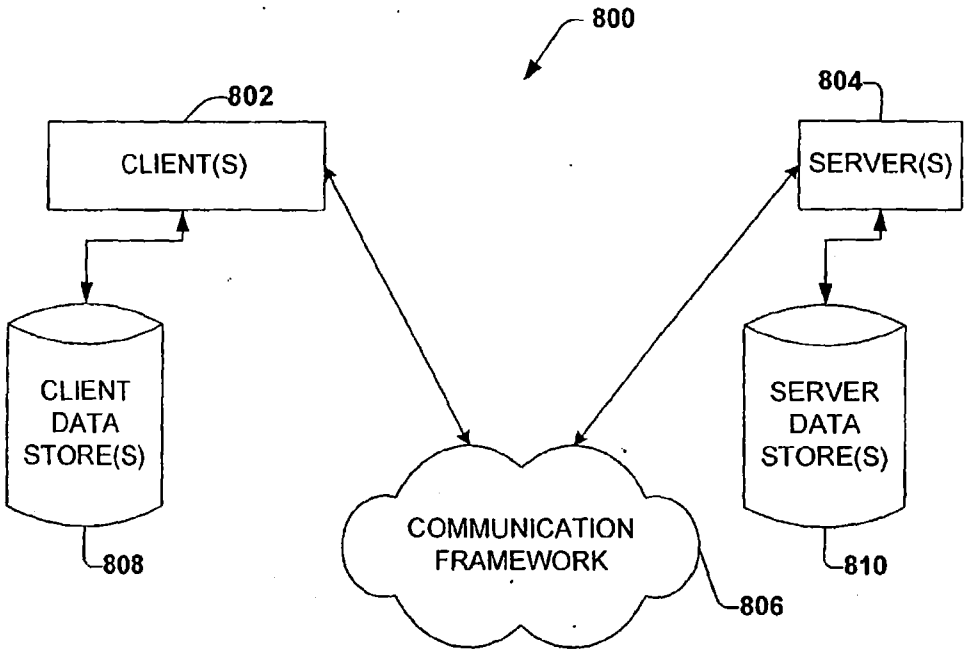
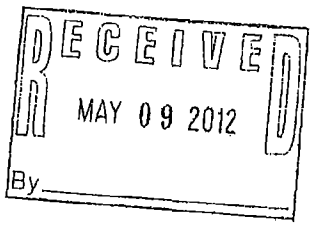

800
802
CLIENT(S)
804
SERVER(S)
CLIENT DATA STORE(S)
SERVER DATA STORE(S)
COMMUNICATION FRAMEWORK
808
810
806

FIG. 8

PATENT COOPERATION TREATY

PCT



INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference AND01 158 PCT	**FOR FURTHER ACTION**	see Form PCT/ISA/220 as well as, where applicable, item 5 below.
International application No. PCT/US2012/025052	International filing date *(day/month/year)* 14/02/2012	(Earliest) Priority Date *(day/month/year)* 14/02/2011
Applicant ANDREW LLC		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 4 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**
   a. With regard to the **language,** the international search was carried out on the basis of:
      [X] the international application in the language in which it was filed
      [ ] a translation of the international application into _____, which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b))
   b. [ ] This international search report has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43.6*bis*(a)).
   c. [ ] With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, see Box No. I.

2. [ ] **Certain claims were found unsearchable** (See Box No. II)

3. [ ] **Unity of invention is lacking** (see Box No III)

4. With regard to the **title,**
   [ ] the text is approved as submitted by the applicant
   [X] the text has been established by this Authority to read as follows:
   METHOD FOR MOBILE LOCATION BY DYNAMIC CLUSTERING

5. With regard to the **abstract,**
   [X] the text is approved as submitted by the applicant
   [ ] the text has been established, according to Rule 38.2, by this Authority as it appears in Box No. IV. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority

6. With regard to the **drawings,**
   a. the figure of the **drawings** to be published with the abstract is Figure No. 2
      [X] as suggested by the applicant
      [ ] as selected by this Authority, because the applicant failed to suggest a figure
      [ ] as selected by this Authority, because this figure better characterizes the invention
   b. [ ] none of the figures is to be published with the abstract

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/025052

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W64/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04W

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JIAN ZHU ET AL: "Indoor/Outdoor Location of Cellular Handsets Based on Received Signal Strength", 2005 IEEE 61ST VEHICULAR TECHNOLOGY CONFERENCE. VTC2005- SPRING - 30 MAY-1 JUNE 2005 - STOCKHOLM, SWEDEN, IEEE, PISCATAWAY, NJ, USA, vol. 1, 30 May 2005 (2005-05-30), pages 92-96, XP010855359, DOI: 10.1109/VETECS.2005.1543256 ISBN: 978-0-7803-8887-1	1,19,24, 29,32
Y	paragraphs I and III	2-18, 20-23, 25-28, 30,31, 33,34
	----- -/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 April 2012	02/05/2012

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Rabe, Marcus

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2007/015188 A1 (KONINKL PHILIPS ELECTRONICS NV [NL]; CHEN NINGJIANG [CN]; CHEN XIN [CN]) 8 February 2007 (2007-02-08) page 2, line 2 - line 8 page 4, line 27 - page 7, line 18	2-18, 20-23, 25-28, 30,31, 33,34
A	WO 2008/097505 A2 (ANDREW CORP [US]; CARLSON JOHN [US]; ALLES MARTIN [US]; MAHER GEORGE []) 14 August 2008 (2008-08-14) paragraph [0007] paragraph [0042] paragraph [0060] - paragraph [0066] figures 2-8	1-34
A	WO 00/18148 A1 (PPM INC [US]; RAO PADMANABHA R [US]; SICCARDO PAOLO L [US]) 30 March 2000 (2000-03-30) page 1, line 38 - line 46 page 3, line 45 - page 6, line 18 page 7, line 17 - page 8, line 12 figure 3	1-34
A	GB 2 364 617 A (SMARTONE MOBILE COMM LTD [HK]) 30 January 2002 (2002-01-30) page 5, line 16 - line 23 page 6, line 12 - page 7, line 3 page 10, line 10 - line 18 figure 1	1-34

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2012/025052

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2007015188 A1	08-02-2007	EP 1961254 A1	27-08-2008
		WO 2007015188 A1	08-02-2007
WO 2008097505 A2	14-08-2008	AT 508374 T	15-05-2011
		CA 2677087 A1	14-08-2008
		CA 2677093 A1	14-08-2008
		CA 2677094 A1	14-08-2008
		CA 2677101 A1	14-08-2008
		CA 2677128 A1	14-08-2008
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PATENT ABSTRACTS OF JAPAN

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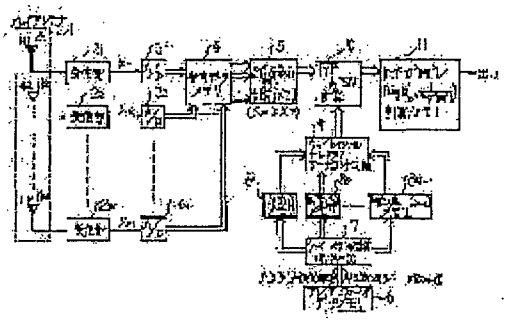
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(54) METHOD AND DEVICE FOR MEASURING BEARING

(57)Abstract:
PURPOSE: To resolve and measure the bearing of interference wave including a coherent signal (also called as a multi-path signal), in which arrival wave are correlated with each other completely at the same frequency, by an array antenna having optional array elements and arrangement.
CONSTITUTION: The device is provided with an A/D converter 3 which divides receiving signals, that are received by an array antenna consisting of M pieces of array element, into real and imaginary parts to convert them into receiving data, a circuit 5 to find out a covariance matrix from the receiving data, and a circuit 11 to calculate an evaluation function relevant to inner noise in connection with the covariance matrix and array manifold, and it detects the combination of arrival bearings by which the evaluation function is minimized.



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* NOTICES *

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1.This document has been translated by computer. So the translation may not reflect the original precisely.
2.**** shows the word which can not be translated.
3.In the drawings, any words are not translated.

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Industrial Application] This invention relates to the bearing measuring method equipment using the super RIZORYUSHON (superresolution) technique which decomposes and measures bearing of an interference wave where two or more incoming waves exist in the same frequency, and its equipment.
[0002]
[Description of the Prior Art] Bearing of an interference wave where two or more incoming waves exist in the same frequency was decomposed using the array component of arbitration, and the array antennas of an array array, and since the method of MUSIC (MUltiple SIgnal Classification) is very efficient as a ****** super RIZORYUSHON technique, it came to be put in practical use in recent years. The method of MUSIC was also called the "characteristic value part solution method" or "characteristic vector method", it was announced by 1981R.O.Schmidt, and research of relation has been made by the researcher of after that many. the following -- R. "O.Schmidt, MultipleEmitter Locaticn and Signal Parameter Estimation" (it is called IEEE TRANSACTION ON ANTENNA AND PROPAGATION, VOL.AP-34.NO, 3PP.276-280, MARCH 1986, and the following reference 1) -- reference -- carrying out -- MUSIC -- the bearing measuring method by law is explained.
[0003] The input signal received with the array antennas which consist of M array components serves as line type association with the input signal (an arrival fraction is assumed to be D) of D individual, and the internal noise of a receiver. It is as follows when this is expressed in procession.
[0004]

$$\begin{bmatrix} X_1 \\ X_2 \\ X_M \end{bmatrix} = \begin{bmatrix} & & \\ a(\theta_1)\ a(\theta_2) \cdots a(\theta_D) & & \\ & & \end{bmatrix} \begin{bmatrix} F_1 \\ F_2 \\ F_D \end{bmatrix} + \begin{bmatrix} N_1 \\ N_2 \\ N_M \end{bmatrix}$$

$$X = AF + N \qquad \cdots (1)$$

[0005] It is vector X=(X1 X2 -- XM) T here. They are M input signals (complex). Moreover, matrix A= (a(theta 1) a (theta 2) -- [a (thetaD) is called an array manifold (array manifold), and the column vector a(theta) =(a1 thetaa2 theta--aM theta) T is the response (complex) of the array antennas to Bearing theta, and is called a mode vector or a steering vector.]) When the linear independence of a (theta) is guaranteed at 0 degree < theta<360 degrees, it is equivalent to the ability of Bearing theta to be found that a (theta) can be found. Vector F=(F1 F2 -- FD) T It is the

input signal (complex) of D individual. Vector N=(N1 N2 -- NM) T It is the internal noise (henceforth a noise) of M receivers, and assumes [having not correlated mutually and]. Moreover, since it is easy, all of M noise power are sigma2 equally. It carries out and it is assumed by prior measurement etc. that it is known. Namely, [0006]

$$|\overline{N_1}|^2 = |\overline{N_2}|^2 = \cdots\cdots |\overline{N_M}|^2 = \sigma^2 \text{ (既知)}$$

[0007] ** -- although assumed -- this assumption -- generality -- ****** -- it is not a thing. T expresses the transpose of a matrix and a bar expresses the average here. Next, it is [0008] when the covariance matrix (covariance matrix) of (1) type is set to S.

$$S = \overline{XX^H} = A\overline{FF^H}A^H + \overline{NN^H}$$

[0009] A next door, [0010]

$$S = APA^H + \sigma^2 I \qquad \text{--- (2)}$$

[0011] It is expressed. However, H expressed complex-conjugate transposition and assumes [having not correlated and] the input signal and the noise. Moreover, [0012]

$$P = \overline{FF^H} \qquad \text{--- (3)}$$

[0013] It is called a ****** matrix of correlation or the power matrix (power matrix) of an input signal, and becomes a positive-definite value (positive delinite). I is a unit matrix. Since the rank (rank: rank) of the signal matrix of correlation P will serve as D supposing it supposes that D<M, i.e., the number of input signals, is smaller than several M of an array component here and there is no perfect correlation between input signals, it is APAH. A rank also serves as D. It is [0014] when the characteristic value of M pieces of a covariance matrix S is arranged in order of magnitude at this time.

$$\underbrace{\lambda_1, \lambda_2, \cdots\cdots, \lambda_D}_{\text{入力信号の固有値}}, \underbrace{\lambda_{D+1}, \cdots\cdots, \lambda_M}_{\text{雑音の固有値}}$$

---- (4)

[0015] It becomes and is [0016] further.

$$\lambda_{D+1} = \lambda_{D+2} = \cdots = \lambda_M = \sigma^2 \text{ (最小固有値)}$$

--- (5)

[0017] It becomes. Moreover, characteristic vector E corresponding to such characteristic value is [0018].

$$\left.\begin{aligned} E &= (E_S E_N) \\ E_S &= (E_1 E_2 \cdots\cdots E_D) \\ E_N &= (E_{D+1} E_{D+2} \cdots\cdots E_M) \end{aligned}\right\} \quad (6)$$

[0019] It becomes. However, ES lambda 1 - lambdaD The signal subspace of the measuring line type space E is stretched by the corresponding signal-space characteristic vector, and it is EN. lambdaD+1 - lambdaM The noise subspace of E is stretched by the corresponding noise space characteristic vector. Moreover, ES EN It is in orthogonality relation (EN is the orthocomplement of ES).

[0020]

$$E = E_S \dotplus E_N \quad (\dotplus : \text{直和(direct sum)})$$

--- (7)

[0021] It becomes. This is based on the following reasons. Characteristic vector E SE=lambdaE (8)
It ****** and is especially lambda=sigma 2. At the time SEN =sigma2 EN (9)
It is [0022] when a next door and (2) types are substituted for (9) types.

$$(APA^H + \sigma^2 I) E_N = \sigma^2 E_N$$

$$APA^H E_N = 0$$

$$E_N{}^H APA^H E_N = (A^H E_N)^H P (A^H E_N) = 0 \quad \text{--- (10)}$$

[0023] It becomes. (10) Set at a ceremony and the ** matrix A is a full rank (that all bearings of an incoming wave differ, and equivalence).
** Matrix P (positive-definite value) is a full rank (that there is no perfect correlation between input signals, and equivalence).
In the ** case AH EN =0 (11)
Since it is an array manifold (set of the mode vector of the incoming wave of D individual), a next door and Matrix A are the signal subspace ES. It belongs and is ES. EN It intersects perpendicularly. Therefore, characteristic vector [as opposed to / decompose the characteristic value of a covariance matrix S and / the minimum characteristic value] EN It asks and they are the mode vectors a (theta) and EN. The inverse number of the square of Euclidean distance
[0024]

$$\frac{1}{a^H(\theta) E_N E_N{}^H a(\theta)} \quad \text{--- (12)}$$

[0025] If consider a performance index, and take out the mode vector a of a certain bearing theta (theta), theta is changed over 0 degree - 360 degrees out of all 0<theta<360-degree array manifolds, (12) types are calculated and a peak (peak) is searched for, bearing of the interference wave of D individual can be decomposed and presumed. In addition, in displaying, when it takes the logarithm of (12) types, since it is convenient, it is [0026].

$$10 \log_{10} \left(\frac{1}{a^H(\theta) E_N E_N{}^H a(\theta)} \right)$$

[0027] ****** may be performed.
[0028] The configuration of the conventional example explained above is shown in drawing 2 . The signal received in two or more array antennas 1 (11 -1M) and receive sections (21 -2M) by drawing 2 is changed into the digital data of real part and imaginary part with A/D converter 3 (31-3M), and is stored in the receiving data memory 4. The received data read from memory 4 are sent to covariance-matrix count / memory circuit 5, and a covariance matrix S is called for. The characteristic value / characteristic vector count / memory circuit 12 which receives this process (4), (5), (6), and (7) types, and asks for a characteristic vector. This output is sent to the circuit 14 which asks for (12) evaluation-of-expression function, and the performance index for bearing measurement is searched for.
[0029]
[Problem(s) to be Solved by the Invention] MUSIC by the reference 1 mentioned above -- there are the following troubles in law. That is, when it includes the coherent signal (or multi-pass signal) which has perfect correlation in the part between the input signals of D individual, the rank of the signal matrix of correlation P becomes smaller than D, and it becomes impossible to

decompose the characteristic value of the input signal of a covariance matrix S into D individual therefore, and it is the signal-space characteristic vector ES. And ES Noise space characteristic vector EN which has the relation of orthocomplement Asking correctly becomes impossible. Even if (11) types stop realizing and calculate (12) types, it becomes impossible therefore, to presume bearing of an incoming wave at this time. As an approach improved so that bearing of an interference wave including such a coherent signal might be decomposed and bearing could be presumed correctly, there is an approach of "tooth-space SHARU smoothing (Spatial Smoothing)." this approach -- MUSIC of drawing 2 -- in the example of law, when array antennas 1 are made into a regular-intervals linear array, application in the case where a coherent signal is included is enabled. "**** Tie-Jum shan and Mazi Wax, AND Thomas Kajlath and On Spatial Smoothing for Direction of-Arrival Estimation of Coherent Signals" () [IEEE TRANSACTION] ON Acastcs, SPEECH, AND SIGNAL PROCESING, VOL.ASSP-33, NO.4, pp 806-811, AUGUST It depends for calling it 1985 and the following reference 2. However, there is a trouble that the number of incoming waves inapplicable to the array component and array array of (1) arbitration in which (2) presumption is possible becomes M/2 (MUSIC about [in the case of law] 1/2) or less in SUPESHARU smoothing.

[0030]

[Means for Solving the Problem] This invention is for decomposing and presuming bearing of a total input signal between input signals also in the case of an interference wave including a coherent signal with perfect correlation, it can apply to the array component and array array of arbitration, and the number of the maximum presumption incoming waves maintains an individual (M-1) (MUSIC law and the same number). Even if the coherent signal was intermingled in order to take the process which decomposes the characteristic value of a covariance matrix S by the MUSIC method, and asks for a characteristic vector, it diagonalized S when the signal matrix of correlation P stopped having been a full rank, and it calculated characteristic value, since it was no longer what decomposed the input signal correctly, it became presumed impossible.

[0031] Even when it does not take but a coherent signal is intermingled with the following means, the process which this invention asks for characteristic value and a characteristic vector decomposes the arrival bearing of total ******, and makes presumption possible. In this invention, in order to solve a problem, the following wait vectors W are introduced. W=(W1 W2 -- WM) T (13)

The multiplication of the ********** value of W is carried out to an input signal X. If a multiplication result is set to Y Y=WH X (14)

It becomes. Furthermore, it is the square average of Y [0032]

$\overline{|Y|^2}$

[0033] It is [0034] when it carries out.

$$\overline{|Y|^2} = \overline{YY^*} = \overline{W^H X X^H W} = W^H \overline{XX^H} W = W^H S W$$

(*は複素共役を表わす) ---(15)

[0035] It becomes. It is [0036] when (2) types are substituted for (15) types here.

$$|Y|^2 = W^H(APA^H + \sigma^2 I)W$$

$$= W^H APA^H W + \sigma^2 \|W\|^2$$

$$= (A^H W)^H P (A^H W) + \sigma^2 \|W\|^2$$

ただし ||W|| は Wのノルム(norm)を表わす。

----(16)

[0037] It becomes. Moreover, if (16) types are transformed, the following performance indices can be acquired.

[0038]

$$|Y|^2 - \sigma^2\|W\|^2 = (A^HW)^HP(A^HW) \quad \cdots\cdots (17)$$

[0039] (17) From a formula AH W=0 (18)
the wait vector W with which like fills [****** primary] a formula -- MUSIC from contrast of (11) types -- noise space characteristic vector EN to the minimum characteristic value in law It turns out that it is equivalent. It is EN to calculate the characteristic value of a covariance matrix S in this invention without carrying out. Performance index which solves the simultaneous equation of (18) equations, searches for the equivalent wait vector W directly, and is calculated from a covariance matrix S and the wait vector W ((15) equations and (17) equations)

[0040]

$$|Y|^2 - \sigma^2\|W\|^2 = W^HSW - \sigma^2\|W\|^2 \quad \cdots\cdots (19)$$

[0041] It is characterized by using and presuming arrival bearing. Therefore, since this invention does not need the full rank conditions of the signal matrix of correlation P, even when a coherent signal is intermingled, it can decompose and presume the arrival bearing of a total input signal. Moreover, it sets at (19) ceremony and the internal-noise power of a receiver is [0042] in a sigma12, sigma22 --, and sigmaM2 and barrack case.

$$\sigma^2\|W\|^2$$

[0043] It is [0044] to instead of.

$$(\sigma_1^2|W_1|^2 + \sigma_2^2|W_2|^2 + \cdots\cdots + \sigma_M^2|W_M|^2)$$

[0045] What is necessary is just to use.

[0046]

[Function] Although the wait vector W searched for from the simultaneous equation of (18) equations in this invention is determined only from the element of the array manifold (theta) A a, i.e., a mode vector, since the arrival fraction D is strange, the number of incoming waves needs to ask for W about each case to 1- (M-1). Namely, [0047]

$$\left.\begin{array}{l} \text{到来波数が1の場合}：\ W(\theta_1) \\ \text{到来波数が2の場合}：\ W(\theta_1,\theta_2) \\ \quad\vdots \qquad\qquad\qquad \vdots \\ \text{到来波数が(M-1)の場合}：\ W(\theta_1,\theta_2,\cdots\theta_{M-1}) \\ \qquad (0^\circ \le \theta_1,\theta_2,\cdots,\theta_{M-1} < 360^\circ) \end{array}\right\} (20)$$

[0048] Moreover, the reason the number of the maximum presumption incoming waves is set to (M-1) is the array manifold AH. It is because the maximum of D for having a solution effective [the matrix AH W of (18) types] except becoming Dx1 matrix and all the elements of W being set to 0 (zero) since a DxM matrix and the wait vector W are Mx1 matrices is set to (M-1). (20) Since wait ** KUTORU W is the combination (combination) of arrival bearing as shown in a formula, bearing of a total input signal will be presumed to coincidence. For example, when D is (M-1), it is theta 1, theta 2, --thetaM-1. Only when combination is presumed correctly, with regards to the rank of the signal matrix of correlation P, there is nothing and a performance-index (19) type can be made into minimum [0(zero)]. On the contrary, when arrival bearing is able to be investigated in combination [it is called a combination search (combination search) below] and (19) evaluation-of-expression function is able to be made into min, it means that the arrival

bearing (put together) of a total input signal was called for.
[0049]
[Example] Next, this invention is explained to **** with reference to a drawing. Drawing 1 is the block diagram showing the configuration of the example of this invention. In drawing 1 , array antennas 1, a receive section 2, the A/D-conversion section 3 that has the function which decomposes an input signal into real part and imaginary part, the receiving data memory 4, the S (covariance matrix) count / memory circuit 5, and the array manifold data memory 6 are provided, and this is as common as the conventional example. That is, the input signal to array antennas 1 to the process of this invention and the MUSIC method which asks for a covariance matrix S using configuration blocks 2, 3, 4, and 5 is the same. However, unlike the MUSIC method, this invention is [0050] by the wait vector W which is the output of a covariance matrix S, and the wait vector selector / search control circuit 9 which count of the characteristic value decomposition / characteristic vector by the characteristic value / characteristic vector count / memory circuit of drawing 2 is not performed, but is an output of 5 to (15) type count circuit 10.

$$|\overline{Y}|^2 = W^H S W \qquad \text{--- (15)}$$

[0051] It calculates. boil a circuit 9 memory 6 -- [0052] which is calculated by the wait calculus-of-vectors circuit 7, and is stored in the wait vector memory 8 from all the stored 0 degree - 360 degrees array manifold data

$$W(\theta_1),\ W(\theta_1,\theta_2),\cdots,W(\theta_1,\theta_2,\cdots,\theta_{M-1})$$

[0053] Drawing and a combination search are performed for a ** wait vector. Next, the output of the count circuit 10 is [0054].

$$|\,|\overline{Y}|^2-\sigma^2\|W\|^2\,| \;/\; 10\log_{10}\left(\frac{1}{|\,|\overline{Y}|^2-\sigma^2\|W\|^2\,|}\right)$$

[0055] It is sent to count / memory circuit 11, and is [0056].

$$|\,|\overline{Y}|^2-\sigma^2\|W\|^2\,|$$

(絶対値をとるのは土の符号は評価上不要のため)

[0057] And it is [0058] for a display.

$$10\log_{10}\left(\frac{1}{|\,|\overline{Y}|^2-\sigma^2\|W\|^2\,|}\right)$$

[0059] It calculates and stores. It is [0060] by combination search.

$$10\log_{10}\left(\frac{1}{|\overline{Y}|^2-\sigma^2\|W\|^2}\right)$$

[0061] theta 1 used as a ** peak, theta 2, --thetaD It becomes the combination of the arrival bearing for which combination asks, and the arrival bearing of the interference wave on which a coherent signal is intermingled can be decomposed and presumed. moreover, the array component and array array of arbitration -- applicable -- the number of the maximum presumption incoming waves -- MUSIC -- law -- being the same (M-1) -- it becomes.
[0062]
[Effect of the Invention] Also in the case of an interference wave including the coherent signal which has perfect correlation in a feeling of an incoming wave, according to this invention, bearing of them can be decomposed and presumed as explained above. Moreover, in the array component of arbitration, and an array array, it can apply, and the bearing measuring device with which the number of incoming waves which can be presumed turns into (the array element

number M-1) can be realized.

[Translation done.]

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H4L LRPLS L209

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INT CL[7] G01S 5/14 , H04M 3/42 11/08 , H04Q 7/38
Online: WPI,EPODOC, PAJ, IEEE and selected internet sites

(54) Abstract Title
Locating system

(57) A locating system for a mobile station of a cellular communications network which uses a locating system computer 140 that compares a normal network measurement report (NMR) 110 (which contains results regarding signal strength from and identities of the serving cell and neighbouring cells) with a network profile database 142. Based on the comparison the latitude and longitude (location) of a mobile station can be computed. The NMR may be validated and synchronised prior to supplying it to the computer. The locating system may comprise a network statistics database 144 used to identify seven adjacent cells and to apply network handover statistics to calculate vicinity information of each identified cell. The system may then further select the three nearest cells and provide the location of the mobile station as the centroid of these three cells. In an alternate embodiment the NMR is compared with a vector quantization codebook 146 and the location is provided based on the matching cell ID only. An alternative embodiment relates to selecting one of a plurality of location determining algorithms in response to the identity of the cell serving the mobile station.

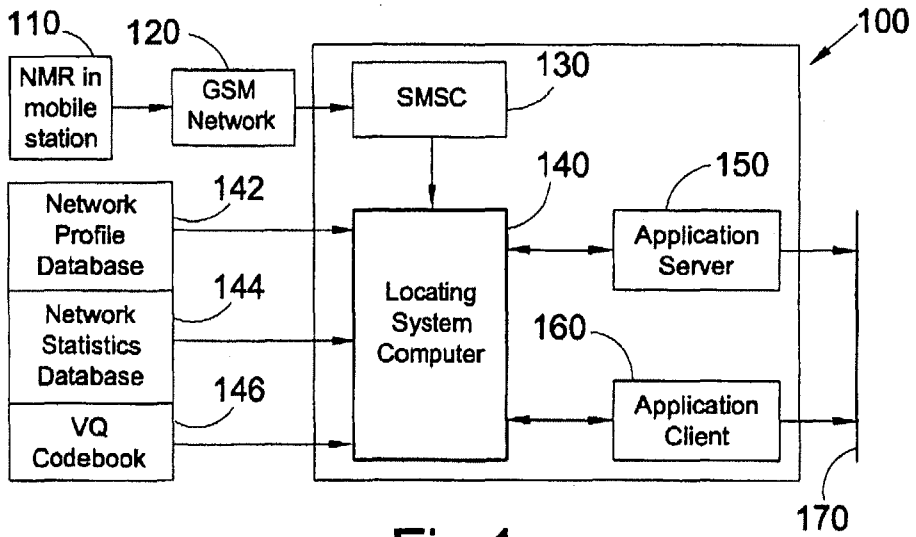


Fig.1

GB 2 364 617 A

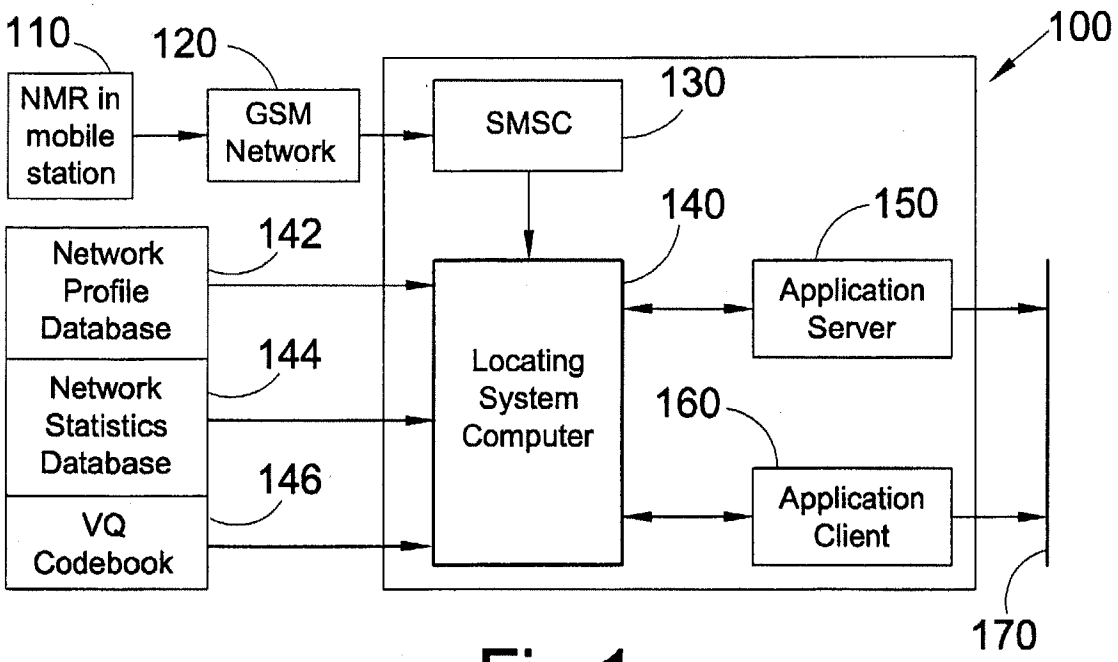

110
120
100
NMR in mobile station
GSM Network
SMSC
130
140
150
142
Network Profile Database
144
Network Statistics Database
146
VQ Codebook
Locating System Computer
Application Server
160
Application Client
170

Fig.1

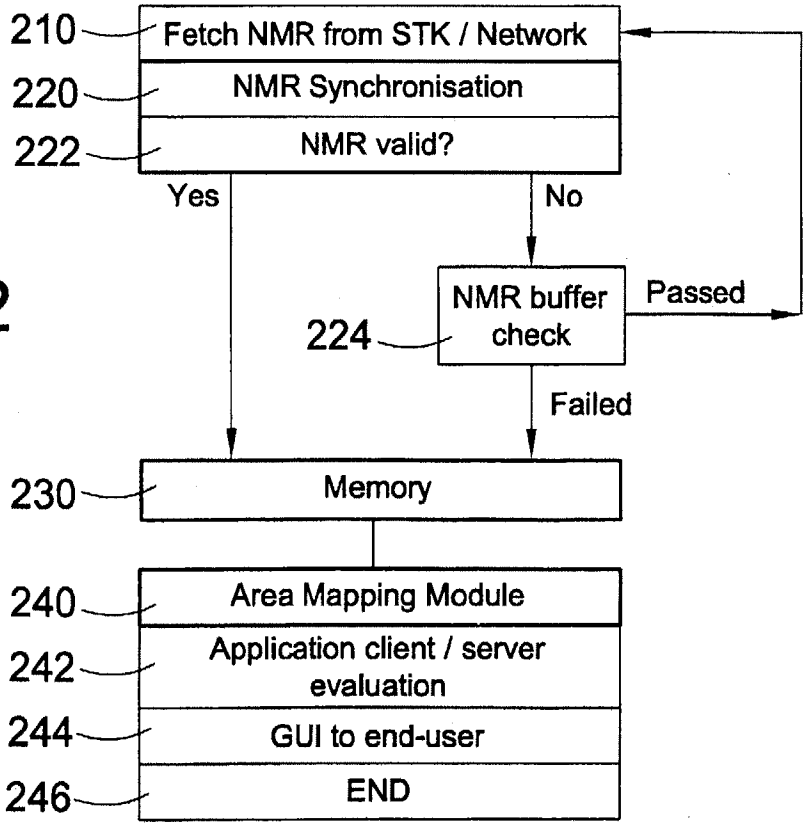

210
Fetch NMR from STK / Network
220
NMR Synchronisation
222
NMR valid?
Yes
No
NMR buffer check
224
Passed
Failed
230
Memory
240
Area Mapping Module
242
Application client / server evaluation
244
GUI to end-user
246
END

Fig.2

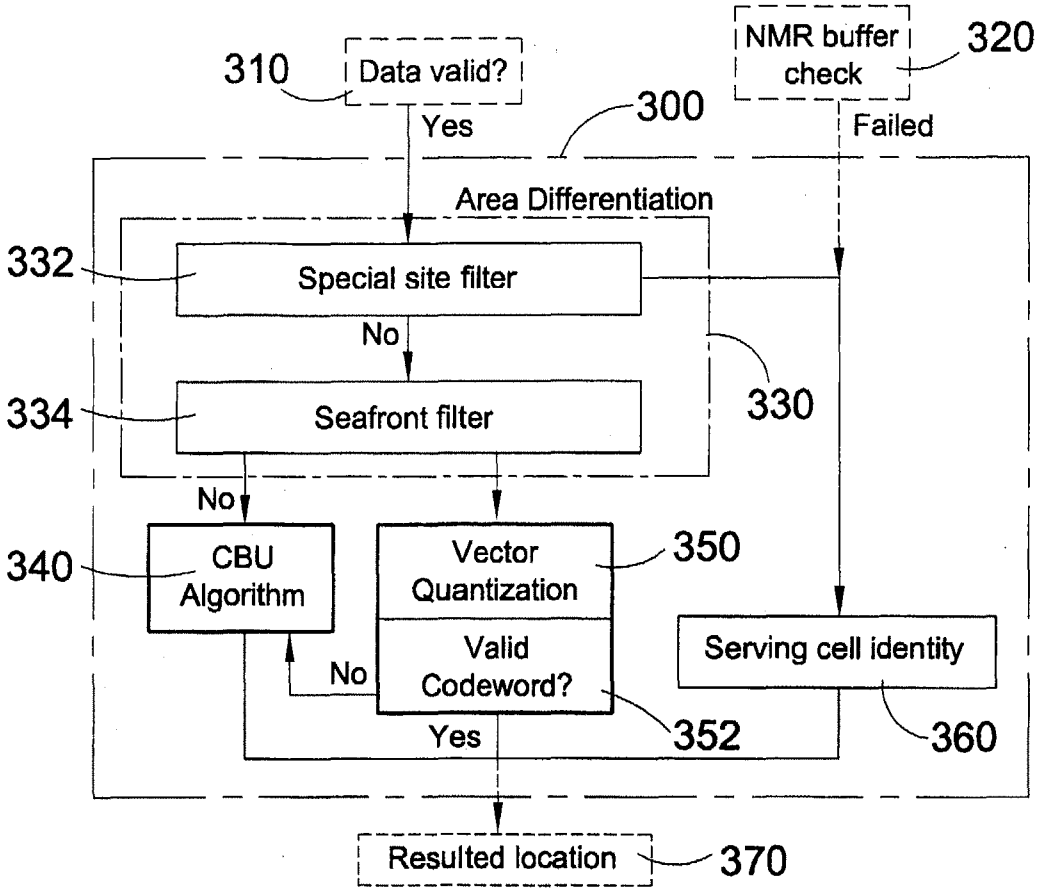

310
Data valid?
NMR buffer check
320
Yes
300
Failed
Area Differentiation
332
Special site filter
No
330
334
Seafront filter
No
340
CBU Algorithm
Vector Quantization
350
Valid Codeword?
No
Yes
352
Serving cell identity
360
Resulted location
370

Fig.3

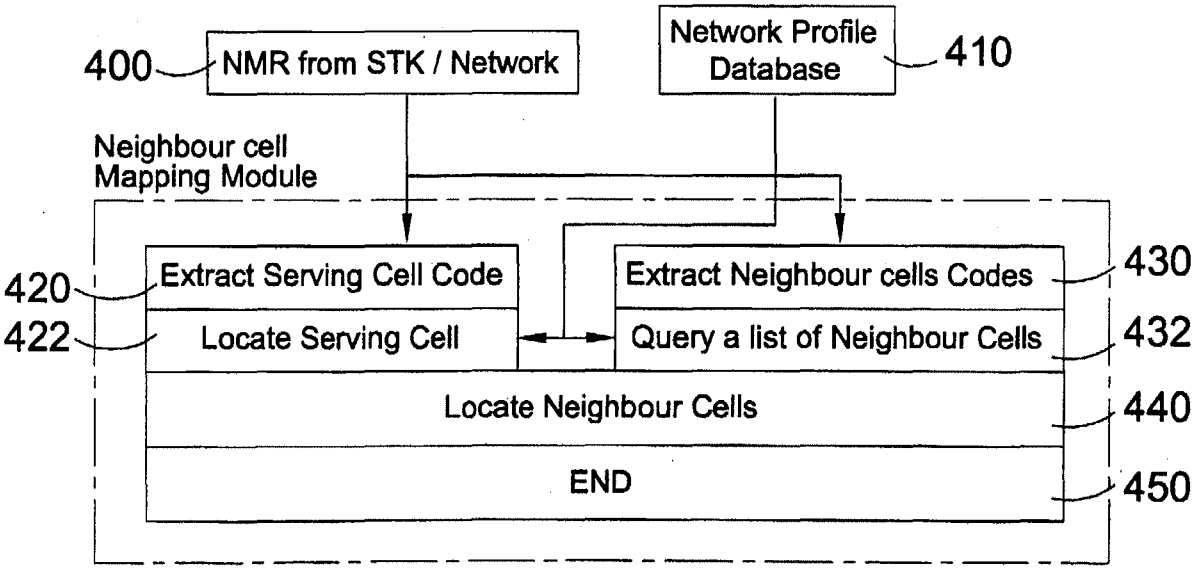

400
NMR from STK / Network
Network Profile Database
410
Neighbour cell Mapping Module
420
Extract Serving Cell Code
Extract Neighbour cells Codes
430
422
Locate Serving Cell
Query a list of Neighbour Cells
432
Locate Neighbour Cells
440
END
450

Fig.4

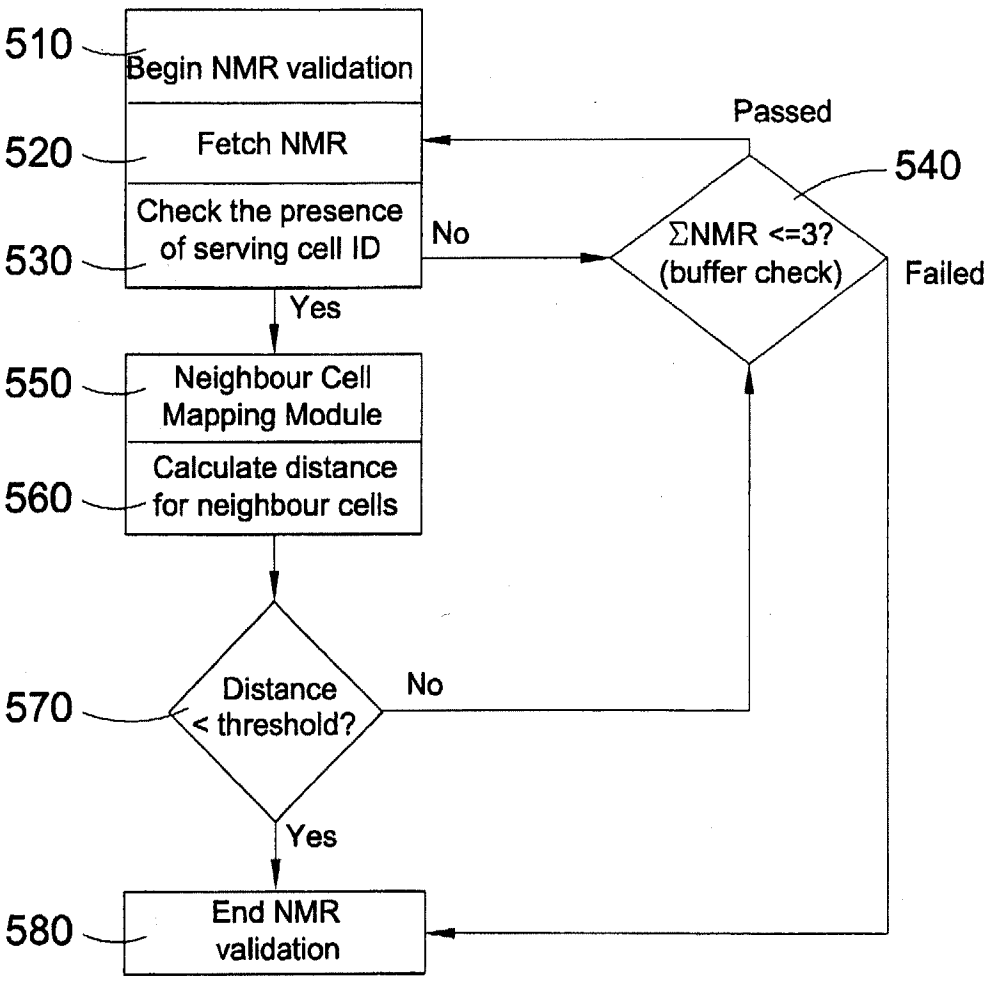

510
Begin NMR validation
520
Fetch NMR
530
Check the presence of serving cell ID
No
Yes
Passed
540
ΣNMR <=3? (buffer check)
Failed
550
Neighbour Cell Mapping Module
560
Calculate distance for neighbour cells
570
Distance < threshold?
No
Yes
580
End NMR validation

Fig.5

LOCATING SYSTEM

This invention relates to locating systems for mobile communication units.

A "Second Generation" of mobile communications industry has come to a stage where voice only services may not satisfy subscribers' needs and ensure further growth for mobile network operators. For Global System for Mobile Communications (GSM), in particular, the short message services and Unstructured Supplementary Service Data (USSD) have already provided a platform for developing information services applications.

The Unstructured Supplementary Service Data (USSD) procedure is used to trigger the ISE service because it provides a more simple and easy to use user interface platform for subscribers. USSD enables a mobile user to invoke and control supplementary services, that are :

- not supported by the mobile user's mobile equipment, i.e. the needed functionality (e.g. signalling) is not implemented in the mobile.
- non-GSM supplementary services for which no functional signalling is defined.

ETSI/GSM 02.90 & ETSI/GSM 02.30 have defined the rules for constructing a USSD procedure. The mobile station (MS) shall support the MMI procedure specified as:

Activation	: *SC*SI#
Deactivation	: #SC*SI#
Interrogation	: *#SC*SI#
Registration	: *SC*SI# and **SC*SI#
Erasure	: ##SC*SI#

The structure consists of the following parts :

- Service Code, SC (2 or 3 digits)
- Supplementary Information, SI (variable length)

The procedure always starts with *, #, **, ## or *# and ends with #. Each parameter within the procedure is separated by *.

A unique SC is used to define each Supplementary Service. The SI can be comprised of say a stock code or a PIN code. When a particular request does not require any SI, "*SI" is not entered. When more than one piece of supplementary information is required, the SIs can be entered consecutively, e.g. **SC*SIA*SIB#SEND.

The use of SIs, SIA, SIB and SIC, in a particular procedure is optional. *SI# shall be entered in any of the following formats:

- *SIA#
- *SIA*SIB#

- *SIA*SIB*SIC#
- *SIA**SIC#
- **SIB#
- ***SIC# etc...

The advent of SIM Application Toolkit (STK) gives even much flexibility to program the SIM card for more sophisticated applications. Geographical locations applications of mobile handsets (or units) have utility for fleet management, location-based services and on-the-spot advertisements. Many such proposals are available in the market, however their order of accuracy and requirements in network architecture, mobile handsets and SIM cards are not generally not compatible.

The most commonly known locating or positioning system is the Global Positioning System (GPS). A constellation of 24 NAVSTAR (GPS) satellites circles the Earth every 12 hours emitting radio signals identifying their positions. GPS uses spread spectrum that enables use of very low received signal levels. The claimed accuracy can be up to 100 metres. It can be further enhanced to 5-10 metres by using the Differential GPS (DGPS). However, the high cost and non-availability of a GPS inside GSM mobile handsets make this unsuitable. Moreover, in some dense urban areas there may be a problem in receiving signals because of there being too

few satellite signals available.

There are several types of GSM-based locating or positioning techniques, namely, cell identity (cell ID), time advance (TA), time of arrival (TOA), enhanced observed time difference (E-OTD), and angle of arrival (AOA).

Using cell identity (cell ID) as a reference location is a simple and straightforward solution, which involves no software or hardware changes at all. However, its accuracy is heavily dependent on the network topology and site-to-site distance that could range from 100 metres to 30 kilometres. Time advance (TA) might carry more information in a distance sense. But, it requires some software changes in the GSM network and it is only good for applications requiring low accuracy, say up to one kilometre. Differences between the times of arrival (TOA) of signal from a handset at three Base Transceiver Station (BTS) can be used to calculate the location of the mobile handset. Although accuracy may be 125 metres or below, required expensive network infrastructure includes Location Measurement Units (LMU) and a highly accurate clock, GPS or atomic clock, to synchronize the different Base Station Controllers (BSC) involved.

The hardware requirement for Angle of Arrival (AOA) is

similar to that of TOA. AOA uses a beam forming technology, which makes use of the sophisticated and expensive antenna arrays to determine the directions of signal arrival. However, accuracy is severely degraded if there is no clear line of sight. The use of enhanced observed time difference (E-OTD) needs additional Location Measurement Units (LMU) for the Base Transceiver Station (BTS) and modifications in the mobile handsets. Although the accuracy may be up to 125 metres or better, expensive network infrastructure is required.

It is an object of the invention to overcome or at least reduce these problems.

According to one aspect of the invention there is provided a locating system for a mobile station which comprises a locating system computer, the system supplying a normal network measurement report (NMR) for the mobile station to the computer, comparing the NMR with a network profile database, and computing resulted latitude and longitude for the mobile station where a suitable comparison is found.

Steps of validating and synchronising the NMR prior to supplying the NMR to the computer may be included.

The locating may be carried out using a network statistics database for comparison in the computer, the database is derived using an algorithm to find the cell identity (ID) of seven most important adjacent cells, as measured by the mobile station, applying network handover statistics to calculate vicinity information of each cell, selecting the three nearest cells according to the calculation, and providing the resulted latitude and longitude as a centroid of the latitudes and longitudes of the three cells.

The locating system may include comparing the NMR with a vector quantization (VQ) code book that contains codeword locations for cells located at special regions of the network, providing the resulted latitude or longitude based on any matching cell ID only.

According to another aspect of the invention there is provided a method for approximately locating a mobile station (MS) in a cellular mobile communications system, comprising the steps of identifying three cells in the vicinity of the mobile station, each said cell having a cell location; and determining an approximate position of the mobile station using the locations of the three cells.

The approximate position of the mobile station may be determined by calculating a centroid of a triangle formed by said three cells.

The said three cells may be selected from a plurality of candidate cells neighbouring a serving cell for the mobile station.

A said neighbouring cell may be determined using at least one system parameter relating to the mobile station selected from a group including an ID of the serving cell, an ID of a base station in communication with the mobile station, and a candidate neighbouring cell frequency channel.

A said neighbouring cell may be determined using a database comprising cell mapping data defining physical cell locations.

The said three cells may be selected from six candidate neighbouring cells.

The method may comprise measuring, for each neighbouring cell, a signal strength for a signal transmitted between the mobile station and the neighbouring cell; and selecting said three cells using the measured signal strengths and a database of cell-to-neighbour-cell handover statistics.

The method may include calculating, for each neighbouring cell, a value representing a probability of a successful handover to that cell, and wherein said selecting is responsive to the calculated probability.

The said plurality of candidate neighbouring cells may include a cell identified as a handover target cell in a or the said database of cell-to-neighbour-cell handover statistics.

The approximate position of the mobile station may be determined using only the serving cell identity rather than by identifying three cells in the vicinity of the mobile station.

According to a further aspect of the invention there is provided a method for approximately locating a mobile station (MS) in a cellular mobile communications system, comprising the steps of using a compressed system parameter report to look up an approximate mobile station location in a vector quantization codebook.

According to a yet further aspect of the invention there is provided a method for approximately locating a mobile station (MS) in a cellular mobile communications system, comprising selecting one of a plurality of

location - determining algorithms responsive to the identity of a cell serving the mobile station.

Embodiments of the invention make use of screening filters to partition the locating system into three entities, which enables the use of area differentiation upon the measurement reports. A knowledge-based heuristic algorithm can be used to enhance the accuracy of locating system compared to only using cell identity. Also, a codebook using vector quantization can be used to model radio characteristics of some special or specific, such as sea-front regions, regions in the GSM network, which can be applied via compressed measurement reports.

Locating systems for mobile telephones according to the invention will now be described by way of example with reference to the accompanying drawings in which :-

Figure 1 shows schematically an overall architecture for the locating system and inputs for the system;

Figure 2 is a flow diagram of the operation from retrieval of Network Measurement Reports (NMR) to the output of calculated location-based information;

Figure 3 shows a functional flow diagram for the operation of calculating a location from valid or

partially valid data within the locating system;

Figure 4 shows a neighbour cell mapping module for decoding the NMR for neighbour cell information, which is applicable to processes in the locating system; and

Figure 5 is a flow chart for NMR validation and synchronization processes.

Referring to the drawings, in Figure 1 a normal network measurement report (NMR), or other GSM features, is collected from a mobile telephone or station 110 using an SIM Application Toolkit (STK) in the mobile station 110. A normal report has been defined in ETSI/GSM 04.08 (9.1.20) and refers to the measurement data collected from both the mobile station and the BTS (Base Transceiver Station). It will be sent from the BTS to the BSC (Base Station Controller).

The entire information in the NMR is not used, only the entity called 'Measurement Results'. The content of the 'Measurement Result' is well defined in ETSI/GSM 04.08 (10.5.2.11). The 'Measurement Result' is recorded by the mobile station and will be sent to the BTS for evaluating handovers. The following information inside the 'measurement result' is used :

- serving cell identity
- serving cell signal strength as received by mobile

station

- serving cell broadcast channel / frequency (BCCHNO) and base station identity code (BSIC)
- Six pairs of neighbouring cell broadcast channels / frequencies (BCCHNO) and base station identity code (BSIC)
- SIX neighbouring cells' signal strength as received by the mobile station

The locating process can be either triggered by a subscriber or by the locating system in a central controller of the network. The NMR is transmitted through a GSM network 120 over a Short Message Service (SMS) bearer, or other suitable bearer such as General Packet Radio Service (GPRS) 130. This is applicable to a single 900-band GSM network, a single 1800-band GSM network and a 900/1800 dual-band GSM network 120. A locating system central location system computer 140 collects the NMR as its primary input.

Two databases provide statistics and network background data to the computer 140 as secondary inputs. Network statistics database 144 provides cell-to-neighbour cells handover statistics. A network profile database 142 provides a map of the communications network with pre-defined areas, site locations, including latitude and longitude, the network base station BSC parameters of cell names, cell global identity (CGI), broadcast

channel (BCCH) and base station "colour code" (BSIC).

The generation and storage of the mapping data can be provided in two ways. The first way is a two-stage searching algorithm. It involves generating and storing mapping data as follows:

1. define the entire city / country map into a certain number of meaningful areas.

2. mark the areas on the digitized map using a geographical software tool called MapInfo(RTM).

3. export a table from MapInfo to extract the latitude-longitude pairs for different areas.

4. as this provides the area name, latitude and longitude information in one table, apply any location with latitude and longitude to determine the belonging area by searching through this table.

The searching speed may be too slow for a large city. If so:

To increase speed, generate a number of grid tables defining corners of the grid squares at different resolutions. An entire city is divided into 100 squares (10x10) using a relatively low resolution. The latitude

and longitude of all corners of those 100 squares are stored into a table (T_0). Generate another 100 tables (T_1 - T_{100}) similar to the first table but with a relatively higher resolution and also containing the area name for each point. Then locate the mobile station in T_0 by given latitude and longitude. Identify the square, go to the specified table out of T_1 - T_{100} to look for the area name.

The second way uses the steps 1 and 2 above. Thereafter MapInfo's function call is used to extract the area name. This function call can be implemented using Visual Basics (RTM) or Visual C++.

A Vector Quantization (VQ) codebook 146 contains the up-to-date compressed NMRs as codewords for location look-ups in specified sea-front regions or other special regions. This is tertiary input for the computer 140.

Added components of the system include applications server(s) 150 and application client(s) 160. Their specifications are open and such components are not part of the present invention but represent building blocks for future development. For example, an application server could be a vehicle tracking system for fleet management. While for individual usage, an application client could become a location-based

shopping guide. However, both client and server applications can share the same protocol towards locating system that consists of resulted or calculated locations with latitude and longitude, time-stamps and the matched areas. Some applications may require connections from the application server to another database server or data warehouse 170 for example, which could make the locating system a 3-tier or even an n-tier system.

In Figure 2, the flow diagram of the operation between retrieval of NMR to an output of calculated location-based information for the location system comprises the following steps:

STEP 210: Begin fetching NMR (or other GSM features) from the STK in the mobile station 110 via the GSM network 120 and Short Message Service Center (SMSC) 130.

STEP 220: The NMR is decoded inside the computer 140 and a validation index is calculated for justification.

STEP 222: The validation index may be checked against an experimental value, or applying a synchronisation step (see below). If the NMR is valid, it is fed into a memory 300 as its input.

STEP 224: If NMR is not valid, a buffer is checked for additional NMR. If such NMR is available, the process starts again STEP 210. If not, the NMR is deemed to be

invalid, and the most reliable NMR will be used by the memory 300.

STEP 230: The memory 300 uses the NMR to determine a resulted location, latitude and longitude of the mobile station.

STEP 240: An area-mapping module computes a matched area from a map using the resulted latitude and longitude 370.

STEP 242: The mobile station evaluates the results from the computer 300.

STEP 244: The results are displayed on a graphical user interface (GUI). The display can be varied from text-based only, bundled with information from another database or be a map display with flashing and zoning features.

STEP 246: Ending the procedure of the Positioning System triggers a closed session for both the STK 110 and SMSC 130 data channel connection.

Figure 2 includes step 220 that comprises an NMR synchronization step. A full NMR comprises the serving cell information and the neighbour cell information. The serving cell information is trusted whenever the serving ce'll identity (serving cell ID) is present. However, the neighbour cell information may not be synchronized with the serving cell information. The current neighbour cell information may belong to the some other previous NMR, having a different serving

cell ID from that in the current NMR in a worst case. Possible reasons for a synchronization problem includes there being different designs or performances in updating NMR for different mobile handsets, the NMR being only partially updated during an idle mode, or some parts of the NMR not being updated after a recent handover.

For dealing with this situation, the NMR validation step shown in Figure 5 is as follows :-

STEP 510: Begin the NMR validation step or process.

STEP 520: Start fetching an NMR from a buffer.

STEP 530: Check whether the NMR contains the serving cell ID information.

STEP 540: If there is no serving cell ID in the NMR, the NMR should be discarded. The buffer size for the number of different NMR data is three. If there is one or more NMR left in the buffer, the NMR is fetched and the procedure starts again from STEP 520. If none of the NMR's have a serving cell ID, the perceived most reliable NMR among the three NMRs in the buffer is used.

STEP 550: A Neighbour Cell Mapping Module (as explained below with reference to Figure 4) is used to decode neighbour cell messages and determine the corresponding neighbour cells.

STEP 560: The distances from the serving cell to all

neighbour cells are calculated, the longest distance or the average distance is used as a synchronizing index.

STEP 570: If the distance (synchronizing index) exceeds a pre-set threshold (an empirical or recorded data value, that may be changed on the fly) the system will try another NMR left behind in the buffer, if any.

STEP 580: End the NMR validation and synchronization process.

The location system makes use of a neighbour cell mapping module. Figure 4 is a flow diagram of use of the neighbour cell mapping module for decoding the NMR for deducing neighbour cell identities, and comprises the following steps:

STEP 400: Take NMR (or other GSM features) from the SIM Application Toolkit (STK).

STEP 410: Take data from a network profile database **142** that serve as look-ups for cell identities and site locations.

STEP 420: Input serving cell codes. This is a 16-bit word and should be less than 65535, it can be extracted directly from the NMR and is included in normal GSM specifications.

STEP 422: Check serving cell location by longitude and latitude from the network profile database 142.

STEP 430: The codes extracted for neighbour cells are the broadcast channel (BCCH) and the base station

colour code (BSIC).

STEP 432: Each particular (BCCH, BSIC) combination is a one-to-many mapping function to the cell identities in the network profile database 142. There may be a number of identical BCCH and BSIC found. This is because each is reused throughout any GSM network; identical combinations will however be widely spaced apart or geographically separated by other cells. In any event, a list of potential neighbour cells may be found after mapping for a six pairs of (BCCH, BSIC) combinations.

STEP 440: In order to locate the correct neighbour cells, distances from all potential neighbour cells 142 to the location of the current serving cell 422 are calculated. By applying a minimum function to the distances of neighbour cells for every (BCCH, BSIC) pair, the identities for the six neighbour cells can easily be deduced, even where identical pairs crop up.

STEP 450: End the neighbour cell mapping module.

In order to calculate the location of a mobile telephone a functional flow diagram for the operation of a calculation from the valid or partially valid data within the computer 300 is now described with reference to Figure 3.

Two filters within an area differentiation module 330 determine the appropriate algorithm to be applied to a current NMR. Normally, details and identification of

special sites and partially valid NMRs 320 are based on the serving cell ID 360 within the NMR data only. In case of the serving cell of the valid NMR 310 lying within a special sea front region, for example, a Vector Quantization 350 will be used. Otherwise, an CBU Algorithm 340 (explained below) will be applied. The resulted location 370 will be passed on to an area mapping module 240.

The two screening filters to partition the positioning system into three entities.

A special site filter 332 looks up a list of the special sites from the network profile database 142 using the serving cell information in the current NMR. The special sites could be a sea front region, a vehicle tunnel or an underground station where the location of the cell is known and geographically well-defined. Whenever matching is found in the list, the location evaluation will be based only on the serving cell ID 360. The definition of special site is invariably an GSM base station serving a very confined area and having very little overlapping with its neighbour cells. By making use only of the ID information of these special sites, an accurate resulted location 370 can be produced in a speedy manner.

The sea front filter 334 makes use of a table from the network profile database 142, which identifies boundaries of all the important sea front regions in terms of longitude and latitude. If the location of the serving cell is bounded by a sea front boundaries, Vector Quantization 350 will be applied as the preferred algorithm. Otherwise, the (default) Algorithm 340 will be applied.

The Algorithm 340 is applied to work out the resulted location 370 from a current valid NMR 310 by looking through a network profile database 142 and network statistics database 144. This algorithm is applied in three phases.

Phase 1 involves the extraction of the cell identities for seven most importantly related cells, which is measured by and based on NMR from the mobile station. The serving cell ID is immediately available from the current valid NMR 310 while the other six neighbour cell mapping module has been described with reference to Figure 4. The received signal strength values are piggy-backed to the cell identities forming a group of SEVEN pairs of NMR cell information F: $(F_{k,1}, F_{k,2})$, where k=0, 1, 2, 3, 4, 5, 6:

$F_{k,1}$ = cell ID received by the mobile station

$F_{k,2}$ = signal strength for the kth cell perceived by the mobile station

Note that k = 0 refers to serving cell information.

Phase 2 requires two input sources, one of them is the NMR cell information F: ($F_{k,1}$, $F_{k,2}$) while another one is the matrix of handover statistics H: ($H_{q,1}$, $H_{q,2}$, $H_{q,3}$), where q=1, 2, …, N.

Suppose that:

N = total number of handover relations in the entire network

M = total number of cells in the entire network

P(r) = total number of handover relations originating from the rth cell, different cells may have different values

then,

$H_{r,1}$ = current originating cell ID

$H_{s,2}$ = current target handover cell ID from cell $H_{r,1}$

$H_{q,3}$ = historical number of successful handovers from cell ($H_{r,1}$) to relation ($H_{s,1}$)

where r=1, 2, …, M and s=1, 2, …, P(i)

The next step is to generate a new matrix U from the matrices F and H by applying the criteria $H_{r,1} = F_{k,1}$,

where k=0, 1, 2, 3, 4, 5, 6. The entities for matrix U are defined as follows:

Matrix U: $(U_{a,1}, U_{a,2}, U_{a,3})$, where a=1, 2, …, A (A is the total number of relations for the 7 cells in F.)

Suppose that:

m(r) = the maximum count of successful handover among all handover relations for a particular originating cell $(H_{r,1})$

then,

$U_{a,1} = H_{r,1} = F_{k,1}$

$U_{a,2} = H_{s,2}$

$U_{a,3} = F_{k,2} * H_{q,3} / m(r)$

Thus, $(U_{a,3})$ is the product of received signal strength and successful handovers being normalized by the maximum count of successful handovers of a particular originating cell. $(U_{a,3})$ is termed as the reference index.

Another matrix V is generated from matrix U in order to sum up all the reference index values for every unique target handover cell $(U_{a,2})$.

Matrix V: $(V_{b,1}, V_{b,2})$, where b=1, 2, …, B (B is the total number of distinct target handover cells in U.)

$V_{b,1}$ = any of the distinct elements in $U_{a,2}$

$V_{b,2} = \Sigma(U_{a,3})$ for all $(U_{a,2} = V_{b,1})$ AND $(V_{c,1} = V_{b,1}$ where

$c \neq b)$

Now matrix F contains the vicinity information for the SEVEN cells in the NMR while matrix V contains the reference index values which can be used to infer the location of the mobile station. To combine matrices F and V, another matrix W is formed.

Matrix W: $(W_{d,1}, W_{d,2})$

For d=0 to 6,

$W_{d,1} = F_{k,1}$

$W_{d,2} = \alpha * F_{k,2}$

where k=0, 1, 2, 3, 4, 5, 6; α=2.5 which is a weighting factor applied to the SEVEN cells in NMR

For d=7, 8, ..., (B+7) (B is the total number of distinct target handover cells in U.)

$W_{d,1} = V_{b,1}$

$W_{d,2} = V_{b,2}$

Another matrix Z is generated from matrix W in order to sum up all the reference index values for every unique cell ($W_{d,1}$) in W.

Matrix Z: ($Z_{e,1}$, $Z_{e,2}$), where e=1, 2, ..., E (E is the total number of distinct target handover cells in W.)

$Z_{e,1}$ = any of the distinct elements in $W_{d,1}$

$Z_{e,2} = \Sigma(W_{d,2})$ for all ($W_{d,1} = Z_{e,1}$) AND ($Z_{f,1} = Z_{e,1}$ where

$f \neq e$)

Thus in an embodiment each pair of the 7 pairs in matrix F may be treated individually. For each $F_{k,1}$ or H_{r-1} there is a list of target handover cells ($H_{s,2}$) which may or may not be included in matrix F; and $H_{r,1} \rightarrow H_{s,2}$ (or $F_{k,1} \rightarrow H_{s,2}$) is a pair of neighbouring relations. For each relation, the chance of successful handover i.e. $H_{q,3}$ / m(r) is multiplied by signal strength corresponds to $F_{k,1}$ which is $F_{k,2}$. Thus the calculation involves handover from one of the seven cells in matrix F. In this embodiment Matrix W includes all 7 cells of Matrix F when d=0 to 6 (i.e. serving cell and 6 neighbouring cells included in the nmr) and also all target handover cells neighbouring those 7 cells (i.e. from d=7 onwards).

Phase 3 searches the THREE cells ($Z_{e,1}$) with maximum values of ($Z_{e,2}$). These cells are used to identify the mobile station's location. The locations of these THREE cells form the vertices of a triangle. The resulted location is the centroid latitude and longitude of the triangle.

The vector quantization 350 makes use of a codebook, which models the radio characteristics of some specific sea-front regions in the GSM network, for future look-up by the compressed measurement reports 310. If the codeword is valid (352), the resulted location 370 is retrieved from the codebook immediately. Otherwise, the default Algorithm 340 is used. Vector quantization can be regarded as a form of pattern recognition where an

input pattern is "approximated" by one of a predetermined set of standard patterns, or in other words, the input pattern is matched with one of a stored set of templates or codewords. A vector quantizer Q of dimension k and size N is a mapping from a vector (or a "point") in k-dimensional Euclidean space, R^k, into a finite set C containing N output or reproduction points, called code vectors or codewords. Thus, $Q:R^k \rightarrow C$, where $C = (y_1, y_2, \cdots, y_N)$ and $y_i \in J \equiv \{1, 2, \cdots, N\}$. The set C is the codebook or the code and has size N, meaning it has N distinct elements, where each is a vector in R^k. The resolution, the code rate, or, simply rate of a vector quantizer is $r=(\log_2 N)/k$, which measures the number of bits per vector component used to represent the input vector. This gives an indication of the accuracy or precision that is achieved with a vector quantizer where the codebook is well-designed.

The codebook is typically implemented as a table in a digital memory and the number of bits of precision used to represent each component of each code vector does not affect the resolution or the bit-rate of the vector quantizer. In the present embodiment, every codeword in the codebook C represents a point in a sea front region, for example. Each codeword comprises a variable number of entities since the number of perceived cells varies from point to point. However, each entity

comprises the cell identity and its received signal strength as perceived by the mobile station in that geographical region. The codebook is $C=(y_1, y_2, \ldots, y_N)$ where $y_i = \{(c_1, s_1), (c_2, s_2), (c_3, s_3), \ldots, (c_{m(i)}, s_{m(i)})\}$. The codewords are collected using data derived during extensive drive tests and walk tests along pre-defined routes within the network. The entire codebook is updated regularly in order to remain current and valid, despite any changes caused by network expansion or network re-configuration.

The current valid NMR 310 collected from the SIM Application Toolkit (STK) is checked against the codebook, initially using the cell identities. Although each NMR has at most seven cells' identities and received signal strength values, it is common that less than seven cells' information can be received or decoded in practice due to many reasons, including radio interference. If too few cell identities are decoded from the NMR, the resolution for Vector Quantization 350 is regarded as too low for a reliable output. Therefore, only NMR with three or more cell identities is used for Vector Quantization in this embodiment.

In any case, multiple codewords are matched with a certain number of cell identities in a current NMR, and

the deviations from the quantization level, signal strength values are used to determine the closest match.

The locating system 230 provides resulted locations in terms of longitude and latitude. However, it is sometimes more user-useful in practical applications to have an area name rather than a numerical result. In that case, Area Mapping Module 240 maps the resulted location to an area by using the network profile database 142. If a single point is to be traditionally searched, throughout the entire digital map of the concerned country or city, substantial memory space and long searching time are needed. Thus, instead of using a traditional search, a two-step searching algorithm is used as follows, in order save memory space and to speed up the searching time required.

STEP 1: An initial search is made at a relatively low resolution. This is equivalent to dividing an entire map into a number of big squares. Longitude and latitude is then checked against corners of the squares to find the nearest square for the resulted location.

STEP 2: The first step acts as the table index search. There are a number of tables storing detailed location points relating to area information. The square found in STEP 1 corresponds to a particular table, which is

then be loaded into a memory for more specific location searching.

This two-step searching algorithm enables the area mapping module 240 to be implemented in the same platform of memory 230, which is Java(tm). A single platform implementation allows use of a more consistent and reliable software design, which is less subjective to program incompatibilities, software version updates and maintenance problems.

Alternatively as mentioned earlier, the area mapping function can also be accomplished by a function call from MapInfo, which is a known geographical displaying tool. Whenever the resulted location is inputted, the function quickly maps to one of the pre-defined area objects and returns the area name. It is necessary to build an interface between the memory 230 and the area mapping module 240. The interface can be implemented in two possible ways, for example, one way is based on Visual Basics 6.0 and the other way is written by Visual C++.

CLAIMS

1. A locating system for a mobile station which comprises a locating system computer, the system supplying a normal network measurement report (NMR) for the mobile station to the computer, comparing the NMR with a network profile database, and computing resulted latitude and longitude for the mobile station where a suitable comparison is found.

2. A locating system according to claim 1, including the steps of validating and synchronising the NMR prior to supplying the NMR to the computer.

3. A locating system according to claim 1 or 2, in which the locating is carried out using a network statistics database for comparison in the computer, the database is derived using an algorithm to find the cell identity (ID) of seven most important adjacent cells, as measured by the mobile station, applying network handover statistics to calculate vicinity information of each cell, selecting the three nearest cells according to the calculation, and providing the resulted latitude and longitude as a centroid of the latitudes and longitudes of the three cells.

4. A locating system according to any of claims 1 to 3, including comparing the NMR with a vector

quantization (VQ) code book that contains codeword locations for cells located at special regions of the network, providing the resulted latitude or longitude based on any matching cell ID only.

5. A method for approximately locating a mobile station (MS) in a cellular mobile communications system, comprising the steps of identifying three cells in the vicinity of the mobile station, each said cell having a cell location; and determining an approximate position of the mobile station using the locations of the three cells.

6. A method as claimed in claim 5, wherein the approximate position of the mobile station is determined by calculating a centroid of a triangle formed by said three cells.

7. A method as claimed in claim 5 or 6, wherein the said three cells are selected from a plurality of candidate cells neighbouring a serving cell for the mobile station.

8. A method as claimed in claim 7, wherein a said neighbouring cell is determined using at least one system parameter relating to the mobile station selected from a group including an ID of the serving cell, an ID of a base station in communication with the

mobile station, and a candidate neighbouring cell frequency channel.

9. A method as claimed in claim 7 or 8, wherein a said neighbouring cell is determined using a database (142) comprising cell mapping data defining physical cell locations.

10. A method as claimed in any one of claims 7 to 9, wherein the said three cells are selected from six candidate neighbouring cells.

11. A method as claimed in any one claims 7 to 10 further comprising measuring, for each neighbouring cell, a signal strength for a signal transmitted between the mobile station and the neighbouring cell; and selecting said three cells using the measured signal strengths and a database (144) of cell-to-neighbour-cell handover statistics.

12. A method as claimed in claim 11 further comprising calculating, for each neighbouring cell, a value representing a probability of a successful handover to that cell, and wherein said selecting is responsive to the calculated probability.

13. A method as claimed in claim 5 wherein, responsive to the identity of a cell serving the mobile station indicating that the mobile station is close to a sea front region or other predetermined special site, the approximate position of the mobile station is determined using only the serving cell identity rather than by identifying three cells in the vicinity of the mobile station.

14. A method for approximately locating a mobile station (MS) in a cellular mobile communications system, comprising the steps of using a compressed system parameter report to look up an approximate mobile station location in a vector quantization codebook.

15. A method for approximately locating a mobile station (MS) in a cellular mobile communications system, comprising selecting one of a plurality of location - determining algorithms responsive to the identity of a cell serving the mobile station.

16. A method as claimed in any one of claims 5 to 15 for approximately locating a mobile phone in a mobile phone network.

17. A method as claimed in claim 16 wherein the mobile phone network is a phone network using GSM protocols.

18. Apparatus for carrying out the method of any oneof claims 5 to 18.

19. Software on a data carrier for carrying out the method of any one of claims 5 to 17.

INVESTOR IN PEOPLE

Application No: GB 0007111.8 **Examiner:** Adam Tucker
Claims searched: 1-4 **Date of search:** 26 October 2001

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.S): H4L LRPLS, LDGR, LDPB

Int Cl (Ed.7): H04Q 7/38, H04M 3/42, 11/08, G01S 5/14

Other: Online: WPI, EPODOC, PAJ, IEEE and selected internet sites

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X, E	GB 2353671 A	(ROKE MANOR) See in particular page 12 line 1-page 13 line 29	1, 2
X	GB 2239758 A	(STC plc) See in particular page 1 line 26-page 2 line 25, page 3 lines 4-19 and page 5 lines 12-21	1, 2
X	WO 98/15149 A1	(NOKIA) See in particular page 4 line 24-page 5 line 14, page 5 line 33-page 6 line 30	1, 2
A	WO 97/24010 A1	(BELL) See in particular page 4 lines 7-29, page 12 line 16-page 16 line 4	-
X	WO 96/39638 A1	(AIRNET) See in particular page 3 lines 16-28, page 6 line 32-page 7 line 3, page 7 lines 13-23, page 9 line 21-page 10 line 18 and page 11 line 31-page 12 line 8	1, 2
A	JP 10262007	(NIPPON) See in particular enclosed PAJ translation of Means of the invention	-

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Application No: GB 0007111.8 **Examiner:** Adam Tucker
Claims searched: 1-4 **Date of search:** 26 October 2001

Category	Identity of document and relevant passage	Relevant to claims
A	http://www.simpleteam.com/download/en_300940v070700-04.08.pdf, GSM/ETSI Mobile interface layer 3 specification GSM 04.08 version 7.7.0 release 1998, Global System for Mobile Communications, See pages enclosed	1, 2

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

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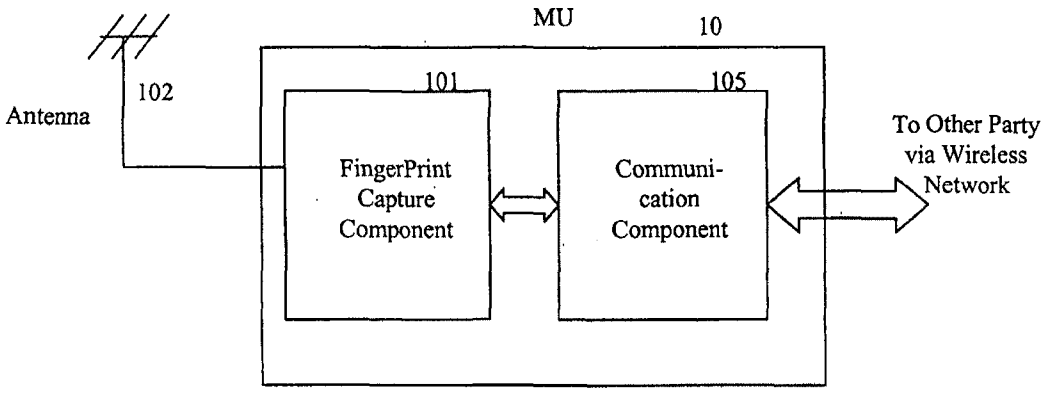
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(54) Title: LOCATION DETERMINATION USING RF FINGERPRINTING



(57) Abstract

The location of a mobile unit (MU) (10) in a wireless communication system is determined by comparing a snapshot of a predetermined portion of the radio-frequency (RF) spectrum taken by the MU (10) to a reference database (400) containing multiple snapshots taken at various locations. The result of the comparison is used to determine if the MU (10) is at a specific location. The comparison may be made in the MU (10) or at some other location remotely from the MU (10). In the latter case, sufficient information regarding the captured fingerprint is transmitted from the MU (10) to the remote location (30). The database (400) may be pre-compiled or generated on the fly.

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LOCATION DETERMINATION USING RF FINGERPRINTING

BACKGROUND OF THE INVENTION

The present invention relates generally to telecommunications, and more specifically to wireless messaging systems.

In connection with mobile communication systems, it is becoming increasingly important to determine the location of the communicating Mobile Unit (MU). Various systems for locating are already well known. One solution that is readily available in most modern cellular systems is to use the ID of the cell from which the MU is communicating. Typically, this information is accurate to a resolution of several miles. A second solution is to compute the location of the MU based on the cellular network signaling parameters (angle of arrival, time delay of arrival, signal strength, etc.). This information is typically accurate to several tens of meters. Yet another solution is to equip the MU with a GPS receiver which then attempts to track the location of the MU as accurately as possible. Typically, GPS receivers can compute locations to within several tens of meters of accuracy. When combined with differential corrections, the accuracy can be improved to less than 10 meters with a high degree of probability.

As far as reliability is concerned the cell ID information is the most reliable, and is guaranteed to be available as long as the cellular network is functioning normally. The network signal based location computations are less reliable, since they are dependent on several conditions being true at the time of the call. For example, most schemes require the MU to have line-of-sight visibility to multiple cellular base stations. This is not always possible. GPS based location computation is also not always reliable since the MU may be in an environment where there is no penetration of the GPS satellite signals.

SUMMARY OF THE INVENTION

The present invention provides a method for determining the location of a mobile unit in a wireless communication system and presenting it to a remote party.

According to one aspect of the invention location of a remote MU is determined by comparing a snapshot of a predefined portion of the radio-frequency (RF) spectrum taken by the MU to a reference database containing multiple snapshots taken at various locations. The result of the comparison is used to determine if the MU is at a specific location. The comparison may be made in the MU, or at some other location situated remotely from the MU. In the latter case, sufficient information regarding the captured fingerprint is transmitted from the MU to the remote location. The database may be pre-compiled or generated on the fly.

A further understanding of the nature and advantages of the present invention may be realized by reference to the remaining portions of the specification and the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a representative wireless communication system;

Fig. 2 is a high level diagram of the Mobile Unit;

Fig. 3 is a flow diagram of the position determining process employed by this invention;

Fig. 4 is an illustration of the organization of the fingerprint data; and

Fig. 5 is an illustration of the organization of the fingerprint database.

DESCRIPTION OF SPECIFIC EMBODIMENTS

The present invention provides a new method for determining the location estimate of a Mobile Unit (MU) in a wireless communication network.

Fig. 1 is a high level block diagram of a wireless communication network. A Mobile Unit 10 has a connection with a wireless network 15, which in turn is connected to an Other Party 30. The Other Party may or may not be mobile. The location of the MU is of interest to the Other Party for several reasons such as provisioning of prompt and efficient personalized services, dispatching emergency assistance personnel, tracking the movements of the MU, etc.

There are several different methods for determining the location of MU 10, as is known to one skilled in the art. For example, the MU could be equipped with a GPS receiver. Alternatively, the wireless network could be equipped to determine the location of MU 10. For example, the network could monitor the time of arrival of signals from the MU at various nodes and from that information determine its location. Again, such techniques are well known to one skilled in the art.

All of the prior art techniques have significant disadvantages. For example, it is well known that GPS receivers do not work very well in urban canyons and indoor locations where signal strength is very low. The network based schemes such as TDOA and AOA (both well known prior art) are disadvantaged in that they need significant infrastructural modifications.

The present invention provides a new method for determining the location of MU 10 which (a) works in areas where GPS coverage is not typically available, and (b) does not require any infrastructural modifications. Thus, the present invention complements existing location determining technologies and, when used in conjunction with them, augments their performance.

The invention is based on the principle that any location has a unique Radio Frequency (RF) spectral fingerprint. Spectral fingerprint in

this context is defined as a predetermined combination of observable RF spectral parameters. For instance, observed signal strength of a predetermined set of signals in the RF spectrum constitutes a fingerprint. Today, worldwide, practically the entire RF spectrum, up to 2 GHz and above, is being utilized by several different applications. The signal characteristics vary greatly across this spectrum, however, for any given location, it is possible to pre-select a portion of the spectrum and a combination of signal parameters in the pre-selected band that will be unique to that location.

In accordance with the invention MU 10 is equipped with circuitry and software that is capable of capturing information from predetermined portions of the RF spectrum. In one embodiment the predetermined portions of the RF spectrum all fall within or in close proximity to the same band as that utilized by the wireless communication network. In such an instance the same hardware circuitry can be used for performing both functions. In another embodiment the predetermined portions of the RF spectrum are different from the wireless communication band and in such an instance additional circuitry is required. For example, the MU may use signal characteristics from the television UHF band, in which case it will require a television tuner capable of capturing the appropriate television channels. In another example the MU is equipped with a tuner designed to capture AM or FM radio broadcasts. In this case the MU is equipped with a radio capable of tuning to the appropriate radio broadcasting bands.

Fig. 2 shows the MU containing a component 101 for tuning to a predetermined portion of the RF spectrum. Also included is a communication component 105 for communicating information with the Other Party over an existing wireless infrastructure. Component 101 obtains information from the RF spectrum via an Antenna 102.

In many instances, Other Party 30 is interested in only determining if MU 10 is at a particular location or not. The resolution of knowing the MU's location is not high (e.g., several meters), but much coarser, such as of the order of several tens of meters. For example, Other Party 30 may be interested in knowing if MU 10 is inside a particular building, or a campus or a block. In such cases it is not necessary to provide very high-resolution information to Other Party 30.

There are other instances where Other Party 30 is desirous of knowing the accurate location of MU 10, however, is incapable of doing so. This could be because other location determining capabilities in the system, such as GPS, are not functional at the instant when the location information is desired. This is typical when the MU is in an area where GPS signals are not available, such as inside a building. The location determining method described in this invention is capable of operating in areas where GPS and other location technologies are not.

When a location estimate of the MU is desired (either by itself

or by the Other Party), it activates component 101 (Fig. 2), which captures predetermined information from a predetermined portion of the RF spectrum. Instructions regarding what information to capture and the portion of the RF spectrum from which to capture may be either pre-programmed in the MU, or generated in real time. In the latter case, it may be generated in the MU, or downloaded into the MU from the Other Party over the wireless network. The MU may capture multiple pieces of information or from multiple portions of the spectrum.

The spectral fingerprint may be generated using many different parameters, either individually or in combination. In one embodiment, signal strength is used. In another embodiment, phase information is used. In another embodiment, the identity of the received signals (e.g., frequency) is used. In yet another embodiment the identity of the signal source (e.g., channel number or station code) is used. In yet another embodiment, the geographic locations of the transmitters from which the signals originate are used.

The MU is equipped with the appropriate circuitry and software to capture the required signals and their parameters. In one embodiment the MU has an antenna that is designed to have a bandwidth spanning a large portion of the VHF and UHF spectrum, e.g., from 70 MHz to 1 GHz. In another embodiment, the MU has an antenna that is designed to capture only a narrowband of the spectrum. Such an antenna may be cheaper to implement and unobtrusive. In one embodiment the MU is equipped with appropriate circuitry to determine the strength of the received signal. In one instance the location of the transmitter is broadcast in the signal and is extracted in the MU.

In one embodiment, the MU is instructed by the Other Party to scan selected portions of the spectrum and capture selected parameters from the received signals. The Other Party determines which portions of the spectrum to scan and what parameters to capture based on other information it has received or generated regarding the MU. For example, in one instance the Other Party knows the approximate location of the MU by receiving identity of the (wireless communication network) cell that the MU is in at that time. By looking up a database the Other Party can determine the geographic location of the cell. The Other Party then determines which signals in the vicinity of said cell are most suitable for generating a fingerprint. For example, certain television signals may have better coverage of the cell than other signals. The Other Party then transmits this information (e.g., television channel numbers) to the MU via the wireless link requesting it to scan only those selected signals.

In another embodiment of the invention, the MU determines which portion of the spectrum to scan, and what parameters to use for generating the fingerprint.

After the MU captures the appropriate signals and extracts the parameters, it has the basic information for generating the fingerprint.

Some preprocessing may be required to refine the raw data. For example, signal strengths may have to be lower and upper limited to eliminate very weak and very strong signals.

Once the fingerprint is generated, its association with a certain location has to be determined. According to this invention this is done by utilizing a fingerprint database that contains a number of fingerprints along with their corresponding location identities. In one embodiment the database is stored in the MU. The generated fingerprint is compared with the fingerprints in the database and the fingerprint in the database that is closest to the generated fingerprint is selected as the match. The corresponding location in the database is then chosen as the location of the MU. In one embodiment of the invention, the search algorithm takes more than one fingerprint from the database that are closest to the generated fingerprint and interpolates the most plausible location for the MU from the locations of the chosen fingerprints.

In another embodiment the fingerprint database is stored at the Other Party and the generated fingerprint (in the MU) is transmitted to the Other Party over the wireless link. The search for the closest fingerprint is then done in the Other Party from which it determines the location of the MU.

Fig. 3 depicts the flow of events in this case. A request for position of the MU is generated, as shown in box 301. The request may be generated by the user carrying the MU, or remotely by the Other Party. On receipt of the request the MU captures the fingerprint of its current location (box 303). The captured fingerprint is processed appropriately. Processing may include filtering the fingerprint data and reformatting it to reduce its storage space. Subsequently the fingerprint is transmitted over the wireless link to the Other Party as shown in box 305. The Other Party has a database into which it executes a search for the closest matching fingerprint, as shown in box 307. Box 309 shows the process culminating in the retrieval of the best matching fingerprint along with its corresponding location. In one embodiment the search also returns a confidence measure that depicts the closeness of the match.

According to one aspect of this invention the fingerprint database is designed to take into account any dynamic, but predetermined, variations in the RF signal characteristics. For example, it is not uncommon that some AM radio broadcast stations lower their transmitter power at night to minimize interference with other stations. In some countries this is mandated by law. If signal strength is one of the parameters used for generating the fingerprint then it is essential that that dynamic change in transmitted power be taken into consideration before any decision is made. According to this aspect of the invention the fingerprint database and the decision algorithms are designed to accommodate such dynamic changes. Since the change pattern in signal characteristics is predetermined, the database is constructed by capturing

the fingerprints at different times so as to cover all the different patterns in the transmitted signals. The time at which a fingerprint was captured is also stored along with its location identity.

There are many choices for the search algorithm that is required to determine the closest matching fingerprint, as can be appreciated by one skilled in the art of statistical pattern matching. Specifically, the choice of the algorithm is a function of what parameters are used to generate the fingerprints. In one instance the search algorithm chooses the fingerprint from the database that has the smallest mathematical distance between itself and the captured fingerprint. The mathematical distance is defined as a norm between the two data sets. For example, it could be the average squared difference between the two fingerprints. There are many different ways to define "closeness" between two fingerprints; again, this is dependent on the signal parameters used to generate the fingerprints. In one embodiment the search algorithm also has built in heuristics that make the best possible decision in case none of the fingerprints in the database matches well with the generated fingerprint.

The complexity of the search can be greatly reduced if an approximate estimate of the MU's location is already available. For example, if the identity of the cell in which the MU is located is known, then according to this invention, the search algorithm will limit its search to only those fingerprints that correspond to locations contained within said cell.

Similarly, the search complexity is reduced by noting the time at which the location information is requested. As previously mentioned, not all fingerprints in the database are valid for all times in the day. Knowing the time at which the request is received, the database engine limits the search to the appropriate fingerprints.

Fig. 4 illustrates a structure 400 of the fingerprint in one embodiment of this invention. As mentioned previously there are several possible methods for defining the fingerprint. Fig. 4 is but an example. The time at which the fingerprint is captured is stored in the fingerprint structure, as shown by box 401. In one embodiment the UTC format is used to store time. There are several fields in the structure, some of which are optionally filled by the MU. Some other fields are optionally filled by the Other Party. It is not necessary that all fields be filled since the necessary fields can be predetermined based on system parameters.

The fingerprint comprises characteristics of received signals at multiple frequencies. Each column in Fig. 4 is information pertaining to a particular frequency or carrier. A Station ID field 403 indicates the unique identifying code of a broadcasting station from which the signal emanated. This field is optional. In one embodiment this field is filled by the MU using information received in the signal. In another embodiment this field is filled by the Other Party to indicate to the MU as to which

signals to capture for the fingerprint. A Frequency field 405 is the unique frequency value at which a signal is captured. Either the Station ID field or the Frequency field is mandatory since without both it is not possible to identify the signal. A Tuning Parameter field 407 is used when the MU requires additional information to tune to a particular carrier. In one embodiment this field is supplied by the Other Party with information containing the modulation characteristics of the signal. This field is optional. In one embodiment a Transmitter Location field 409 is used to characterize the received signals. In another embodiment this field is filled by the Other Party. The MU may optionally use this information to determine if it wants to capture the signal emanating from a particular transmitter. Finally, Signal Strength fields 411, 413, are filled by the MU based on the signal strengths of the received carriers. In one embodiment the signal strength is sampled multiple times for each frequency in order to smooth out any variations. At least one of the Signal Strength fields is required to be filled by the MU.

Fig. 5 shows the high level structure of the fingerprint database 501 in one embodiment. As one skilled in the art can appreciate, there are many methods for building, managing and searching databases. The purpose of Fig. 5 is merely to illustrate the structure of the database in one embodiment. Each row in database 501 corresponds to one fingerprint. The Lat and Long fields indicate the latitude and longitude of the location to which the fingerprint corresponds. In one instance the fingerprint corresponds not to one exact spot on the surface of the earth, but instead to a small area. The Lat and Long fields in this embodiment indicate a position inside the area, preferably the center point. The Time column indicates the time at which the fingerprint was captured. In one embodiment the UTC time format is used to indicate this time. The Fingerprint column contains the actual fingerprint data. In one embodiment the structure depicted in Fig. 4 is used to store the fingerprint data. Finally, the Description column contains a short description of the location corresponding to the fingerprint. For example, it may indicate a street address, or an intersection. This field is optional.

Generation of the fingerprint database is another aspect of this invention. In one embodiment the database is built by taking off-line snapshots of fingerprints at various locations. The fingerprint information along with the coordinates of the location are entered into the database. The more the locations, the richer the database. The resolution of location determination is also controlled by how far apart the fingerprint samples are taken. The closer they are, the higher the resolution. Of course, a person skilled in the art can appreciate that the resolution of the database is limited by the sensitivity of the fingerprint measuring device. In one embodiment the fingerprints are taken using very sensitive signal measuring devices that enable locations that are very close to each other to have distinct fingerprints.

In another embodiment the database is built by taking fingerprint measurements at predetermined locations and using intelligent algorithms that interpolate the fingerprints at all locations in between the sampled locations. This method has the advantage of not requiring a great many physical measurements to be made, however, it does suffer from some loss in accuracy. This is because, however clever, the interpolating algorithms will not be as accurate as making the actual measurements.

In yet another embodiment the database is generated on the fly using smart algorithms that can predict the fingerprints in a local area. This scheme is effective in instances where an approximate idea of the MU is already available. For example, this could be the cell in which the MU is.

Conclusion

In conclusion, it can be seen that this invention has two significant improvements over prior art location techniques. One, it can be be implemented without requiring any modifications to existing This invention has two significant improvements utilized in areas where GPS coverage is not available. This is because the fingerprints are generated by using portions of the RF spectrum that typically have superior coverage and in-building penetration than GPS signals. Second, it can infrastructure.

While the above is a complete description of specific embodiments of the invention, various modifications, alternative constructions, and equivalents may be used. Therefore, the above description should not be taken as limiting the scope of the invention as defined by the claims.

WHAT IS CLAIMED IS:

1. A method for locating the position of a mobile unit in a wireless communication network said method comprising the following steps:

capturing a first fingerprint of the RF spectrum in the mobile unit;

comparing said first fingerprint with a multiplicity of fingerprints, each said multiplicity of fingerprints corresponding to a unique location;

selecting a second fingerprint from said multiplicity of fingerprints as the closest matching fingerprint to said first fingerprint; and

assigning a location corresponding to said second fingerprint to said mobile unit.

2. The method of claim 1 wherein said first and second fingerprints are generated using a predetermined portion of the RF spectrum.

3. The method of claim 1 wherein said first and second fingerprints are generated using a predetermined set of signal parameters.

4. The method of claim 1 wherein said multiplicity of fingerprints is stored in the mobile unit.

5. The method of claim 1 wherein said multiplicity of fingerprints is stored in an Other Party that is linked to the mobile unit via the wireless communication network.

6. The method of claim 5 wherein said first fingerprint is processed and transmitted over the wireless communication network to the Other Party.

7. The method of claim 4 wherein said location assignment is performed by the mobile unit.

8. The method of claim 6 wherein said location assignment is performed by the Other Party.

9. The method of claim 2 wherein said predetermined portion of the RF spectrum overlaps with the portion of the RF spectrum utilized by the wireless communication network.

10. The method of claim 2 wherein said predetermined portion of the RF spectrum overlaps with the portion of the spectrum utilized by commercial FM radio broadcasting stations.

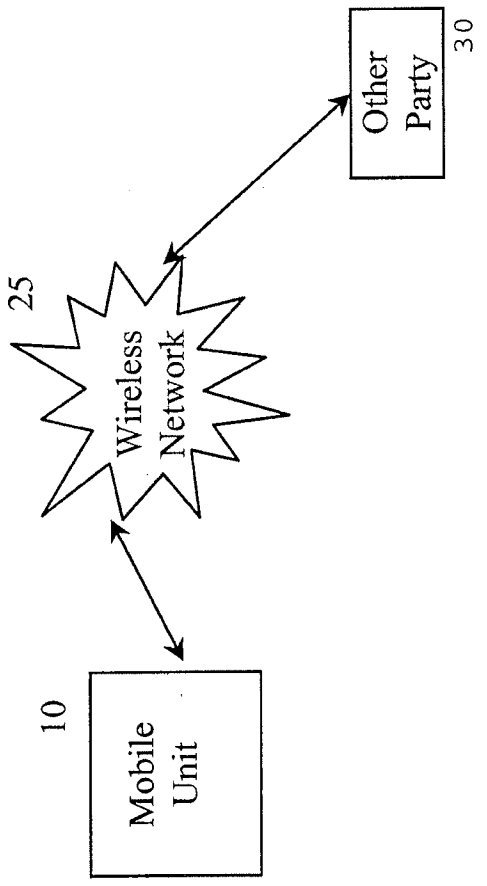


Fig. 1

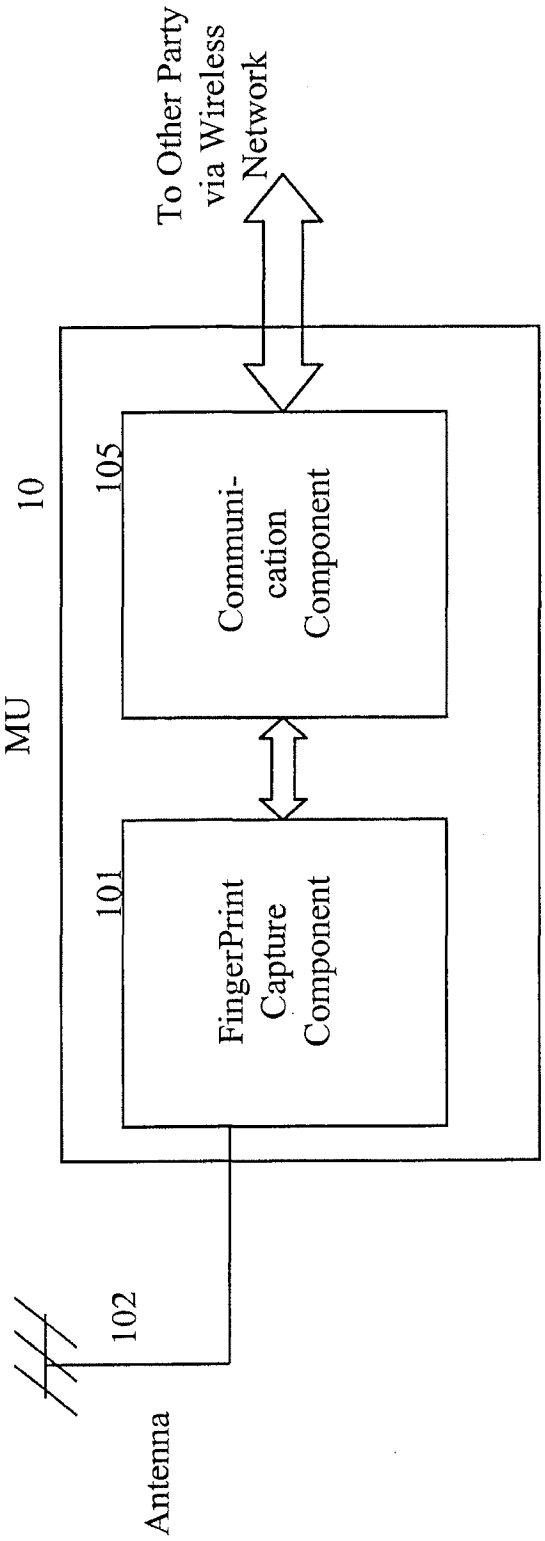

To Other Party via Wireless Network
MU
10
105
Communi-cation Component
101
FingerPrint Capture Component
102
Antenna

Fig. 2

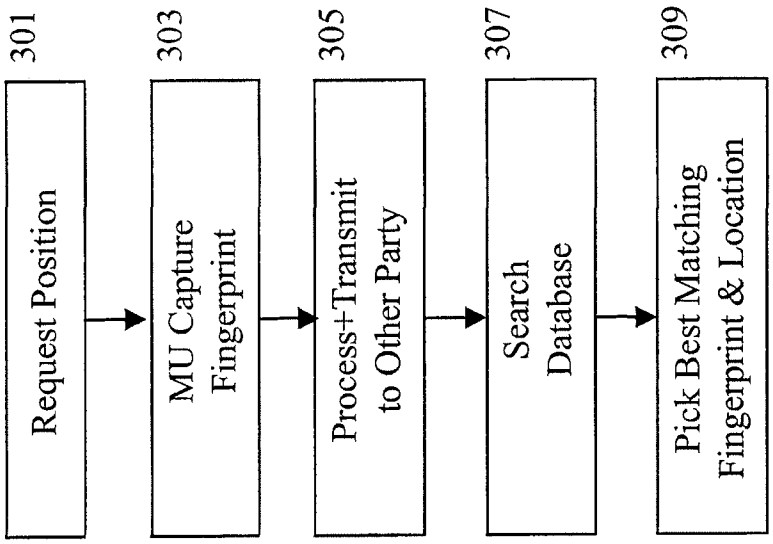

301
Request Position
303
MU Capture Fingerprint
305
Process+Transmit to Other Party
307
Search Database
309
Pick Best Matching Fingerprint & Location

Fig. 3

400	Fingerprint Structure					
401	Time of Capture:					
403	Station ID:	I1	I2	I3	…	In
405	Frequency:	F1	F2	F3	…	Fn
407	Tuning Parameters:	P1	P2	P3	…	Pn
409	Transmitter Location:	L1	L2	L3	…	Ln
411	Signal Strength 1:	S11	S12	S13	…	S1n
413	Signal Strength 2:	S21	S22	S23	…	S2n
415	…	…	…	…	…	…
417	Signal Strength m:	SSm1	SSm2	SSm3	…	SSmn

Fig. 4

SUBSTITUTE SHEET (RULE 26)

501

Fingerprint Database					
No.	Lat	Long	Time	FingerPrint	Description
1					
2					
3					
4					
5					
6					
...					
L					

Fig. 5

SUBSTITUTE SHEET (RULE 26)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/21742

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) :H04Q 7/06
US CL : 455/456
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Minimum documentation searched (classification system followed by classification symbols)

U.S. : 455/456,440,454,186.1; 342/457

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	US 5,493,286 A (GRUBE ET AL.) 20 FEBRUARY 1996, SEE ABSTRACT	1-10
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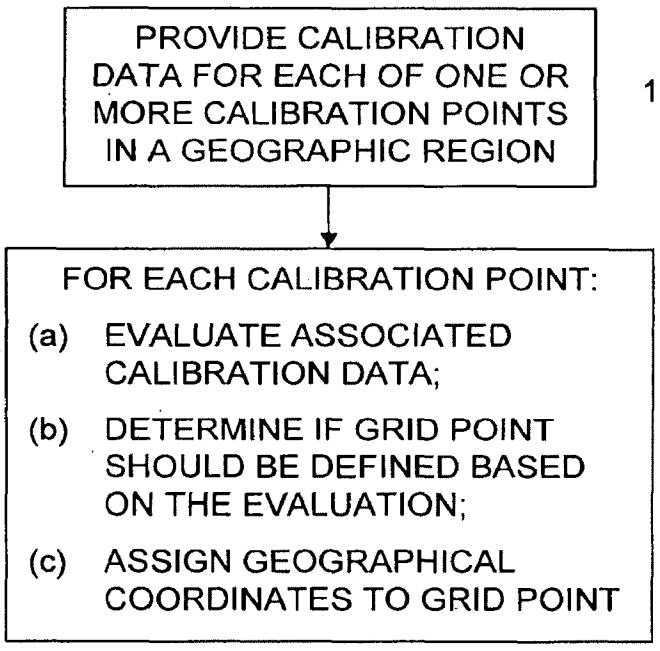
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(54) Title: SYSTEM AND METHOD FOR GENERATING NON-UNIFORM GRID POINTS FROM CALIBRATION DATA



(57) Abstract: The location of a wireless mobile device may be estimated using, at least in part, one or more pre-existing Network Measurement Reports ("NMRs") which include calibration data for a number of locations within a geographic region. The calibration data for these locations is gathered and analyzed so that particular grid points within the geographic region can be determined and associated with a particular set or sets of calibration data from, for example, one or more NMRs. Received signal level measurements reported by a mobile device for which a location estimate is to be determined may be compared with the data associated with the various grid points to estimate the location of the mobile device.

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UNITED STATES PATENT APPLICATION

of

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for

SYSTEM AND METHOD FOR GENERATING NON-UNIFORM GRID POINTS FROM CALIBRATION DATA

Cross Reference to Related Applications

[001] The present application claims priority benefit to and hereby incorporates by reference in its entirety co-pending U.S. Provisional Patent Application Serial Number 60/899,379 filed on 5 February 2007.

Background

[002] The present disclosure is directed generally towards a system and method for estimating the location of a wireless mobile device that is in communication with a wireless communications network. More specifically, the disclosure relates to the problem of estimating the location of a wireless mobile device using information from one or more Network Measurement Reports ("NMRs") which may be generated by a wireless communications network or the mobile device.

[003] As is well known in the art, the use of wireless communication devices such as telephones, pagers, personal digital assistants, laptop computers, anti-theft devices, etc., hereinafter referred to collectively as "mobile devices", has become prevalent in today's society. Along with the proliferation of these mobile devices is the safety concern associated with the need to locate the mobile device, for example in an emergency situation. For example, the Federal Communication Commission ("FCC") has issued a geolocation mandate for providers of wireless telephone communication services that puts in place a schedule and an accuracy standard under which the providers of wireless communications must implement geolocation technology for wireless telephones when used to make a 911 emergency telephone call (FCC 94-102 E911). In

addition to E911 emergency related issues, there has been increased interest in technology which can determine the geographic position, or "geolocate" a mobile device. For example, wireless telecommunications providers are developing location-enabled services for their subscribers including roadside assistance, turn-by-turn driving directions, concierge services, location-specific billing rates and location-specific advertising.

[004] Currently in the art, there are a number of different ways to geolocate a mobile device. For example, providers of wireless communication services have installed mobile device location capabilities into their networks. In operation, these network overlay location systems take measurements on radio frequency ("RF") transmissions from mobile devices at base station locations surrounding the mobile device and estimate the location of the mobile device with respect to the base stations. Because the geographic location of the base stations is known, the determination of the location of the mobile device with respect to the base station permits the geographic location of the mobile device to be determined. The RF measurements of the transmitted signal at the base stations can include the time of arrival, the angle of arrival, the signal power, or the unique/repeatable radio propagation path (radio fingerprinting) derivable features. In addition, the geolocation systems can also use collateral information, e.g., information other than that derived for the RF measurement to assist in the geolocation of the mobile device, i.e., location of roads, dead-reckoning, topography, map matching, etc.

[005] In a network-based geolocation system, the mobile device to be located is typically identified and radio channel assignments determined by (a)

monitoring the control information transmitted on radio channel for telephone calls being placed by the mobile device or on a wireline interface to detect calls of interest, i.e., 911, (b) a location request provided by a non-mobile device source, i.e., an enhanced services provider. Once a mobile device to be located has been identified and radio channel assignments determined, the location determining system is first tasked to determine the geolocation of the mobile device and then directed to report the determined position to the requesting entity or enhanced services provider.

[006] The monitoring of the RF transmissions from the mobile device or wireline interfaces to identify calls of interest is known as "tipping", and generally involves recognizing a call of interest being made from a mobile device and collecting the call setup information. Once the mobile device is identified and the call setup information is collected, the location determining system can be tasked to geolocate the mobile device.

[007] While the above-described systems are useful in certain situations, there is a need to streamline the process in order to efficiently and effectively handle the vast amount of data being sent between the wireless communications network and the large number of mobile devices for which locations are to be determined. In this regard, the present disclosure overcomes the limitations of the prior art by estimating the location of a wireless mobile device using, at least in part, one or more pre-existing Network Measurement Reports ("NMRs") which include calibration data for a number of locations within a geographic region. The calibration data for these locations must be gathered and analyzed so that particular points (e.g., "grid points") within the geographic region can be

determined and associated with a particular set or sets of calibration data from, for example, one or more NMRs. Then, the received signal level measurements reported by the mobile device to be geolocated may be compared with the data associated with the various grid points to estimate the location of the mobile device. The performance of a grid-based pattern matching system such as that disclosed herein is typically dependent on stored received signal level measurements that accurately reflect the levels that are likely to be reported by the mobile device to be located. These grid points do not necessarily have to be part of a uniform grid and usually will not be uniformly distributed throughout the geographic region. These non-uniform grid points ("NUGs"), once determined, can be assigned geographic coordinates so that the NUGs may be used in determining the location of a mobile device exhibiting certain attributes as discussed in more detail below.

[008] Accordingly, an embodiment of the present disclosure provides a method for assigning geographical coordinates to a grid point located in a geographic region for the location of a mobile device where the method provides calibration data for each of one or more calibration points in the geographic region and where for each of the calibration points the associated calibration data is evaluated and based on that evaluation a determination is made as to whether at least one grid point should be defined, and if so, geographical coordinates are assigned to the grid point.

[009] An additional embodiment of the present disclosure further includes in the above method a determination of geographical coordinates for each of a plurality of nodes of a uniform grid spanning the geographic region and for each of the grid points

determining a closest node from the plurality of nodes and assigning characteristic data associated with the grid point to the closest node.

[010] A further embodiment includes a method of assigning geographical coordinates to a grid point located in a geographic region for the location of a mobile device where calibration data for each of one or more calibration points in the geographic region are provided, and where for the calibration data associated with each of the calibration points the calibration data is evaluated, a determination is made based on the evaluation as to whether at least one grid point should be defined, and geographical coordinates are assigned to the grid point.

[011] In another embodiment of the present disclosure, a system for assigning geographical coordinates to a grid point located in a geographic region is presented where the system includes a database and a processor for receiving calibration data for each of one or more calibration points in the geographic region and for each of the calibration points the processor is programmed to evaluate the associated calibration data, determine if at least one grid point should be defined based on the evaluation, assign geographical coordinates to the at least one grid point, and populate the database with the geographical coordinates.

[012] A further embodiment of the present disclosure includes in the above system circuitry for determining geographical coordinates for each of a plurality of nodes of a uniform grid spanning the geographic region, and circuitry for determining, for each of the at least one grid point, a closest node from the plurality of nodes and assigning characteristic data associated with the grid point to the closest node.

Brief Description of the Drawings

[013] Figure 1 is a flow chart for a method for assigning geographical coordinates according to an embodiment of the disclosure.

[014] Figure 2 is a flow chart for a method for assigning geographical coordinates including a calibration point according to an embodiment of the disclosure.

[015] Figure 3 is a flow chart for a method for assigning geographical coordinates including calibration data according to an embodiment of the disclosure.

[016] Figure 4 is a flow chart for a method for assigning geographical coordinates including clustering of data according to an embodiment of the disclosure.

[017] Figure 5 is a flow chart for a method for assigning geographical coordinates including clustering of data vectors according to an embodiment of the disclosure.

[018] Figure 6 is a flow chart for a method for assigning geographical coordinates including clustering according to an embodiment of the disclosure.

[019] Figure 7 is a flow chart for a method for assigning geographical coordinates including determining outliers according to an embodiment of the disclosure.

[020] Figure 8 is a flow chart for a method for assigning geographical coordinates including clustering of data vectors at the same calibration point according to an embodiment of the disclosure.

[021] Figure 9 is a flow chart for a method for assigning geographical coordinates including clustering of data vectors at the same calibration point according to an embodiment of the disclosure.

[022] Figure 10 is a flow chart for a method for assigning geographical coordinates to a grid point according to an embodiment of the disclosure.

[023] Figure 11 is a flow chart for a method for assigning geographical coordinates including assigning geographical coordinates to a grid point where only one calibration point is in a geographic region according to an embodiment of the disclosure.

[024] Figure 12 is a flow chart for a method for assigning geographical coordinates including assigning geographical coordinates to a grid point where there are plural calibration points in a geographic region according to an embodiment of the disclosure.

[025] Figure 13 is a flow chart for a method for assigning geographical coordinates including calibration data information according to an embodiment of the disclosure.

[026] Figure 14 is a flow chart for a method for assigning geographical coordinates including evaluating calibration data according to an embodiment of the disclosure.

[027] Figure 15 is a flow chart for a method for assigning geographical coordinates including populating a database with the geographical coordinates according to an embodiment of the disclosure.

[028] Figure 16 is a flow chart for a method for assigning geographical coordinates including database information according to an embodiment of the disclosure.

[029] Figure 17 is a flow chart for a method for assigning geographical coordinates including determining geographical coordinates for nodes of a uniform grid according to an embodiment of the disclosure.

[030] Figure 18 is a flow chart for a method for assigning geographical coordinates including characteristic data to nodes of uniform grid according to an embodiment of the disclosure.

[031] Figure 19 is a flow chart for a method for assigning geographical coordinates for calibration data for each of one or more calibration points in a geographic region according to an embodiment of the disclosure.

[032] Figure 20 is a block diagram for a system for assigning geographical coordinates according to an embodiment of the disclosure.

[033] Figure 21 is a block diagram for a system for assigning geographical coordinates including a determination of clustering of plural data vectors according to an embodiment of the disclosure.

[034] Figure 22 is a block diagram for a system for assigning geographical coordinates including comparing clusters of data vectors from different calibration points according to an embodiment of the disclosure.

[035] Figure 23 is a block diagram for a system for assigning geographical coordinates including comparing clusters of data vectors from the same calibration point according to an embodiment of the disclosure.

[036] Figure 24 is a block diagram for a system for assigning geographical coordinates including calibration data according to an embodiment of the disclosure.

[037] Figure 25 is a block diagram for a system for assigning geographical coordinates including evaluating calibration data according to an embodiment of the disclosure.

[038] Figure 26 is a block diagram for a system for assigning geographical coordinates including information for populating a database according to an embodiment of the disclosure.

[039] Figure 27 is a block diagram for a system for assigning geographical coordinates including circuitry for determining geographical coordinates for nodes of a uniform grid according to an embodiment of the disclosure.

[040] Figure 28 is a block diagram for a system for assigning geographical coordinates including characteristic data according to an embodiment of the disclosure.

Detailed Description

[041] With reference to the Figures where generally like elements have been given like numerical designations to facilitate an understanding of the present subject matter, the various embodiments of a system and method for assigning

geographical coordinates to a grid point in a geographic region for the location of a mobile device are herein described.

[042] The present disclosure is directed generally to the problem of estimating the location of a wireless mobile device using calibration data contained in one or more Network Measurement Reports ("NMRs"). The calibration data for various points must be gathered and analyzed so that particular points (e.g., "grid points") within the geographic region can be determined and associated with a particular set or sets of calibration data from, for example, one or more NMRs. In order to do so geographic coordinates may be assigned to grid points located in a geographic region. The grid points may be non-uniformly spaced throughout the geographic region and hence may be referred to as non-uniform grid points ("NUGs"). The location of a wireless mobile device may be estimated by comparing data reported by the mobile device to be geolocated with the data, and more particularly the characteristics derived from the data, associated with the various grid points to thereby estimate the location of the mobile.

[043] The system and/or method of the present disclosure may apply to the situation where calibration data is available over discrete points in a 2-dimensional region "R" (3-D region is also contemplated such as within large multi-level structures). The calibration data may be contained within a Network Measurement Report ("NMR") as is known in the art or the calibration data may be obtained using other known methods. The calibration data may be obtained at each of several calibration points, which may be discrete points within region R each having geographical coordinates (e.g., latitude and longitude) associated therewith. The calibration data may include, but is not limited to,

the following: (a) signal strengths observed for signals transmitted by a set of transmitters of known location within or in proximity to the region R; (b) signal strength of a transmitter located at the calibration point as measured by a set of receivers of known location within or in proximity to the region R; (c) round trip time for a signal between the calibration point and an external known point; (d) time difference of arrival at the calibration point with respect pairs of external points located within or in proximity to region R as measured by either a receiver at the calibration point or the external points; (e) the serving cell or sector for a mobile wireless device operating at that calibration point; (f) the network state at the time of collection – a finite number of such states may be required to distinguish between network conditions that vary diurnally, weekly or in some other manner; and (g) combinations of the above.

[044] As a non-limiting example, the case in (a) may apply to the Integrated Digital Enhanced Network ("IDEN") specification, (c) may apply to the Global System for Mobile communications ("GSM") specification as in the Timing Advance ("TA") parameter or the Round Trip Time ("RTT") parameter in the Universal Mobile Telecommunications System ("UMTS") specification, (d) may apply to the UMTS specification, while the external receivers may be the base stations. In general, the calibration data may be any of those measurements made by a mobile wireless device located at the calibration point or any measurement made on the transmissions or characteristics of the mobile wireless device at a set of external transmitter/receivers in the region R or in proximity thereto.

[045] The calibration data may consist of many such sets (i.e., vectors) obtained at one or more calibration points. At each calibration point, the data gathering may have resulted in either a single data vector or multiple data vectors, so that there are potentially multiple sets of data and/or data vectors associated with each calibration point.

[046] A NUG generator or a method to produce NUGs may begin the NUG generation operation using, for example, one of more of the following: (a) a fixed uniform grid ("UG") defined over the region R with the calibration point data being assigned to the fixed grid points by some rule (e.g., allocated by closest fixed grid point, a centroid of a set of fixed grid points, etc.); (b) random grid points to define the start of each NUG; (c) combinations of (a) and (b) depending on the characteristics of the calibration data; or (d) some other useful method.

[047] In any of these cases, the NUG generator may evaluate the data vectors at a particular (candidate) calibration point, or at a fixed grid point to which the data vector(s) is/are assigned. This calibration point or grid point may serve as the root of a first NUG. The root of the NUG may be the calibration data vector that initiates the creation of that NUG. The vectors may be examined using, for example, increasingly stringent tests of statistical sufficiency. In particular, a determination may be made as to whether the data vectors exhibit clustering. If the data exhibits tight clustering, the data for the next candidate calibration point may be aggregated to the former calibration point and the clustering property may be re-evaluated. For example, if the second calibration point also has a cluster but this cluster is sufficiently different than the cluster of the first

calibration point, a determination may be made that the data for the two considered calibration points should be allocated to the roots of separate NUGs. If the aggregate cluster (i.e., a cluster including data from both the first and second calibration points) is statistically very similar to either of the first or second clusters (taken independently), then the data for the two calibration points may be allocated to the same NUG. All adjacent calibration data points may be similarly evaluated with respect to the first considered calibration point. Thus one or more of the adjacent calibration points may either wind up having all their data accumulated into a single NUG or, at the other extreme, each such calibration point may become the root of a separate NUG.

[048] The primary test made to determine the allocation may be one of a variety of clustering tests, such as, for example, the K-means algorithm. Statistical similarity may be determined by, for example, the probability density function ("pdf") of the data parameters (e.g., neighboring cell signal levels, timing information, etc.), the mean and variance of the data parameters, the serving cell/sector, or other functions of the calibration data.

[049] Those measurements or parameter values that do not cluster may be referred to as outliers. The performance of a grid-based pattern matching system such as that disclosed herein is typically dependent on stored received signal level measurements that accurately reflect the levels that are likely to be reported by the mobile device to be located. If the drive test data, for example, used to create the RF signal level grid contains outlier measurements, the statistically consistent value of the signal level will be distorted. Therefore, the present disclosure also describes a system and method used to

identify and eliminate outlier signal level measurements and timing advance values (or in general, any parameter within the NMR) during NUG or grid creation so as to improve the estimate of the mean parameter value.

[050] As a non-limiting example, in a very simple consideration of clustering one could consider the mean value of a parameter. In this scenario, neighbor cell control channel signal level measurement outliers could be eliminated as follows: At each grid point, the average received signal level of a particular control channel signal may be computed from all of the measurements of that signal assigned to the grid point. The deviation of each individual measurement from the mean may be computed. Measurements that deviate by more than a configurable predetermined threshold from the mean may be omitted. The average may then be recomputed without the omitted outliers. In a scenario where there are very few measurements, typically less than five or so, the original mean value will be greatly influenced by any outlier measurements and thus may falsely identify too many of the measurements as outliers, or fail to detect outliers at all. For this reason, another parameter is used to only perform the outlier check if there are at least a minimum number of measurements.

[051] In a more general case, a cluster may be a region in N-dimensional NMR vector space where there is a sufficient number of such vectors with a mutual variation such that the mutual variation could be ascribed purely to noise in the measurement. Thus, for example, if within a few feet of the original measurement, if a particular parameter is blocked (say by a large structure such as a building) that parameter would fall out of the original cluster. If sufficient such blocked locations have

data falling near the original cluster, one may obtain a secondary cluster where the difference between the first and second clusters is the large variation in this particular parameter.

[052] In addition, if any of the examined sets of data associated with a calibration point exhibit more than one cluster, it may be necessary to define one or more co-located NUGs. Thus, if there are, for example, three well defined clusters associated with a particular calibration point, these clusters could form the roots of three co-located NUGs. The data in these NUGs may grow depending on whether similar clusters can also be found in adjacent (or close) calibration points in which case the similar clusters may be aggregated to the original NUGs or, if the adjacent clusters are not similar, the adjacent clusters (or cluster) may form separate root NUGs (or NUG).

[053] Further, if the quantity of data associated with a particular calibration point is insufficient to sensibly test for statistical similarity or clustering, data from adjacent calibration grid points may be accumulated first and the statistical or clustering test performed thereafter. Thus, based on the results of the clustering test using the accumulated data the determination of how one should separate out the data into NUGs may be made.

[054] The technique may be repeated until all calibration grid points in the region R are exhausted. At the end of this process one has divided the region into a collection of NUGs, where multiple co-located NUGs may exist. The NUGs may fully cover the region R and each NUG may have statistically similar data accumulated into itself. The geometrical shape (i.e., the shape defined by the union of locations of

calibration points assigned to the NUG) and the amount of data accumulated into such NUGs is seen to be variable since these are determined by the statistical similarity of the data allocated to a NUG.

[055] Additionally, we may also consider the method of generating NUGs based not on statistical consistency of calibration data, but on other conditions such as (a) a minimum number of unique neighbors observed in data accumulated from allocated calibration grid points; (b) a minimum number of data vectors (NMRs); (c) a maximum and/or minimum NUG radius; (d) a specific set of neighboring cells; (e) a specific set of neighboring cells with power ordering; or (f) any combination of the above. Additionally, the method of using statistical consistency or similarity or data clustering combined with any of these other conditions may be employed.

[056] For each so obtained NUG, a variety of parameters and functions may be generated and stored to describe that NUG. These may be termed the NUG characteristics. The NUG characteristics may be a representation that attempts to capture the nature and variability of the data associated with that NUG in a compact and representative form. These characteristics may include, but are not limited to, the following: (a) an ordered list of neighboring cells; (b) functions defined on the absolute neighboring cell power levels (e.g., mean, median, k^{th} moment, cluster-mean, etc.); (c) functions defined on the relative neighboring cell power differences (e.g., mean, median, k^{th} moment, cluster-mean, etc.); (d) serving cell/sector; (e) timing advance parameter (or equivalent); (f) individual pdf (i.e., probability density function or probability distribution function) of each neighboring cell power level; (g) joint pdf of neighboring cell power

levels; (h) mean and variance of neighboring cell power levels; (i) mobile device orientation (e.g., indoors, outdoors, direction mobile device is facing (e.g., North, South, etc.), tilted upwards, azimuth, elevation, etc.); (j) a compact and/or efficient representation that enables retrieval of the calibration data NMR vectors assigned to this NUG; (k) the network state as indicated in the calibration data; (l) a confidence measure indicative of the reliability of the calibration data feeding this NUG; and (m) any combinations of the above.

[057] If a pdf is determined for a NUG, that pdf may be generated using either the Parzen technique or the method of Gaussian mixtures or some variant thereof. In addition when a need to specify the variance or covariance exists, that parameter may be set to a value dependent on the observed variance for a particular neighboring cell power level or the observed covariance matrix for a set of neighboring cell power levels.

[058] The location ascribed to the NUG may be, for example, any internal point within the NUG. If the NUG contains only a single calibration point, the location of the NUG may be set as the location of the calibration point. If the NUG encompasses several calibration points, the location of any one of the calibration points or the centroid of such calibration points or some other similar measure may be used to define the NUG location. Also, in the case of multiple co-located NUGs, all such NUGs may have their assigned location set to the same value.

[059] With reference now to Figure 1, a flow chart is depicted for a method for assigning geographical coordinates according to an embodiment of the disclosure. At block 101, calibration data may be provided for each of one or more

calibration points in a geographic region. At block 102, for each of the calibration points calibration data associated with the calibration point is evaluated and a determination is made as to whether a grid point, such as a NUG, should be defined. If is it determined that a grid point is to be defined, geographical coordinates are assigned to the grid point so that the grid point may be useful in estimating the location of a mobile device.

[060] Figure 2 is a flow chart for a method for assigning geographical coordinates including a calibration point according to an embodiment of the disclosure. Blocks 201 and 202 are similar to blocks 101 and 102, respectively. At block 213, the calibration point may be located on a predetermined fixed uniform grid defined over the geographic region or the calibration point may be randomly located within the geographic region.

[061] Figure 3 is a flow chart for a method for assigning geographical coordinates including calibration data according to an embodiment of the disclosure. Blocks 301 and 302 are similar to blocks 101 and 102, respectively. At block 313, the calibration data associated with one or more calibration points may be comprised of information from a NMR, or the calibration data for a particular calibration point may be obtained from one or more mobile devices located at or in close proximity to the calibration point, or the calibration data for a particular calibration point may be obtained from a signal transmitted from a mobile device (or devices) located at or in close proximity to the calibration point where the signal is received by a receiver in or in proximity to the geographic region.

[062] Figure 4 is a flow chart for a method for assigning geographical coordinates including clustering of data according to an embodiment of the disclosure. Blocks 401 and 402 are similar to blocks 101 and 102, respectively. At block 413, for one or more of the calibration points the calibration data may include multiple data vectors and, at block 414, the evaluation of the data vectors may include a determination of clustering of the multiple data vectors as described above.

[063] Considering now the flow chart depicted in Figure 5, the flow chart indicates a method for assigning geographical coordinates including clustering of data vectors according to an embodiment of the disclosure. Blocks 501 and 502 are similar to blocks 101 and 102, respectively. At block 503, the determination of whether at least one grid point should be defined based on the evaluation of the calibration data associated with a calibration point includes a comparison of a first cluster of data vectors from a first calibration point to a second cluster of data vectors where the second cluster of data vectors includes the first cluster of data vectors as well as data vectors from a second calibration point. At block 504, if the comparison in block 503 results in the difference between the first and second cluster of data vectors being within a predetermined tolerance value, then the data vectors from the first and second calibration points are assigned to the same grid point. However, if the comparison is not within tolerance, then the data vectors from the first calibration point are assigned to a first grid point and the data vectors from the second calibration point are assigned to a second grid point.

[064] The flow chart shown in Figure 6 illustrates another method for assigning geographical coordinates including clustering according to an embodiment of

the disclosure. Here, blocks 601, 602, 603, and 604 are similar to blocks 501, 502, 503, and 504, respectively. At block 615 the evaluation of calibration data for one or more calibration points may include determining the clustering of plural data vectors using a K-means analysis. At block 616 the comparing of clusters of data vectors may include determining a probability density function of an aspect of the data vectors.

[065] Figure 7 is a flow chart for a method for assigning geographical coordinates including determining outliers according to an embodiment of the disclosure. Blocks 701, 702, 713, and 714 are similar to blocks 401, 402, 413, and 414, respectively. AT block 703, a determination of outlier data vectors may be made and the outlier data vectors may be eliminated from the determination of data vector clustering.

[066] Regarding Figure 8, a flow chart is represented for a method for assigning geographical coordinates including clustering of data vectors at the same calibration point according to an embodiment of the disclosure. Blocks 801 and 802 are similar to blocks 101 and 102, respectively. At block 803, the determination if at least one grid point should be defined based on the evaluation of calibration data may include a comparison of a first cluster of data vectors associated with a first calibration point to a second cluster of data vectors associated with the first calibration point. If the result of the comparison is within a predetermined tolerance, then the data vectors from the first and second clusters may be assigned to the same grid point; otherwise, the data vectors from the first cluster may be assigned to a first grid point while the data vectors from the second cluster may be assigned to a second grid point.

[067] Figure 9 is a flow chart illustrating another method for assigning geographical coordinates including clustering of data vectors at the same calibration point according to an embodiment of the disclosure. Here, blocks 901, 902, 903, and 904 are similar to blocks 801, 802, 803, and 804, respectively. At block 915 the geographical coordinates assigned to the first and second grid points may be identical.

[068] Directing attention now towards Figure 10, a flow chart is presented for a method for assigning geographical coordinates to a grid point according to an embodiment of the disclosure. Blocks 1001 and 1002 are similar to blocks 101 and 102, respectively. At block 1013, the geographical coordinates assigned to a first grid point may be different than the geographical coordinates assigned to a second grid point or the geographical coordinates assigned to a first grid point may be the same as the geographical coordinates assigned to a second grid point.

[069] Figure 11 is a flow chart for a method for assigning geographical coordinates including assigning geographical coordinates to a grid point where only one calibration point is in a geographic region according to an embodiment of the disclosure. Blocks 1101 and 1102 are similar to blocks 101 and 102, respectively. At block 1113, if there is only one calibration point within the geographic region, then the geographical coordinates assigned to a grid point may result in the grid point being located within a predetermined radius of the one calibration point. Or, the geographical coordinates assigned to a grid point may be identical to the geographical coordinates of the calibration point.

[070] Moving now to Figure 12, a flow chart is shown for a method for assigning geographical coordinates including assigning geographical coordinates to a grid point where there are plural calibration points in a geographic region according to an embodiment of the disclosure. Blocks 1201 and 1202 are similar to blocks 101 and 102, respectively. At block 1213, where there are multiple calibration points in the geographic region, the geographical coordinates assigned to a grid point may result in the grid point being located within a predetermined radius of a centroid of a polygon formed by connecting the multiple calibration points.

[071] Figure 13 is a flow chart for a method for assigning geographical coordinates including calibration data information according to an embodiment of the disclosure. Blocks 1301 and 1302 are similar to blocks 101 and 102, respectively. At block 1313, the calibration data may include one or more of the following: signal strength for a signal transmitted by a transmitter having a known location as received by a receiver at a calibration point; signal strength of a signal transmitted by a transmitter located at a calibration point as received by a receiver at a known location; round trip time for a signal traveling between a calibration point and a known location; timing advance of a signal received by a mobile device at a calibration point; time difference of arrival of plural signals at a calibration point with respect to a pair of known locations as measured by a receiver at a calibration point or at the known locations; the identification of a serving cell or serving sector of a mobile device located at a calibration point; a state of a wireless network serving a mobile device, and combinations thereof.

[072] Figure 14 is a flow chart for a method for assigning geographical coordinates including evaluating calibration data according to an embodiment of the disclosure. Blocks 1401 and 1402 are similar to blocks 101 and 102, respectively. At block 1413, the evaluating of the calibration data associated with a calibration point may include an evaluation such as: a minimum number of unique neighboring calibration points as determined by calibration data of the neighboring calibration points; a minimum number of data vectors or network measurement reports; a predetermined maximum or minimum radius from a calibration point; a predetermined set of cells neighboring a cell serving a mobile device; and combinations thereof.

[073] Figure 15 is a flow chart for a method for assigning geographical coordinates including populating a database with the geographical coordinates according to an embodiment of the disclosure. Blocks 1501 and 1502 are similar to blocks 101 and 102, respectively. At block 1503, a database may be populated with the geographical coordinates assigned to the grid points.

[074] Figure 16 is a flow chart for a method for assigning geographical coordinates including database information according to an embodiment of the disclosure. Blocks 1601, 1602, and 1603 are similar to blocks 1501, 1502, and 1503, respectively. At block 1604, the database may be populated with information such as: a list of cells neighboring a cell serving a mobile device; a quantity that is a function of a power level of one or more cells neighboring a cell serving a mobile device; an identity of a cell or a sector serving a mobile device; a timing advance parameter; a geographical orientation of a mobile device; a location of a mobile device; network measurement

report data vectors; a state of a network serving a mobile device; a confidence measure indicative of a reliability of the calibration data; and combinations thereof.

[075] Directing attention now to Figure 17, a flow chart is presented for a method for assigning geographical coordinates including determining geographical coordinates for nodes of a uniform grid according to an embodiment of the disclosure. Blocks 1701 and 1702 are similar to blocks 101 and 102, respectively. At block 1703, geographical coordinates may be determined for the nodes of a uniform grid spanning the geographic region. At block 1704, for each of the grid points, a determination of the closest node of the uniform grid is made and the characteristic data associated with the grid point may be assigned to the closest node.

[076] Further, Figure 18 is a flow chart for a method for assigning geographical coordinates including characteristic data to nodes of uniform grid according to an embodiment of the disclosure. Here, blocks 1801, 1802, 1803, and 1804 are similar to blocks 1701, 1702, 1703, and 1704, respectively. At block 1805, the characteristic data may include a list of cells neighboring a cell serving a mobile device; a quantity that is a function of a power level of one or more cells neighboring a cell serving a mobile device; an identity of a cell or a sector serving a mobile device; a timing advance parameter; a geographical orientation of a mobile device; a location of a mobile device; network measurement report data vectors; a state of a network serving a mobile device; a confidence measure indicative of a reliability of the calibration data; and combinations thereof.

[077] With reference to Figure 19, a flow chart is illustrated for a method for assigning geographical coordinates for calibration data for each of one or more calibration points in a geographic region according to an embodiment of the disclosure. At block 1901, calibration data may be provided for each of one or more calibration points in a geographic region. At block 1902, for the calibration data for each of the calibration points in the geographic region, the calibration data is evaluated and a determination is made as to whether a grid point should be defined based on the evaluation. If is it determined that a grid point is to be defined, geographical coordinates are assigned to the grid point so that the grid point may be useful in estimating the location of a mobile device.

[078] With attention now directed to Figure 20, a block diagram is presented that represents a system for assigning geographical coordinates according to an embodiment of the disclosure. A database 2001 is operatively connected to a processor 2002. The processor 2002 is capable of receiving calibration data for each of one or more calibration points in a geographic region. The processor 2002 may be programmed, as shown in block 2003, to evaluate the calibration data associated with the calibration points, determine if at least one grid point should be defined based on the evaluation, assign geographical coordinates to the one or more grid points, and populate the database 2001 with the geographical coordinates.

[079] Figure 21 is a block diagram for a system for assigning geographical coordinates including a determination of clustering of plural data vectors according to an embodiment of the disclosure. The database 2101, the processor 2102, and block 2103

are similar to the database 2001, the processor 2002, and block 2003, as described above, respectfully. At block 2114, for each of select ones of the calibration points, the calibration data may include multiple data vectors and the evaluating of the calibration data may include a determination of clustering of the multiple data vectors.

[080] Figure 22 is a block diagram for a system for assigning geographical coordinates including a comparing clusters of data vectors from different calibration points according to an embodiment of the disclosure. The database 2201, the processor 2202, block 2203, and block 2214 are similar to the database 2101, the processor 2102, block 2103, and block 2114, as described above, respectfully. At block 2215, the determination if at least one grid point should be defined based on the evaluation may include comparing a first cluster of data vectors from a first one of the select calibration points to a second cluster of data vectors, where the second cluster of data vectors may include the first cluster of data vectors and data vectors from a second one of the select calibration points. At block 2216, if the result of the comparison is within a predetermined tolerance, then the data vectors from the first and second calibration points may be assigned to the same grid point; otherwise, the data vectors from the first calibration point may be assigned to a first grid point and the data vectors from the second calibration point may be assigned to a second grid point.

[081] Figure 23 is a block diagram for a system for assigning geographical coordinates including comparing clusters of data vectors from the same calibration point according to an embodiment of the disclosure. The database 2301, the processor 2302, block 2303, and block 2314 are similar to the database 2101, the processor 2102, block

2103, and block 2114, as described above, respectfully. At block 2315, the determination if at least one grid point should be defined based on the evaluation may include comparing a first cluster of data vectors from a first one of the select calibration points to a second cluster of data vectors from the first one of the select calibration points. At block 2316, if the result of the comparison is within a predetermined tolerance, then the data vectors from the first and second calibration points may be assigned to the same grid point; otherwise, the data vectors from the first cluster may be assigned to a first grid point and the data vectors from the second cluster may be assigned to a second grid point.

[082] Looking now at Figure 24, a block diagram is presented representing a system for assigning geographical coordinates including calibration data according to an embodiment of the disclosure. The database 2401, the processor 2402, and block 2403 are similar to the database 2001, the processor 2002, and block 2003, as described above, respectfully. At block 2414, the calibration data may include: signal strength for a signal transmitted by a transmitter having a known location as received by a receiver at a calibration point; signal strength of a signal transmitted by a transmitter located at a calibration point as received by a receiver at a known location; round trip time for a signal traveling between a calibration point and a known location; timing advance of a signal received by a mobile device at a calibration point; time difference of arrival of multiple signals at a calibration point with respect to a pair of known locations as measured by a receiver at a calibration point or at the known locations; the identification of a serving cell or serving sector of a mobile device located at a calibration point; a state of a wireless network serving a mobile device, and combinations thereof.

[083] Figure 25 is a block diagram for a system for assigning geographical coordinates including evaluating calibration data according to an embodiment of the disclosure. The database 2501, the processor 2502, and block 2503 are similar to the database 2001, the processor 2002, and block 2003, as described above, respectfully. At block 2514, the evaluation of the associated calibration data may include an evaluation such as: a minimum number of unique neighboring calibration points as determined by calibration data of the neighboring calibration points; a minimum number of data vectors or network measurement reports; a predetermined maximum or minimum radius from a calibration point; a predetermined set of cells neighboring a cell serving a mobile device; and combinations thereof.

[084] Figure 26 is a block diagram for a system for assigning geographical coordinates including information for populating a database according to an embodiment of the disclosure. The database 2601 and the processor 2602 are similar to the database 2001 and the processor 2002, as described above, respectfully. At block 2603, the processor 2602 may be programmed to evaluate the calibration data associated with the calibration points, determine if at least one grid point should be defined based on the evaluation, assign geographical coordinates to the one or more grid points, populate the database 2601 with the geographical coordinates, and populate the database 2601 with information which may include: a list of cells neighboring a cell serving a mobile device; a quantity that is a function of a power level of one or more cells neighboring a cell serving a mobile device; an identity of a cell or a sector serving a mobile device; a timing advance parameter; a geographical orientation of a mobile device; a location of a mobile

device; network measurement report data vectors; a state of a network serving a mobile device; a confidence measure indicative of a reliability of the calibration data; and combinations thereof.

[085] Figure 27 is a block diagram for a system for assigning geographical coordinates including circuitry for determining geographical coordinates for nodes of a uniform grid according to an embodiment of the disclosure. The database 2701, the processor 2702, and block 2703 are similar to the database 2601, the processor 2602, and block 2603, as described above, respectfully. The system may further comprise circuitry 2704 for determining geographical coordinates for each of a plurality of nodes of a uniform grid spanning the geographic region, and circuitry 2705 for determining, for each of the one or more grid points, a closest node from the plurality of nodes of the uniform grid and assigning characteristic data associated with each of the grid point to its closest node.

[086] Figure 28 is a block diagram for a system for assigning geographical coordinates including characteristic data according to an embodiment of the disclosure. The database 2801, the processor 2802, block 2803, circuitry 2804, and circuitry 2805 are similar to the database 2701, the processor 2702, block 2703, circuitry 2704, and circuitry 2705, as described above, respectfully. At block 2816, the characteristic data may include: a list of cells neighboring a cell serving a mobile device; a quantity that is a function of a power level of one or more cells neighboring a cell serving a mobile device; an identity of a cell or a sector serving a mobile device; a timing advance parameter; a geographical orientation of a mobile device; a location of a mobile device; network

measurement report data vectors; a state of a network serving a mobile device; a confidence measure indicative of a reliability of the calibration data; and combinations thereof.

[087] While preferred embodiments of the present disclosure have been described, it is to be understood that the embodiments described are illustrative only and that the scope of the invention is to be defined solely by the appended claims when accorded a full range of equivalents, many variations and modifications naturally occurring to those of skill in the art from a perusal hereof.

We Claim:

1. A method of assigning geographical coordinates to a grid point located in a geographic region for the location of a mobile device, comprising:

(a) providing calibration data for each of one or more calibration points in the geographic region; and

(b) for each of said calibration points:

(i) evaluating the associated calibration data;

(ii) determining if at least one grid point should be defined based on said evaluation; and

(iii) assigning geographical coordinates to said at least one grid point.

2. The method of Claim 1 wherein one of said calibration points is located on a predetermined fixed uniform grid defined over said region.

3. The method of Claim 1 wherein one of said calibration points is randomly located within said region.

4. The method of Claim 1 wherein said calibration data comprises information from a network measurement report.

5. The method of Claim 1 wherein said calibration data for one of said calibration points is obtained from one or more mobile devices located in close proximity to said one calibration point.

6. The method of Claim 1 wherein said calibration data for one of said calibration points is obtained from a signal transmitted from a mobile device in close proximity to said one calibration point and received at a receiver in or in proximity to said region.

7. The method of Claim 1 wherein for each of select ones of said calibration points the calibration data includes plural data vectors and the evaluating of said calibration data comprises a determination of clustering of said plural data vectors.

8. The method of Claim 7 wherein said determining if at least one grid point should be defined based on said evaluation includes:

(A) comparing a first cluster of data vectors from a first one of said select calibration points to a second cluster of data vectors comprising said first cluster of data vectors and data vectors from a second one of said select calibration points; and

(B) if said comparison is within a predetermined tolerance, assigning said data vectors from said first and said second calibration points to the same grid point, otherwise assigning the data vectors from said first calibration point to a first grid point and assigning the data vectors from said second calibration point to a second grid point.

9. The method of Claim 8 wherein said determination of clustering of said plural data vectors includes a K-means algorithm analysis and wherein said comparing of a cluster of data vectors includes determining a probability density function of an aspect of said data vectors.

10. The method of Claim 7 further comprising determining outlier data vectors and eliminating said outliers from said determination of clustering.

11. The method of Claim 7 wherein said determining if at least one grid point should be defined based on said evaluation includes:

(A) comparing a first cluster of data vectors from a first one of said select calibration points to a second cluster of data vectors from said first one of said select calibration points; and

(B) if said comparison is within a predetermined tolerance, assigning said data vectors from said first and said second clusters to the same grid point, otherwise assigning the data vectors from said first cluster to a first grid point and assigning the data vectors from said second cluster to a second grid point.

12. The method of Claim 11 wherein the geographical coordinates assigned to said first and second grid points are identical.

13. The method of Claim 1 wherein the geographical coordinates assigned to said at least one grid point are different than the geographical coordinates of any of said calibration points.

14. The method of Claim 1 wherein the geographical coordinates assigned to said at least one grid point are the same as the geographical coordinates of one of said calibration points.

15. The method of Claim 1 wherein only one calibration point is in said geographic region and the geographical coordinates assigned to said at least one grid point result in said at least one grid point being located within a predetermined radius of said one calibration point.

16. The method of Claim 1 wherein only one calibration point is in said geographic region and the geographical coordinates assigned to said at least one grid point are identical to geographic coordinates of said one calibration point.

17. The method of Claim 1 wherein plural calibration points are in said geographic region and wherein the geographical coordinates assigned to said at least one grid point result in said at least one grid point being located within a predetermined radius of a geographic centroid determined from geographic coordinates of said plural calibration points.

18. The method of Claim 1 wherein said calibration data is selected from the group consisting of: signal strength for a signal transmitted by a transmitter having a known location as received by a receiver at said calibration point; signal strength of a signal transmitted by a transmitter located at said calibration point as received by a receiver at a known location; round trip time for a signal traveling between said calibration point and a known location; timing advance of a signal received by said mobile device at said calibration point; time difference of arrival of plural signals at said calibration point with respect to a pair of known locations as measured by a receiver at said calibration point or at said known locations; the identification of a serving cell or serving sector of said mobile device located at said calibration point; a state of a wireless network serving said mobile device, and combinations thereof.

19. The method of Claim 1 wherein said evaluating the associated calibration data includes an evaluation selected from the group consisting of: a minimum number of unique neighboring calibration points as determined by calibration data of said neighboring calibration points; a minimum number of data vectors or network measurement reports; a predetermined maximum or minimum radius from said calibration point; a predetermined set of cells neighboring a cell serving said mobile device; and combinations thereof.

20. The method of Claim 1 further comprising populating a database with said geographical coordinates.

21. The method of Claim 20 further comprising populating said database with information selected from the group consisting of: a list of cells neighboring a cell serving said mobile device; a quantity that is a function of a power level of one or more cells neighboring a cell serving said mobile device; an identity of a cell or a sector serving said mobile device; a timing advance parameter; a geographical orientation of said mobile device; a location of said mobile device; network measurement report data vectors; a state of a network serving said mobile device; a confidence measure indicative of a reliability of the calibration data; and combinations thereof.

22. The method of Claim 1 further comprising:

(c) determining geographical coordinates for each of a plurality of nodes of a uniform grid spanning said geographic region; and

(d) for each of said at least one grid point:

(i) determining a closest node from said plurality of nodes; and

(ii) assigning characteristic data associated with said grid point to said closest node.

23. The method of Claim 22 wherein said characteristic data comprises data selected from the group consisting of: a list of cells neighboring a cell serving said mobile device; a quantity that is a function of a power level of one or more cells neighboring a cell serving said mobile device; an identity of a cell or a sector serving said mobile device; a timing advance parameter; a geographical orientation of said mobile device; a location of said mobile device; network measurement report data vectors; a state of a network serving said mobile device; a confidence measure indicative of a reliability of the calibration data; and combinations thereof.

24. A method of assigning geographical coordinates to a grid point located in a geographic region for the location of a mobile device, comprising:

(a) providing calibration data for each of one or more calibration points in the geographic region; and

(b) for the calibration data associated with each of said calibration points:

(i) evaluating the associated calibration data;

(ii) determining if at least one grid point should be defined based on said evaluation; and

(iii) assigning geographical coordinates to said at least one grid point.

25. A system for assigning geographical coordinates to a grid point located in a geographic region, comprising:

a database; and

a processor for receiving calibration data for each of one or more calibration points in said geographic region and for each of said calibration points said processor is programmed to:

evaluate the associated calibration data;

determine if at least one grid point should be defined based on said evaluation;

assign geographical coordinates to said at least one grid point; and

populate said database with said geographical coordinates.

26. The system of Claim 25 wherein one of said calibration points is located on a predetermined fixed uniform grid defined over said region.

27. The system of Claim 25 wherein one of said calibration points is randomly located within said region.

28. The system of Claim 25 wherein said calibration data comprises information from a network measurement report.

29. The system of Claim 25 wherein said calibration data for one of said calibration points is obtained from one or more mobile devices located in close proximity to said one calibration point.

30. The system of Claim 25 wherein said calibration data for one of said calibration points is obtained from a signal transmitted from a mobile device in close proximity to said one calibration point and received at a receiver in or in proximity to said region.

31. The system of Claim 25 wherein for each of select ones of said calibration points the calibration data includes plural data vectors and the evaluating of said calibration data comprises a determination of clustering of said plural data vectors.

32. The system of Claim 31 wherein said determining if at least one grid point should be defined based on said evaluation includes:

(A) comparing a first cluster of data vectors from a first one of said select calibration points to a second cluster of data vectors comprising said first cluster of data vectors and data vectors from a second one of said select calibration points; and

(B) if said comparison is within a predetermined tolerance, assigning said data vectors from said first and said second calibration points to the same grid point, otherwise assigning the data vectors from said first calibration point to a first grid point and assigning the data vectors from said second calibration point to a second grid point.

33. The system of Claim 32 wherein said determination of clustering of said plural data vectors includes a K-means algorithm analysis and wherein said comparing of a cluster of data vectors includes determining a probability density function of an aspect of said data vectors.

34. The system of Claim 31 wherein said processor is further programmed to determine outlier data vectors and eliminating said outliers from said determination of clustering.

35. The system of Claim 31 wherein said determining if at least one grid point should be defined based on said evaluation includes:

(A) comparing a first cluster of data vectors from a first one of said select calibration points to a second cluster of data vectors from said first one of said select calibration points; and

(B) if said comparison is within a predetermined tolerance, assigning said data vectors from said first and said second clusters to the same grid point, otherwise assigning the data vectors from said first cluster to a first grid point and assigning the data vectors from said second cluster to a second grid point.

36. The system of Claim 35 wherein the geographical coordinates assigned to said first and second grid points are identical.

37. The system of Claim 25 wherein the geographical coordinates assigned to said at least one grid point are different than the geographical coordinates of any of said calibration points.

38. The system of Claim 25 wherein the geographical coordinates assigned to said at least one grid point are the same as the geographical coordinates of one of said calibration points.

39. The system of Claim 25 wherein only one calibration point is in said geographic region and the geographical coordinates assigned to said at least one grid point result in said at least one grid point being located within a predetermined radius of said one calibration point.

40. The system of Claim 25 wherein only one calibration point is in said geographic region and the geographical coordinates assigned to said at least one grid point are identical to geographic coordinates of said one calibration point.

41. The system of Claim 25 wherein plural calibration points are in said geographic region and wherein the geographical coordinates assigned to said at least one grid point result in said at least one grid point being located within a predetermined radius of a geographic centroid determined from geographic coordinates of said plural calibration points.

42. The system of Claim 25 wherein said calibration data is selected from the group consisting of: signal strength for a signal transmitted by a transmitter having a known location as received by a receiver at said calibration point; signal strength of a signal transmitted by a transmitter located at said calibration point as received by a receiver at a known location; round trip time for a signal traveling between said calibration point and a known location; timing advance of a signal received by said mobile device at said calibration point; time difference of arrival of plural signals at said calibration point with respect to a pair of known locations as measured by a receiver at said calibration point or at said known locations; the identification of a serving cell or serving sector of said mobile device located at said calibration point; a state of a wireless network serving said mobile device, and combinations thereof.

43. The system of Claim 25 wherein said evaluating the associated calibration data includes an evaluation selected from the group consisting of: a minimum number of unique neighboring calibration points as determined by calibration data of said neighboring calibration points; a minimum number of data vectors or network measurement reports; a predetermined maximum or minimum radius from said calibration point; a predetermined set of cells neighboring a cell serving said mobile device; and combinations thereof.

44. The system of Claim 25 wherein said processor is further programmed to populate said database with information selected from the group consisting of: a list of cells neighboring a cell serving said mobile device; a quantity that is a function of a power level of one or more cells neighboring a cell serving said mobile device; an identity of a cell or a sector serving said mobile device; a timing advance parameter; a geographical orientation of said mobile device; a location of said mobile device; network measurement report data vectors; a state of a network serving said mobile device; a confidence measure indicative of a reliability of the calibration data; and combinations thereof.

45. The system of Claim 25 further comprising:

circuitry for determining geographical coordinates for each of a plurality of nodes of a uniform grid spanning said geographic region; and

circuitry for determining, for each of said at least one grid point, a closest node from said plurality of nodes and assigning characteristic data associated with said grid point to said closest node.

46. The system of Claim 45 wherein said characteristic data comprises data selected from the group consisting of: a list of cells neighboring a cell serving said mobile device; a quantity that is a function of a power level of one or more cells neighboring a cell serving said mobile device; an identity of a cell or a sector serving said mobile device; a timing advance parameter; a geographical orientation of said mobile device; a location of said mobile device; network measurement report data vectors; a state of a network serving said mobile device; a confidence measure indicative of a reliability of the calibration data; and combinations thereof.

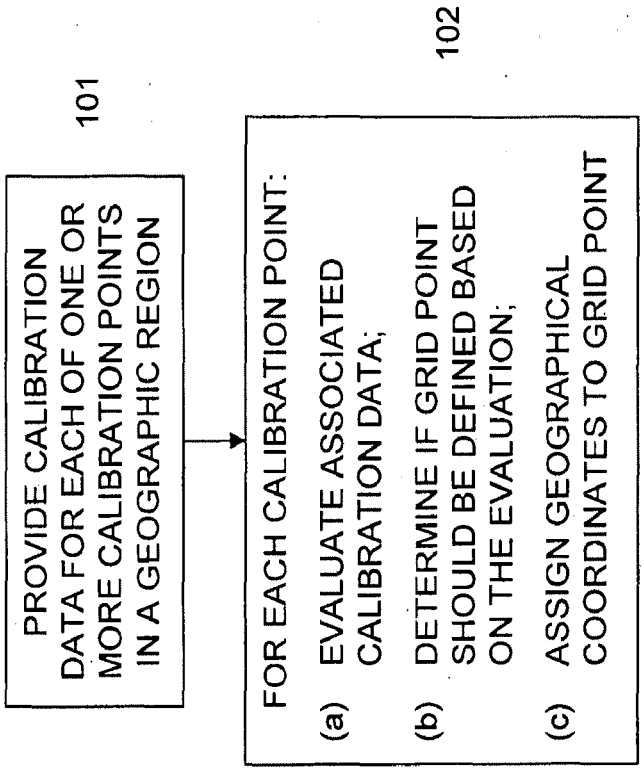

PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
101
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
102

FIGURE 1

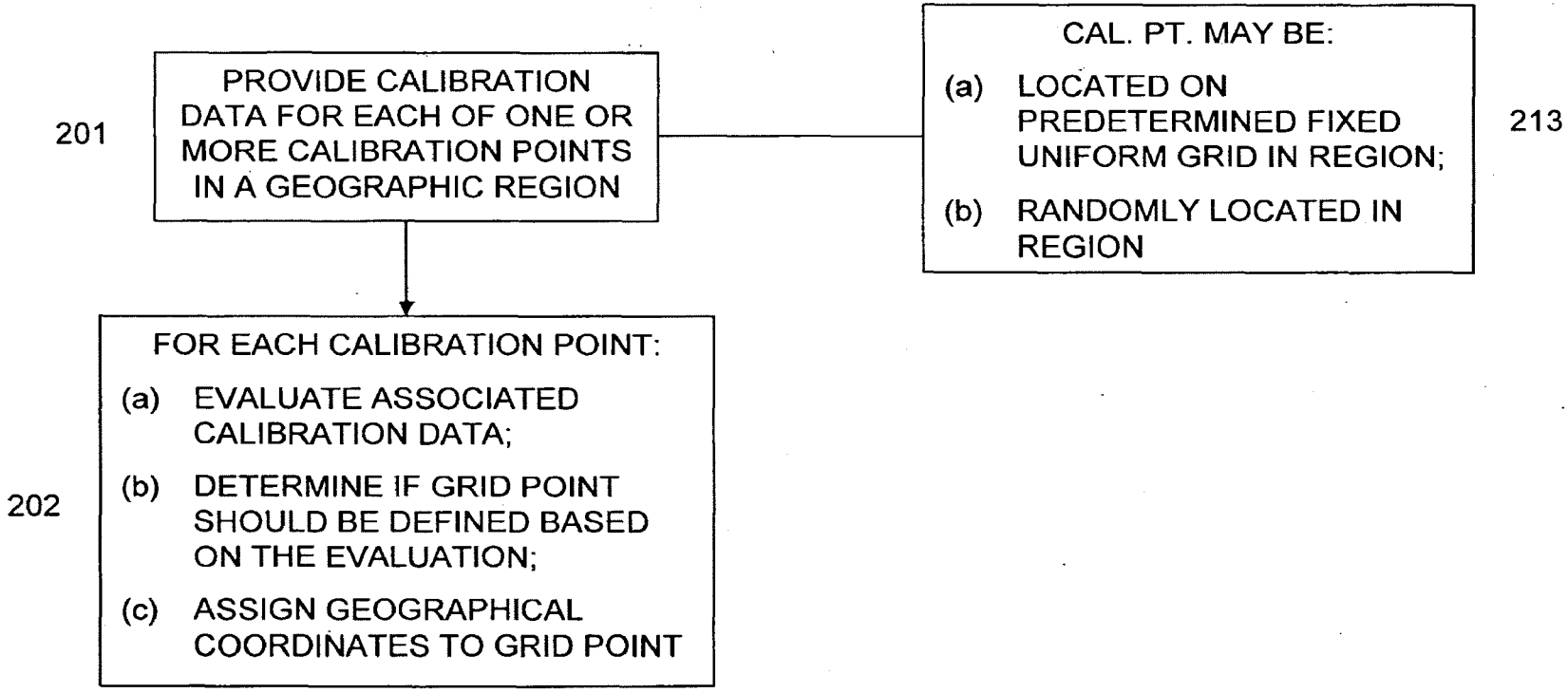

201
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
CAL. PT. MAY BE:
(a) LOCATED ON PREDETERMINED FIXED UNIFORM GRID IN REGION;
(b) RANDOMLY LOCATED IN REGION
213
202
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT

FIGURE 2

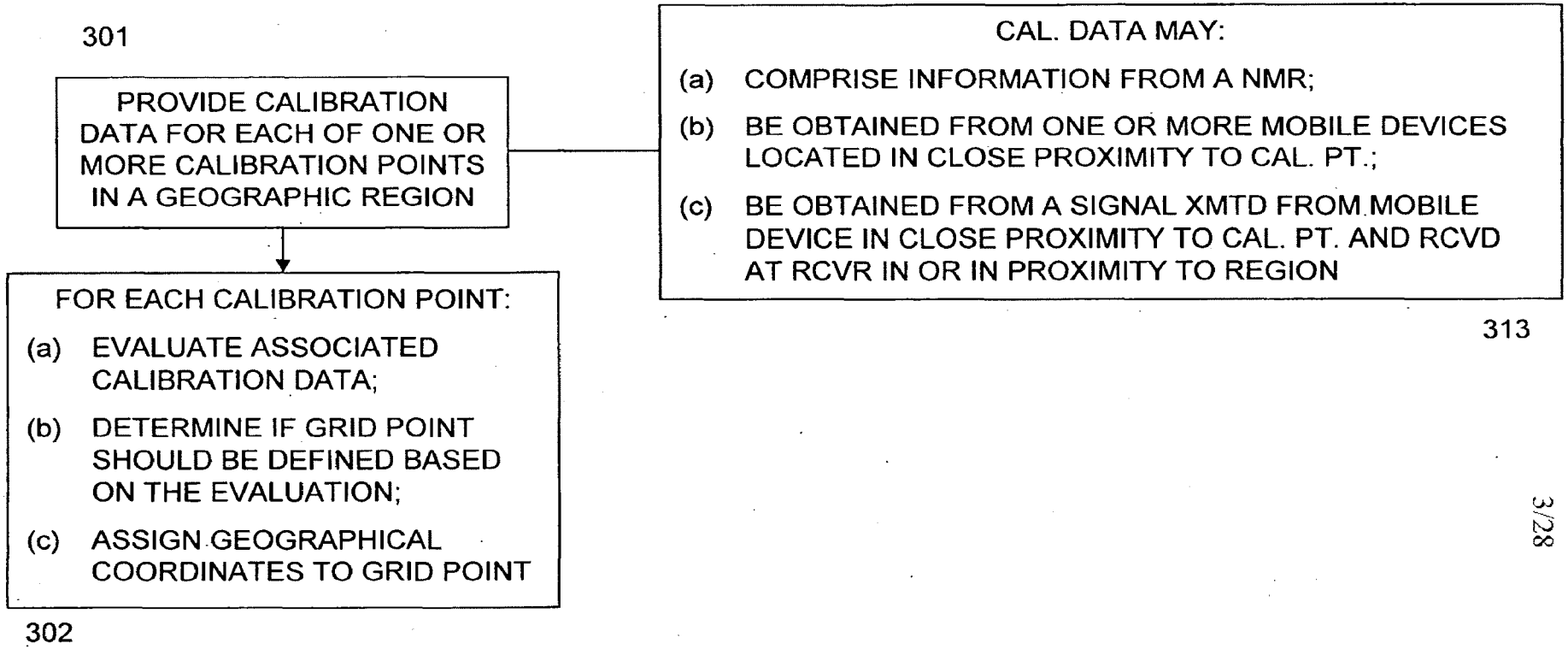

301
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
CAL. DATA MAY:
(a) COMPRISE INFORMATION FROM A NMR;
(b) BE OBTAINED FROM ONE OR MORE MOBILE DEVICES LOCATED IN CLOSE PROXIMITY TO CAL. PT.;
(c) BE OBTAINED FROM A SIGNAL XMTD FROM MOBILE DEVICE IN CLOSE PROXIMITY TO CAL. PT. AND RCVD AT RCVR IN OR IN PROXIMITY TO REGION
313
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
302

FIGURE 3

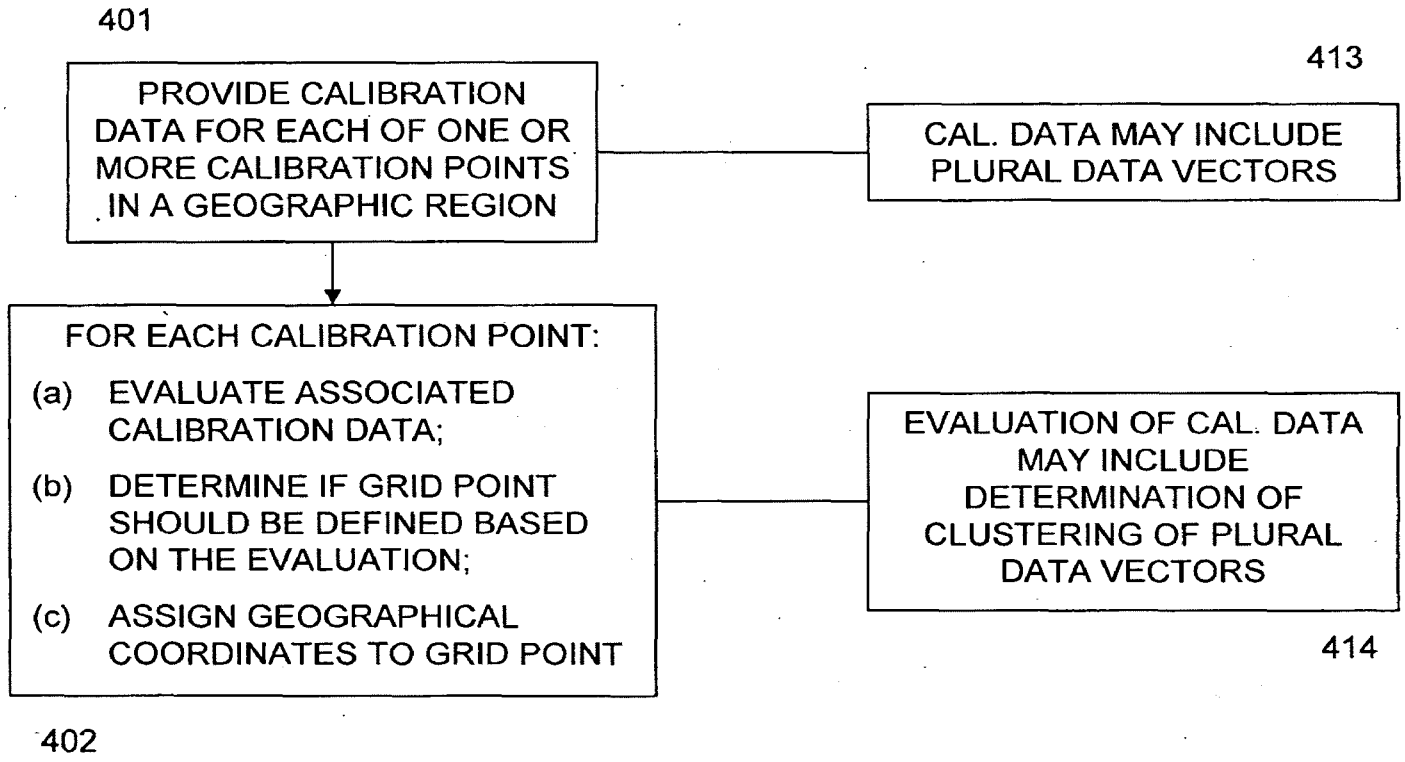

401
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
413
CAL. DATA MAY INCLUDE PLURAL DATA VECTORS
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
EVALUATION OF CAL. DATA MAY INCLUDE DETERMINATION OF CLUSTERING OF PLURAL DATA VECTORS
414
402

FIGURE 4

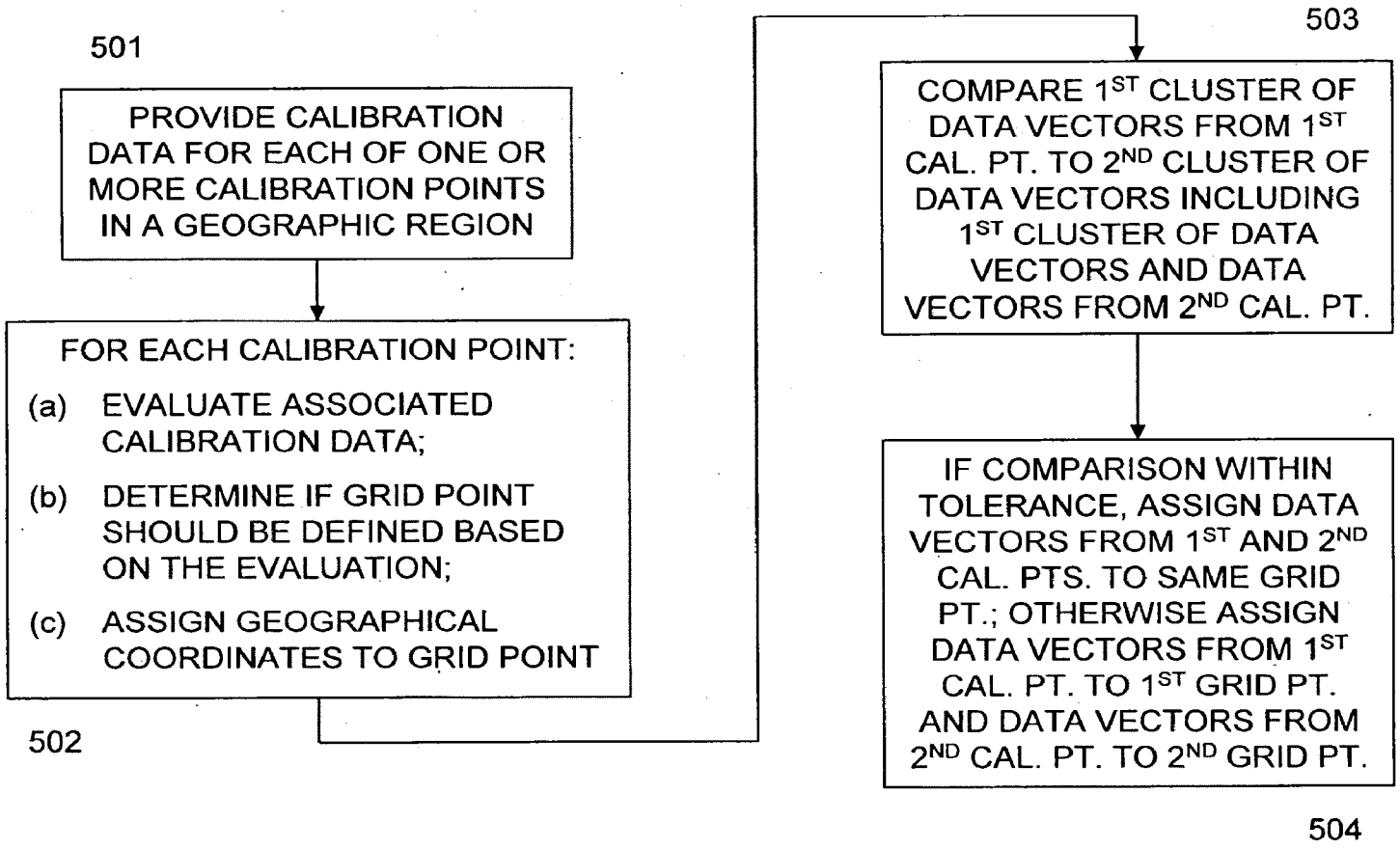

501
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
502
503
COMPARE 1ST CLUSTER OF DATA VECTORS FROM 1ST CAL. PT. TO 2ND CLUSTER OF DATA VECTORS INCLUDING 1ST CLUSTER OF DATA VECTORS AND DATA VECTORS FROM 2ND CAL. PT.
IF COMPARISON WITHIN TOLERANCE, ASSIGN DATA VECTORS FROM 1ST AND 2ND CAL. PTS. TO SAME GRID PT.; OTHERWISE ASSIGN DATA VECTORS FROM 1ST CAL. PT. TO 1ST GRID PT. AND DATA VECTORS FROM 2ND CAL. PT. TO 2ND GRID PT.
504

FIGURE 5

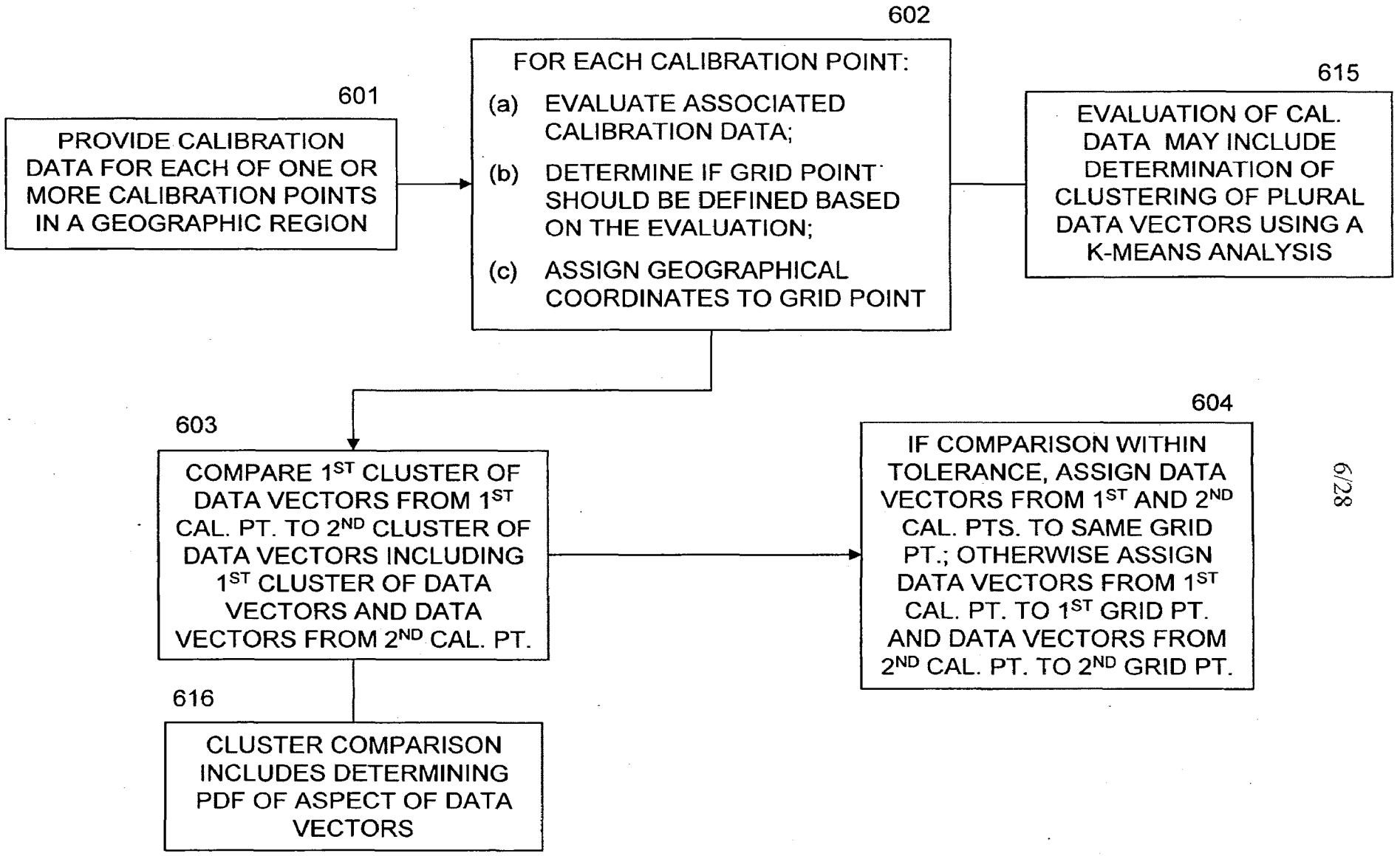

601
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
602
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
615
EVALUATION OF CAL. DATA MAY INCLUDE DETERMINATION OF CLUSTERING OF PLURAL DATA VECTORS USING A K-MEANS ANALYSIS
603
COMPARE 1ST CLUSTER OF DATA VECTORS FROM 1ST CAL. PT. TO 2ND CLUSTER OF DATA VECTORS INCLUDING 1ST CLUSTER OF DATA VECTORS AND DATA VECTORS FROM 2ND CAL. PT.
604
IF COMPARISON WITHIN TOLERANCE, ASSIGN DATA VECTORS FROM 1ST AND 2ND CAL. PTS. TO SAME GRID PT.; OTHERWISE ASSIGN DATA VECTORS FROM 1ST CAL. PT. TO 1ST GRID PT. AND DATA VECTORS FROM 2ND CAL. PT. TO 2ND GRID PT.
616
CLUSTER COMPARISON INCLUDES DETERMINING PDF OF ASPECT OF DATA VECTORS

FIGURE 6

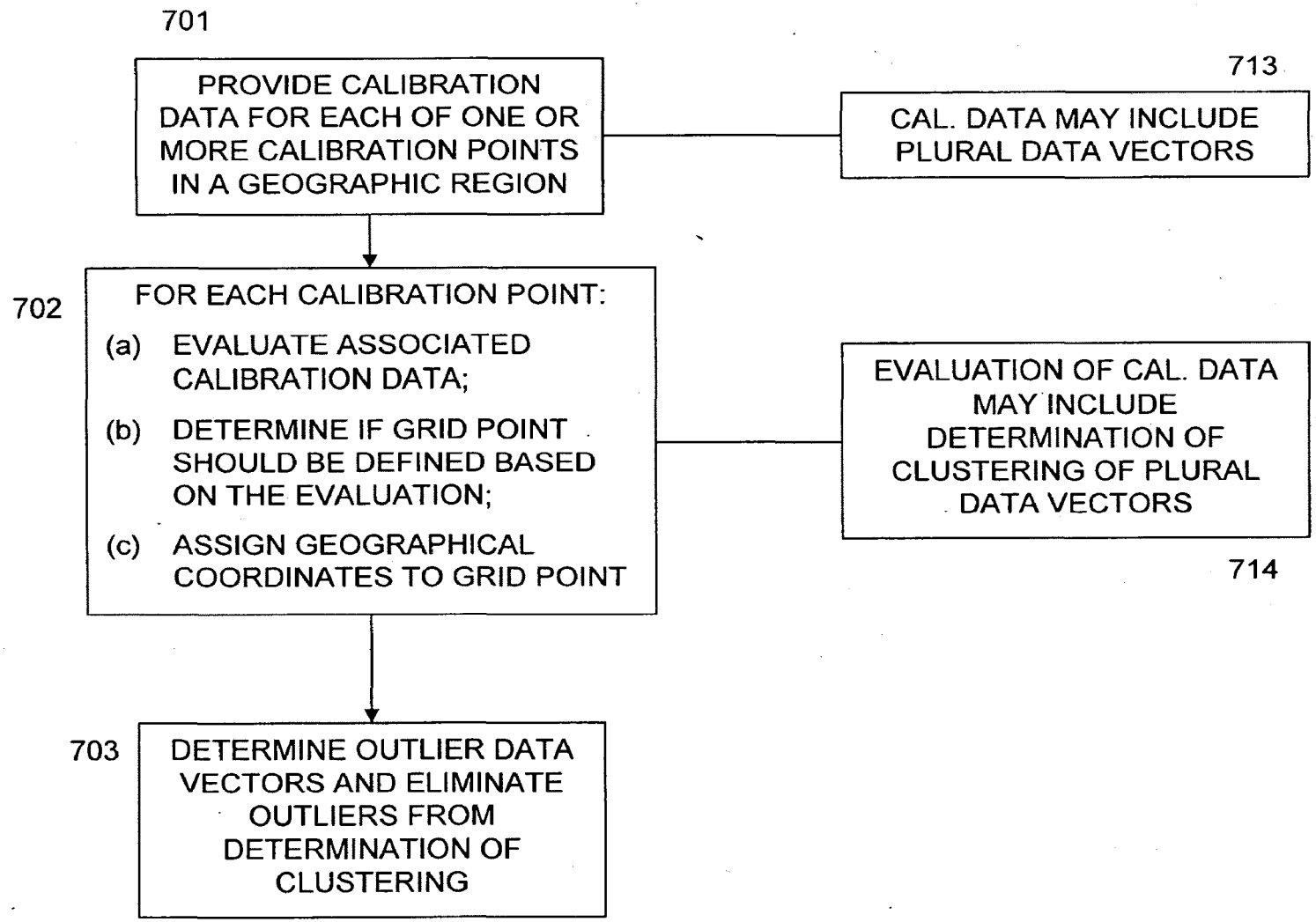

701
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
713
CAL. DATA MAY INCLUDE PLURAL DATA VECTORS
702
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
EVALUATION OF CAL. DATA MAY INCLUDE DETERMINATION OF CLUSTERING OF PLURAL DATA VECTORS
714
703
DETERMINE OUTLIER DATA VECTORS AND ELIMINATE OUTLIERS FROM DETERMINATION OF CLUSTERING

FIGURE 7

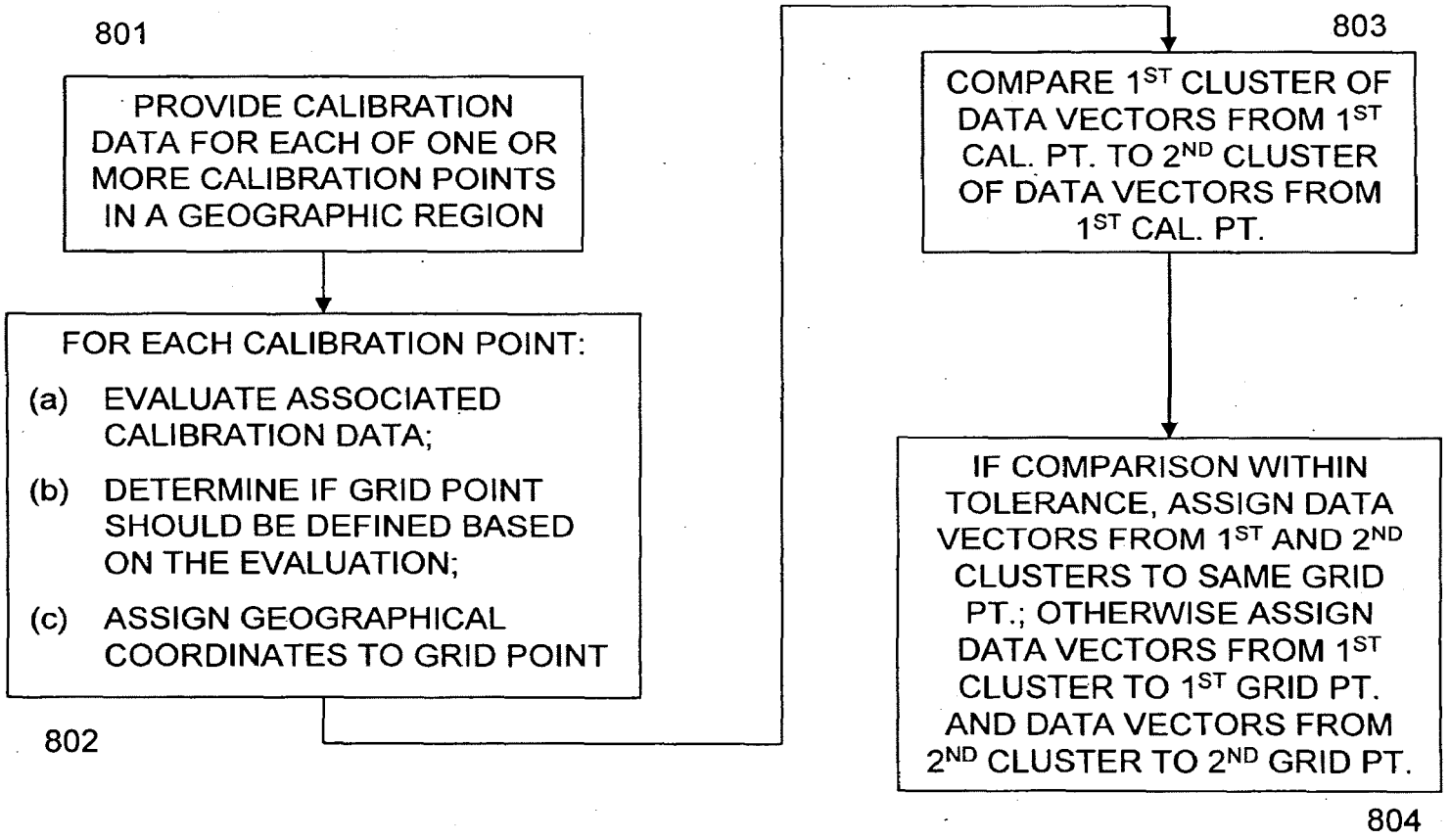

801
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
802
803
COMPARE 1ST CLUSTER OF DATA VECTORS FROM 1ST CAL. PT. TO 2ND CLUSTER OF DATA VECTORS FROM 1ST CAL. PT.
IF COMPARISON WITHIN TOLERANCE, ASSIGN DATA VECTORS FROM 1ST AND 2ND CLUSTERS TO SAME GRID PT.; OTHERWISE ASSIGN DATA VECTORS FROM 1ST CLUSTER TO 1ST GRID PT. AND DATA VECTORS FROM 2ND CLUSTER TO 2ND GRID PT.
804

FIGURE 8

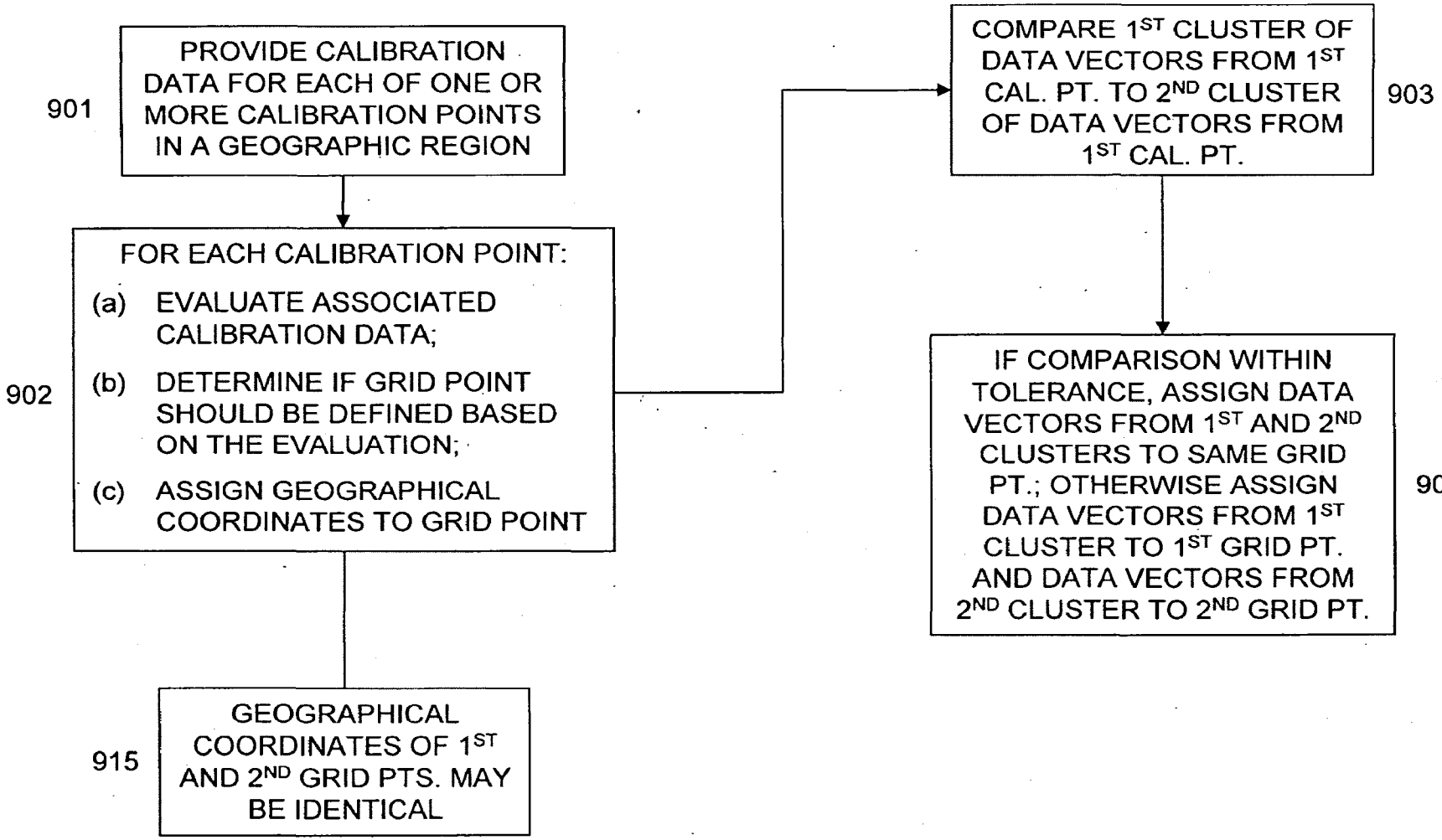

PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
901
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
902
GEOGRAPHICAL COORDINATES OF 1ST AND 2ND GRID PTS. MAY BE IDENTICAL
915
COMPARE 1ST CLUSTER OF DATA VECTORS FROM 1ST CAL. PT. TO 2ND CLUSTER OF DATA VECTORS FROM 1ST CAL. PT.
903
IF COMPARISON WITHIN TOLERANCE, ASSIGN DATA VECTORS FROM 1ST AND 2ND CLUSTERS TO SAME GRID PT.; OTHERWISE ASSIGN DATA VECTORS FROM 1ST CLUSTER TO 1ST GRID PT. AND DATA VECTORS FROM 2ND CLUSTER TO 2ND GRID PT.
904

FIGURE 9

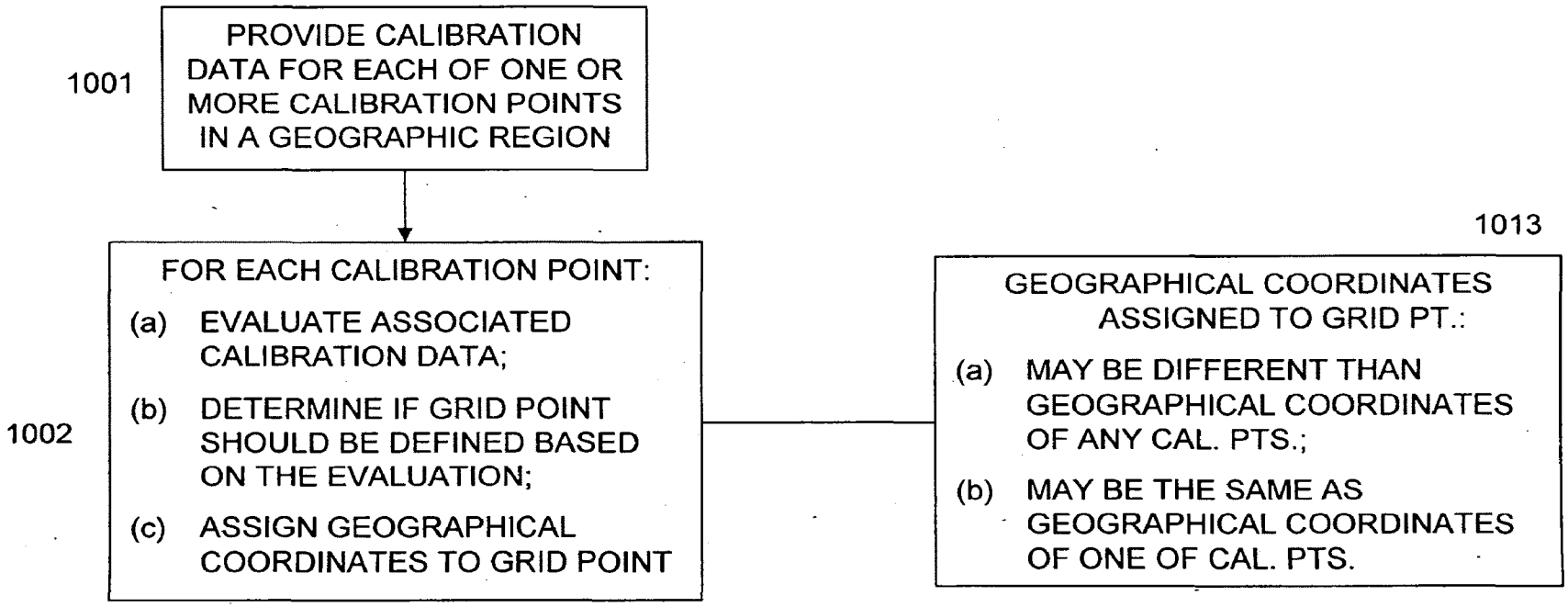

1001
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
1002
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
1013
GEOGRAPHICAL COORDINATES ASSIGNED TO GRID PT.:
(a) MAY BE DIFFERENT THAN GEOGRAPHICAL COORDINATES OF ANY CAL. PTS.;
(b) MAY BE THE SAME AS GEOGRAPHICAL COORDINATES OF ONE OF CAL. PTS.

FIGURE 10

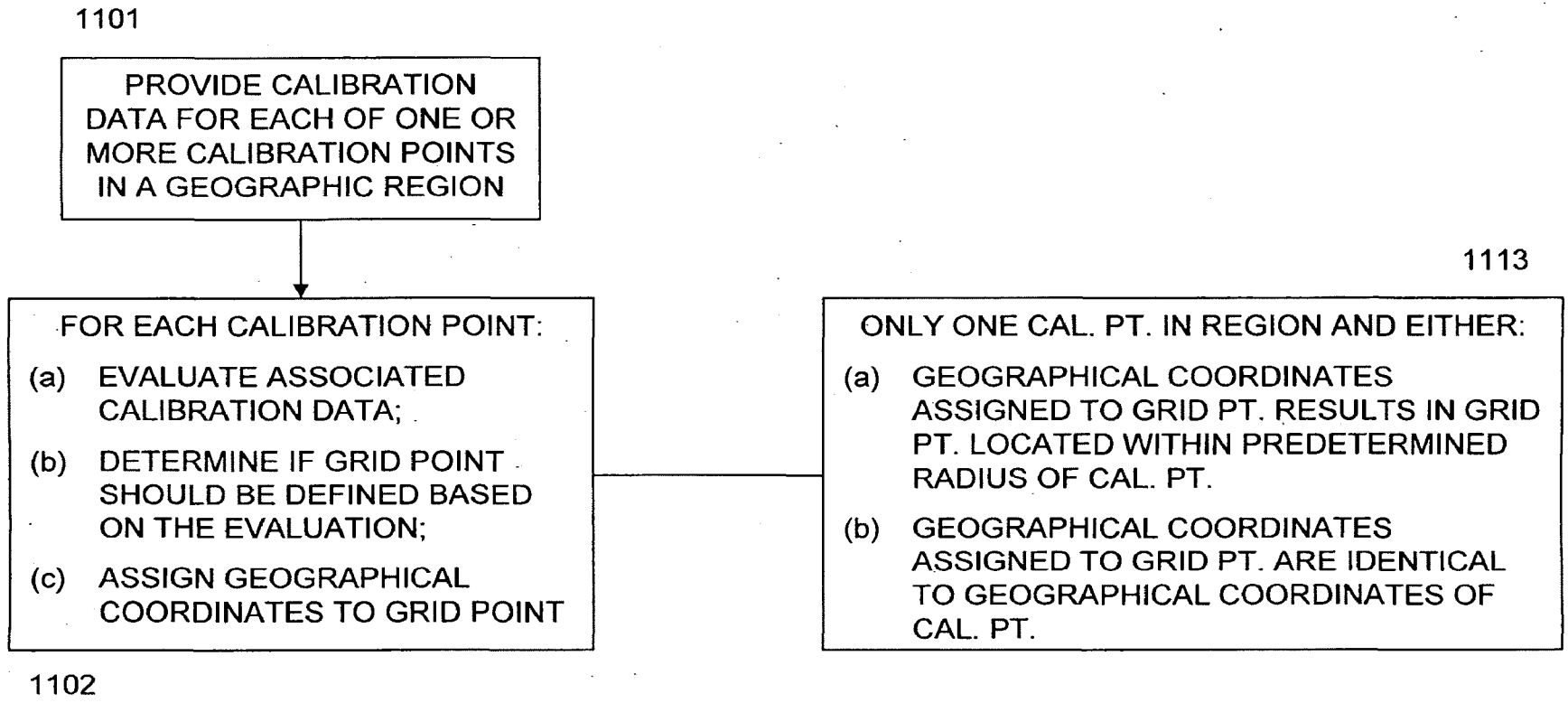

1101
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
1113
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
ONLY ONE CAL. PT. IN REGION AND EITHER:
(a) GEOGRAPHICAL COORDINATES ASSIGNED TO GRID PT. RESULTS IN GRID PT. LOCATED WITHIN PREDETERMINED RADIUS OF CAL. PT.
(b) GEOGRAPHICAL COORDINATES ASSIGNED TO GRID PT. ARE IDENTICAL TO GEOGRAPHICAL COORDINATES OF CAL. PT.
1102

FIGURE 11

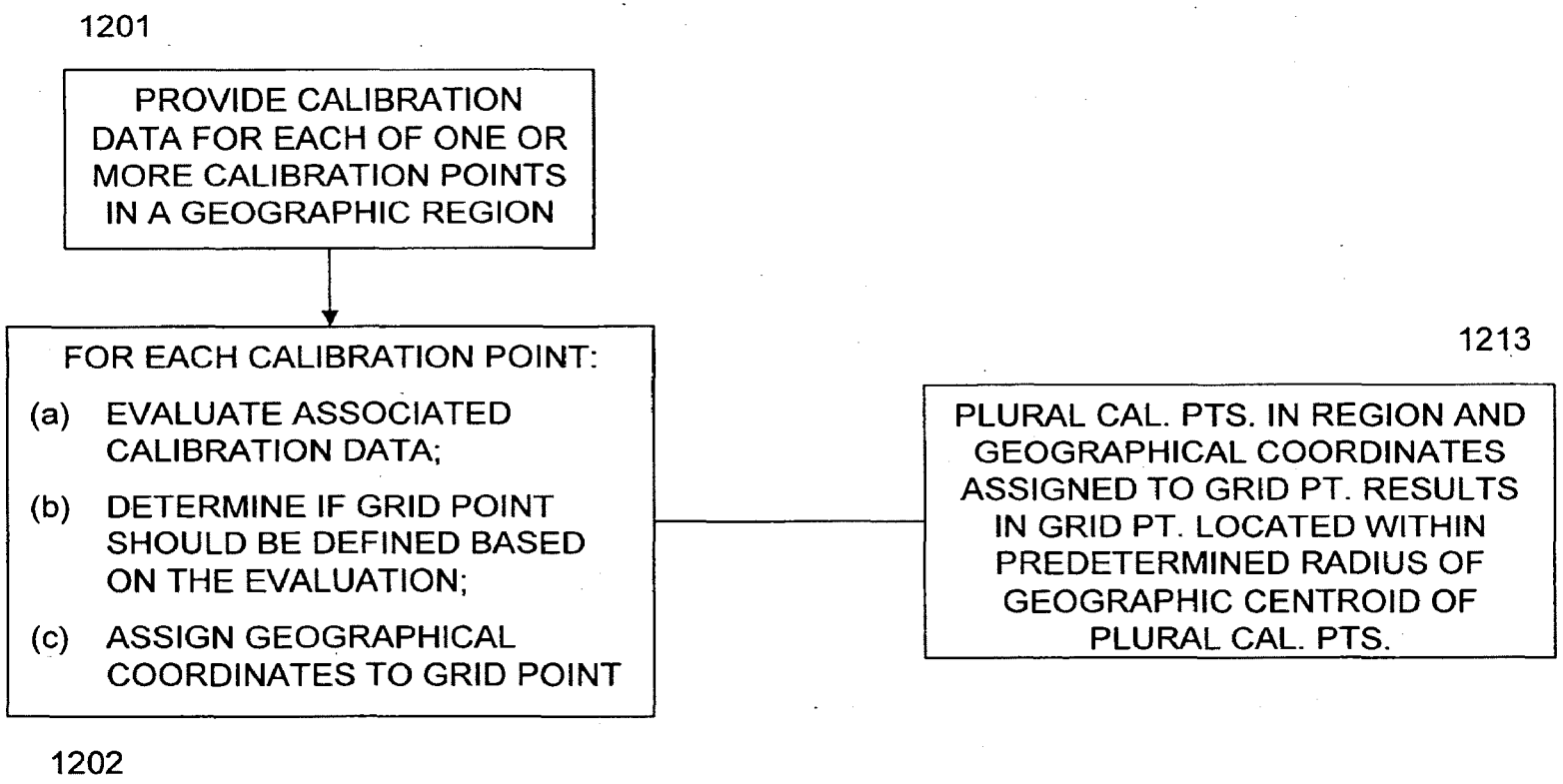

1201
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
1202
1213
PLURAL CAL. PTS. IN REGION AND GEOGRAPHICAL COORDINATES ASSIGNED TO GRID PT. RESULTS IN GRID PT. LOCATED WITHIN PREDETERMINED RADIUS OF GEOGRAPHIC CENTROID OF PLURAL CAL. PTS.

FIGURE 12

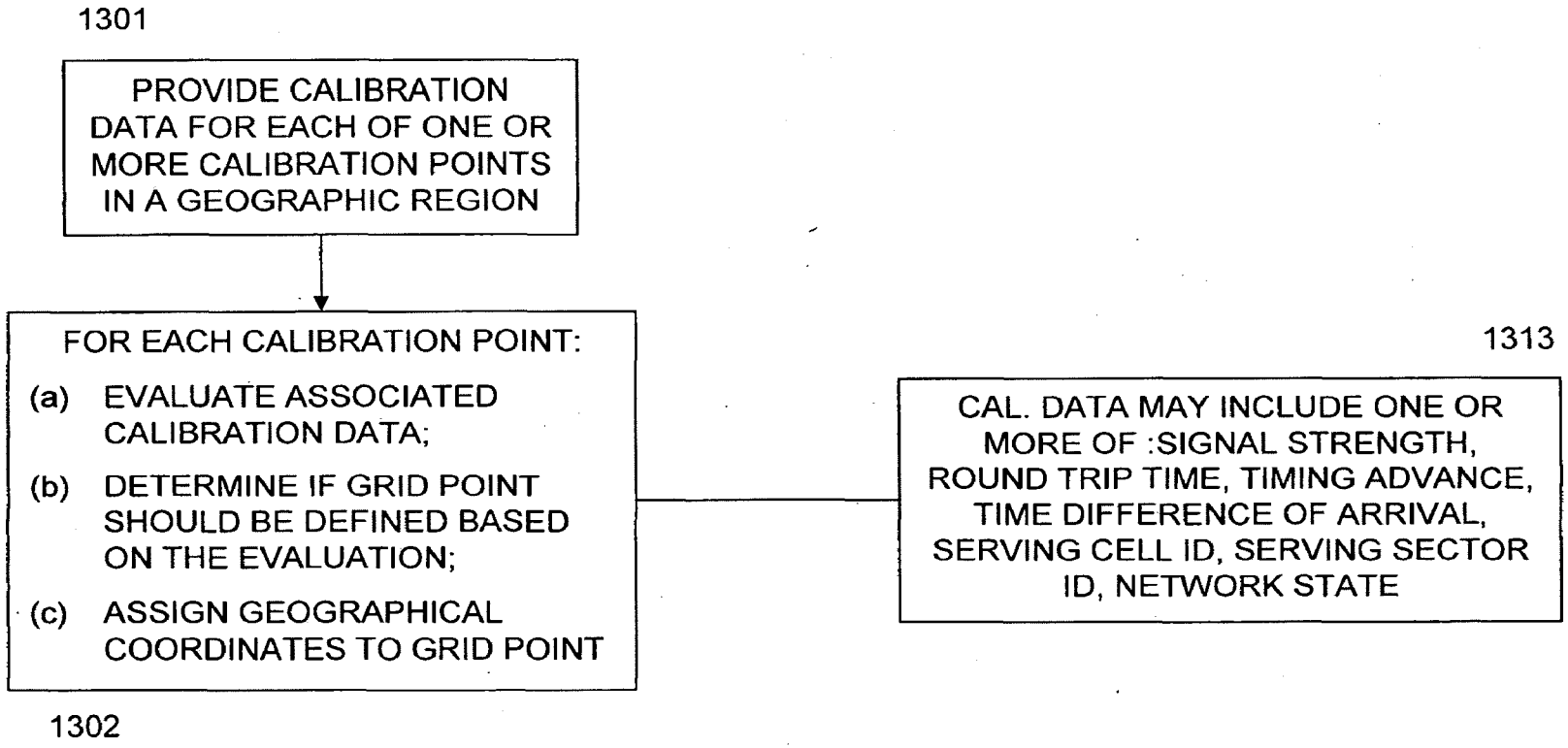

1301
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
1302
1313
CAL. DATA MAY INCLUDE ONE OR MORE OF :SIGNAL STRENGTH, ROUND TRIP TIME, TIMING ADVANCE, TIME DIFFERENCE OF ARRIVAL, SERVING CELL ID, SERVING SECTOR ID, NETWORK STATE

FIGURE 13

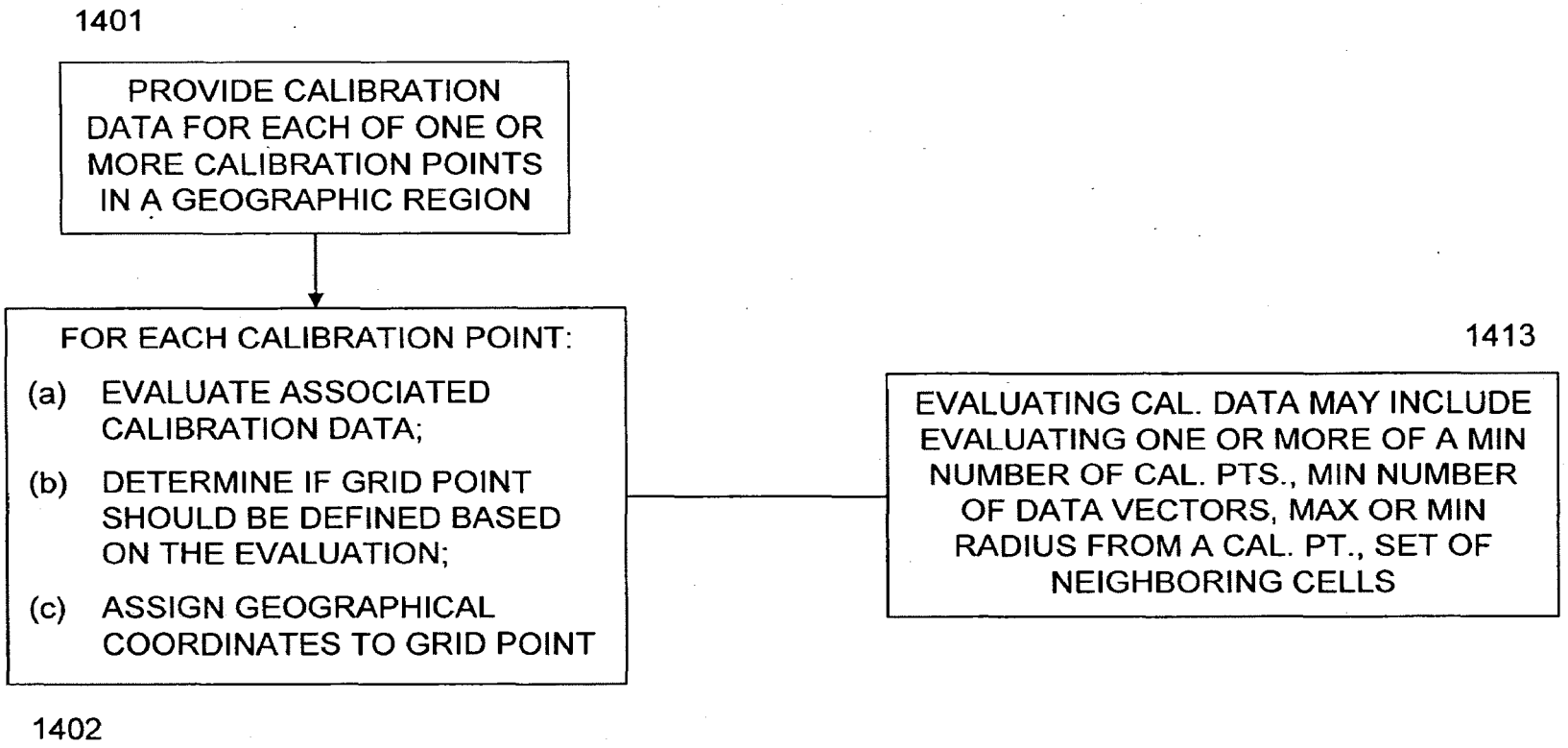

1401
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
1402
1413
EVALUATING CAL. DATA MAY INCLUDE EVALUATING ONE OR MORE OF A MIN NUMBER OF CAL. PTS., MIN NUMBER OF DATA VECTORS, MAX OR MIN RADIUS FROM A CAL. PT., SET OF NEIGHBORING CELLS

FIGURE 14

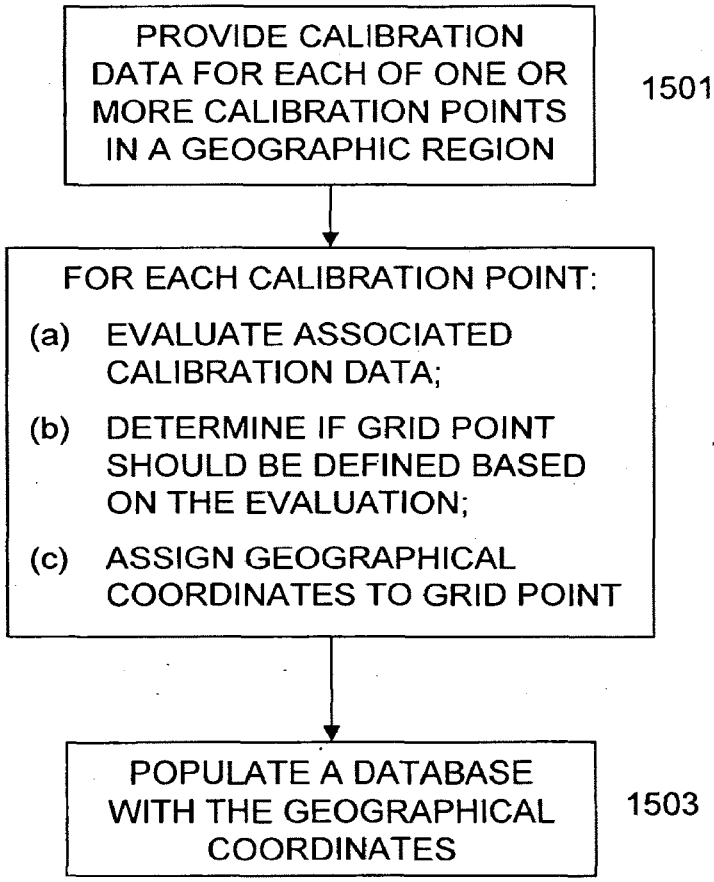

PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
1501
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
1502
POPULATE A DATABASE WITH THE GEOGRAPHICAL COORDINATES
1503

FIGURE 15

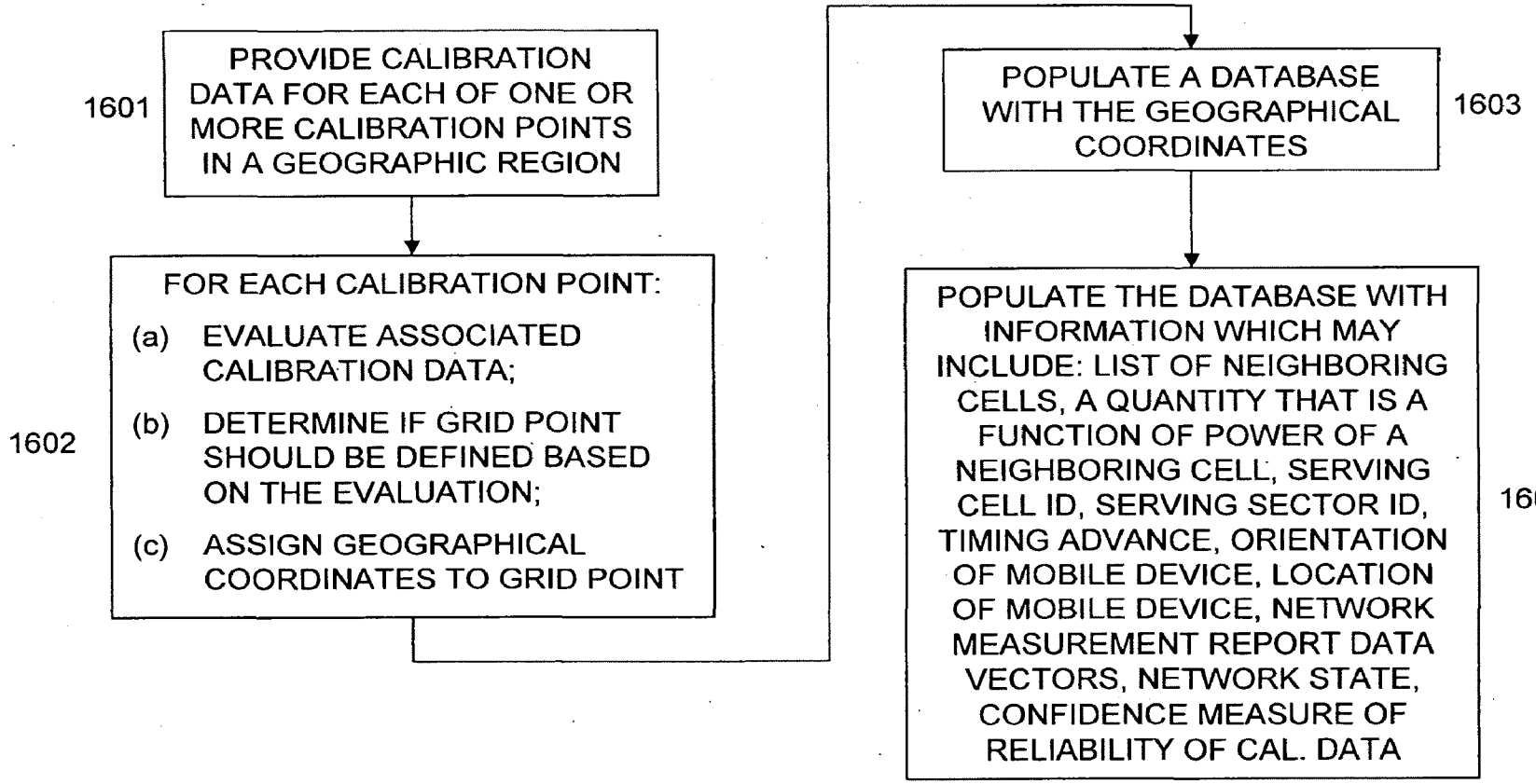

1601
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
1602
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
1603
POPULATE A DATABASE WITH THE GEOGRAPHICAL COORDINATES
1604
POPULATE THE DATABASE WITH INFORMATION WHICH MAY INCLUDE: LIST OF NEIGHBORING CELLS, A QUANTITY THAT IS A FUNCTION OF POWER OF A NEIGHBORING CELL, SERVING CELL ID, SERVING SECTOR ID, TIMING ADVANCE, ORIENTATION OF MOBILE DEVICE, LOCATION OF MOBILE DEVICE, NETWORK MEASUREMENT REPORT DATA VECTORS, NETWORK STATE, CONFIDENCE MEASURE OF RELIABILITY OF CAL. DATA

FIGURE 16

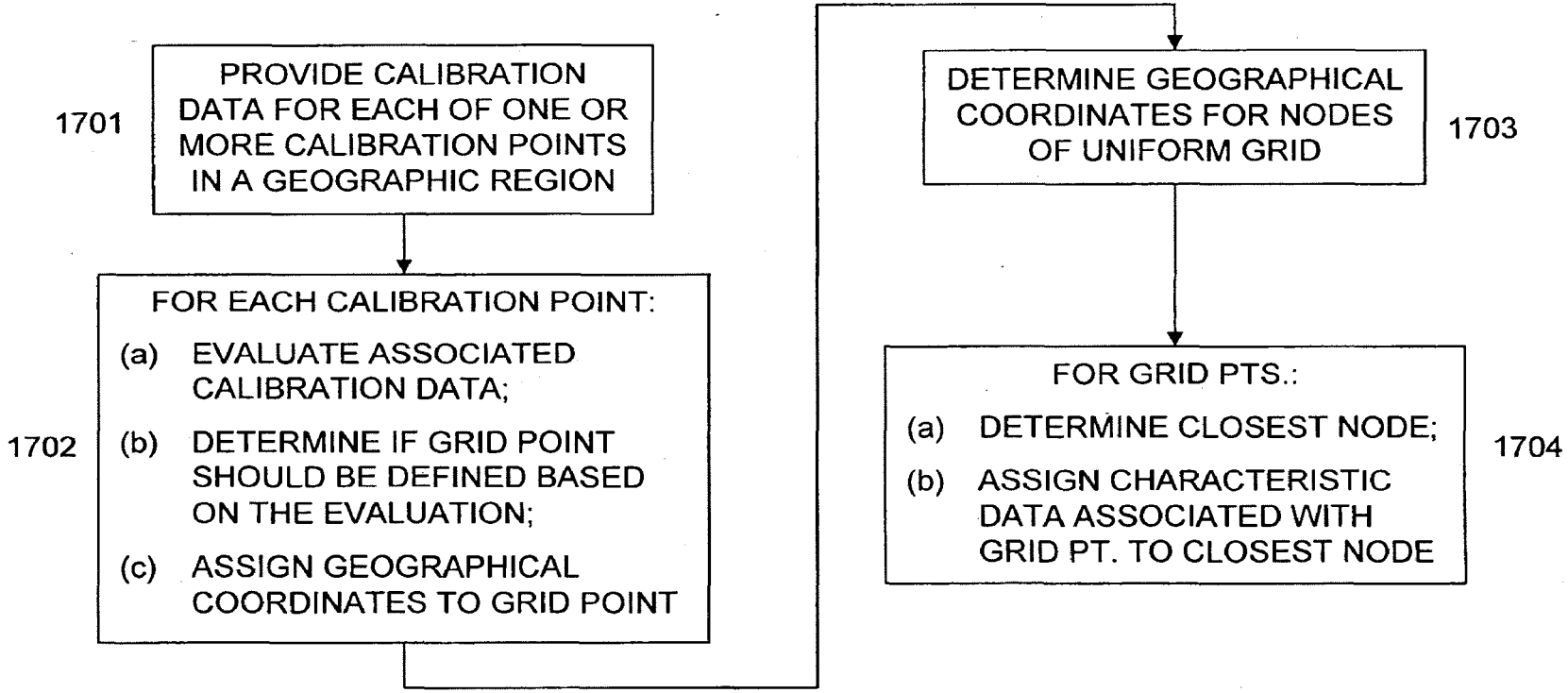

1701
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
1702
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
1703
DETERMINE GEOGRAPHICAL COORDINATES FOR NODES OF UNIFORM GRID
1704
FOR GRID PTS.:
(a) DETERMINE CLOSEST NODE;
(b) ASSIGN CHARACTERISTIC DATA ASSOCIATED WITH GRID PT. TO CLOSEST NODE

FIGURE 17

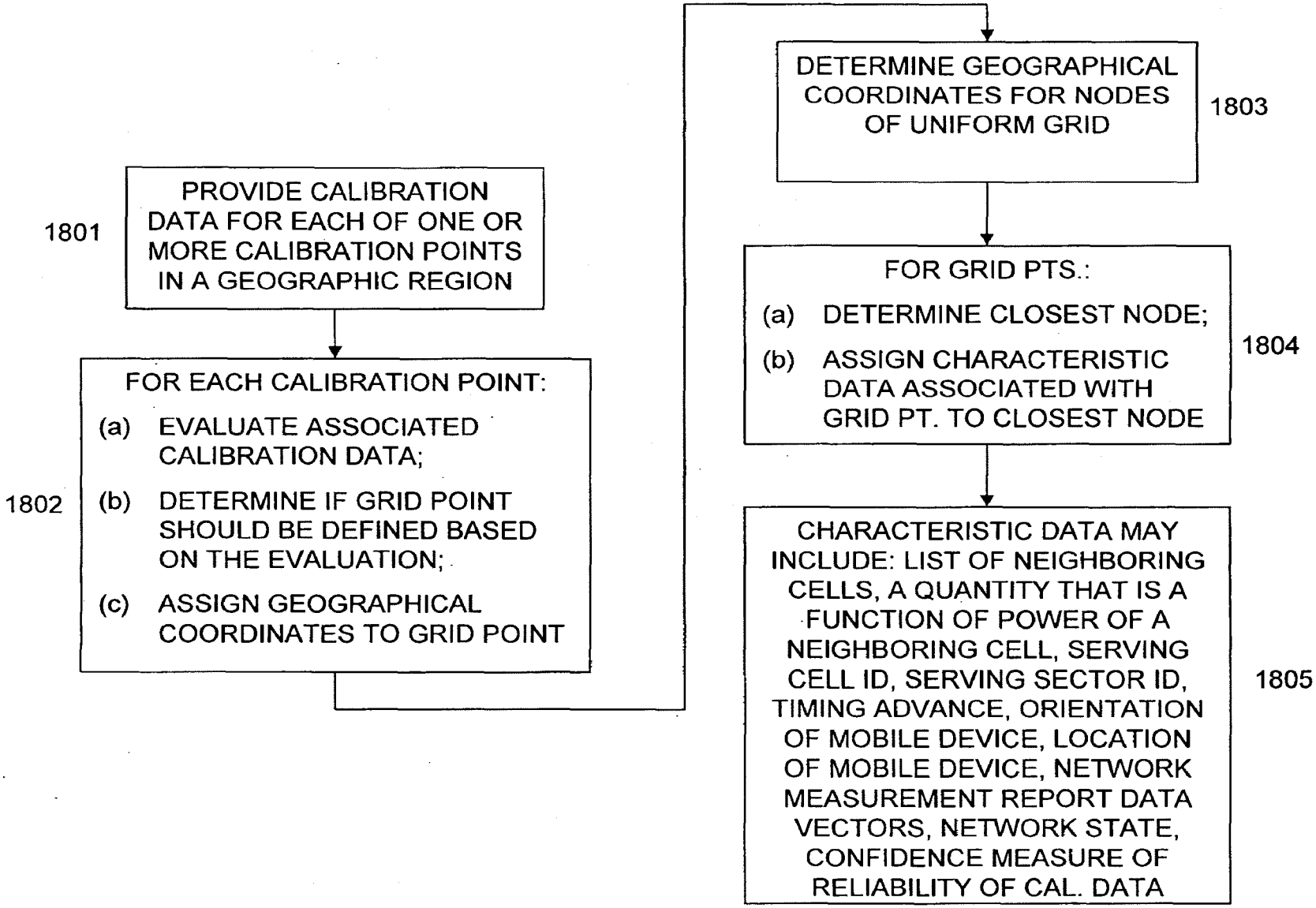

1801
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
1802
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
1803
DETERMINE GEOGRAPHICAL COORDINATES FOR NODES OF UNIFORM GRID
1804
FOR GRID PTS.:
(a) DETERMINE CLOSEST NODE;
(b) ASSIGN CHARACTERISTIC DATA ASSOCIATED WITH GRID PT. TO CLOSEST NODE
1805
CHARACTERISTIC DATA MAY INCLUDE: LIST OF NEIGHBORING CELLS, A QUANTITY THAT IS A FUNCTION OF POWER OF A NEIGHBORING CELL, SERVING CELL ID, SERVING SECTOR ID, TIMING ADVANCE, ORIENTATION OF MOBILE DEVICE, LOCATION OF MOBILE DEVICE, NETWORK MEASUREMENT REPORT DATA VECTORS, NETWORK STATE, CONFIDENCE MEASURE OF RELIABILITY OF CAL. DATA

FIGURE 18

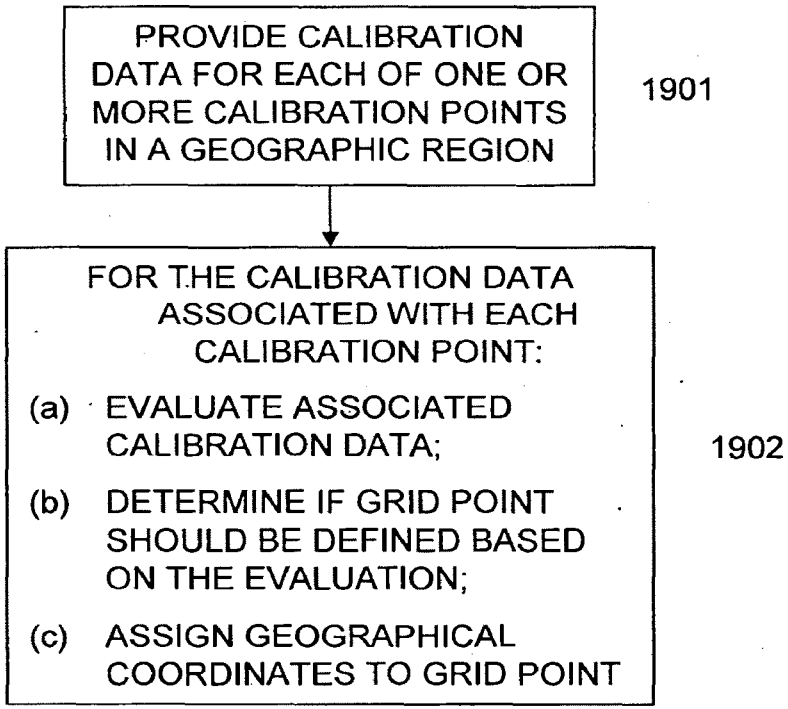

PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
1901
FOR THE CALIBRATION DATA ASSOCIATED WITH EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
1902

FIGURE 19

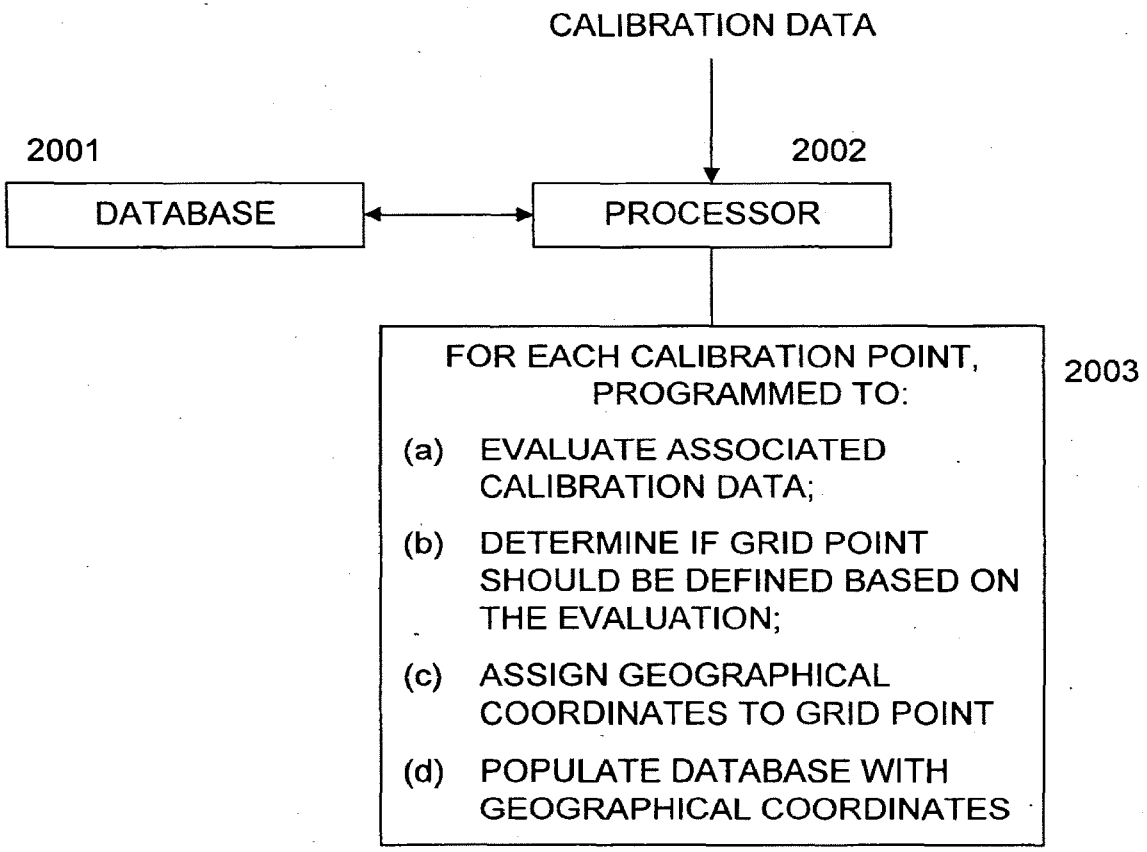

CALIBRATION DATA
2001
2002
DATABASE
PROCESSOR
FOR EACH CALIBRATION POINT, PROGRAMMED TO:
2003
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
(d) POPULATE DATABASE WITH GEOGRAPHICAL COORDINATES

FIGURE 20

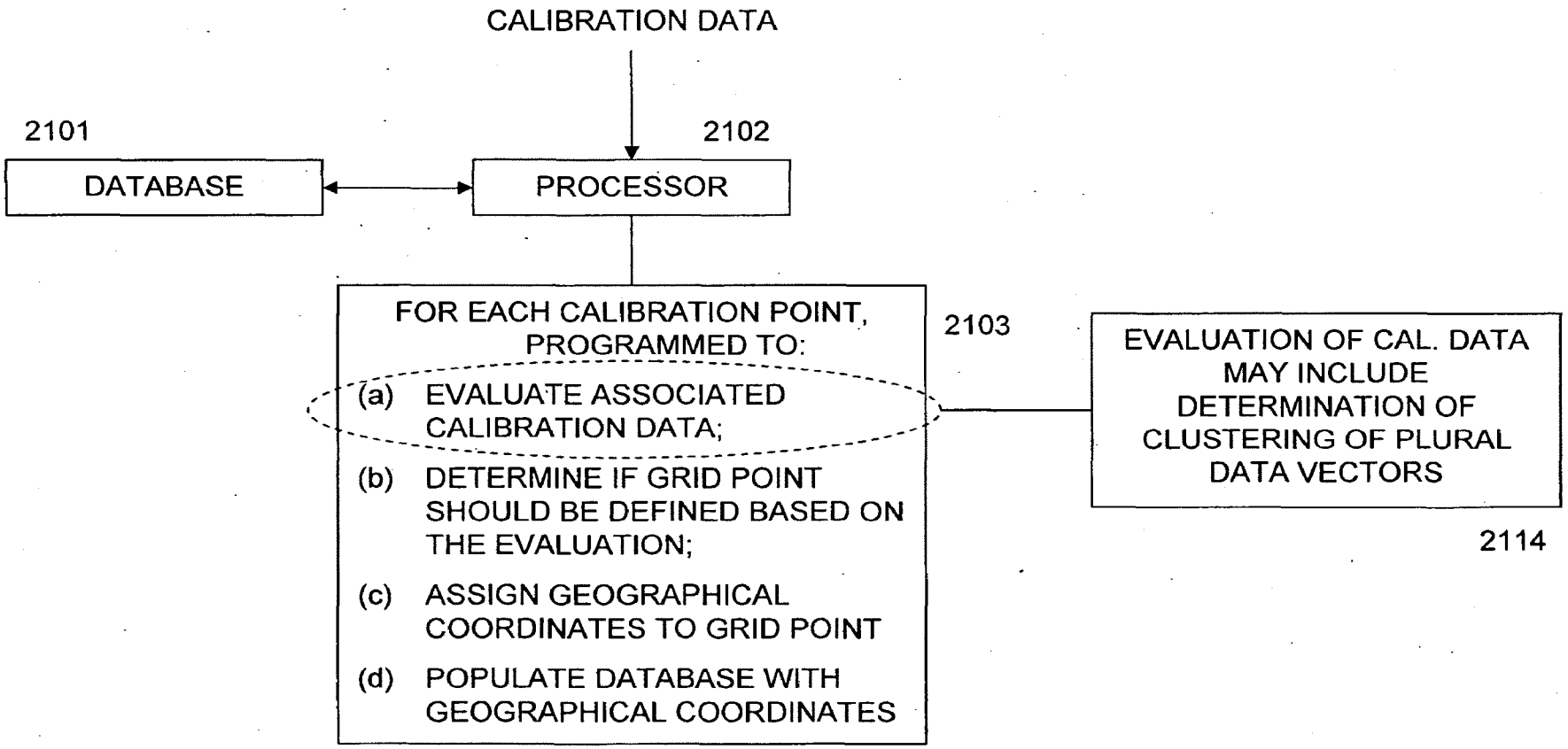

CALIBRATION DATA
2101
2102
DATABASE
PROCESSOR
FOR EACH CALIBRATION POINT, PROGRAMMED TO:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
(d) POPULATE DATABASE WITH GEOGRAPHICAL COORDINATES
2103
EVALUATION OF CAL. DATA MAY INCLUDE DETERMINATION OF CLUSTERING OF PLURAL DATA VECTORS
2114

FIGURE 21

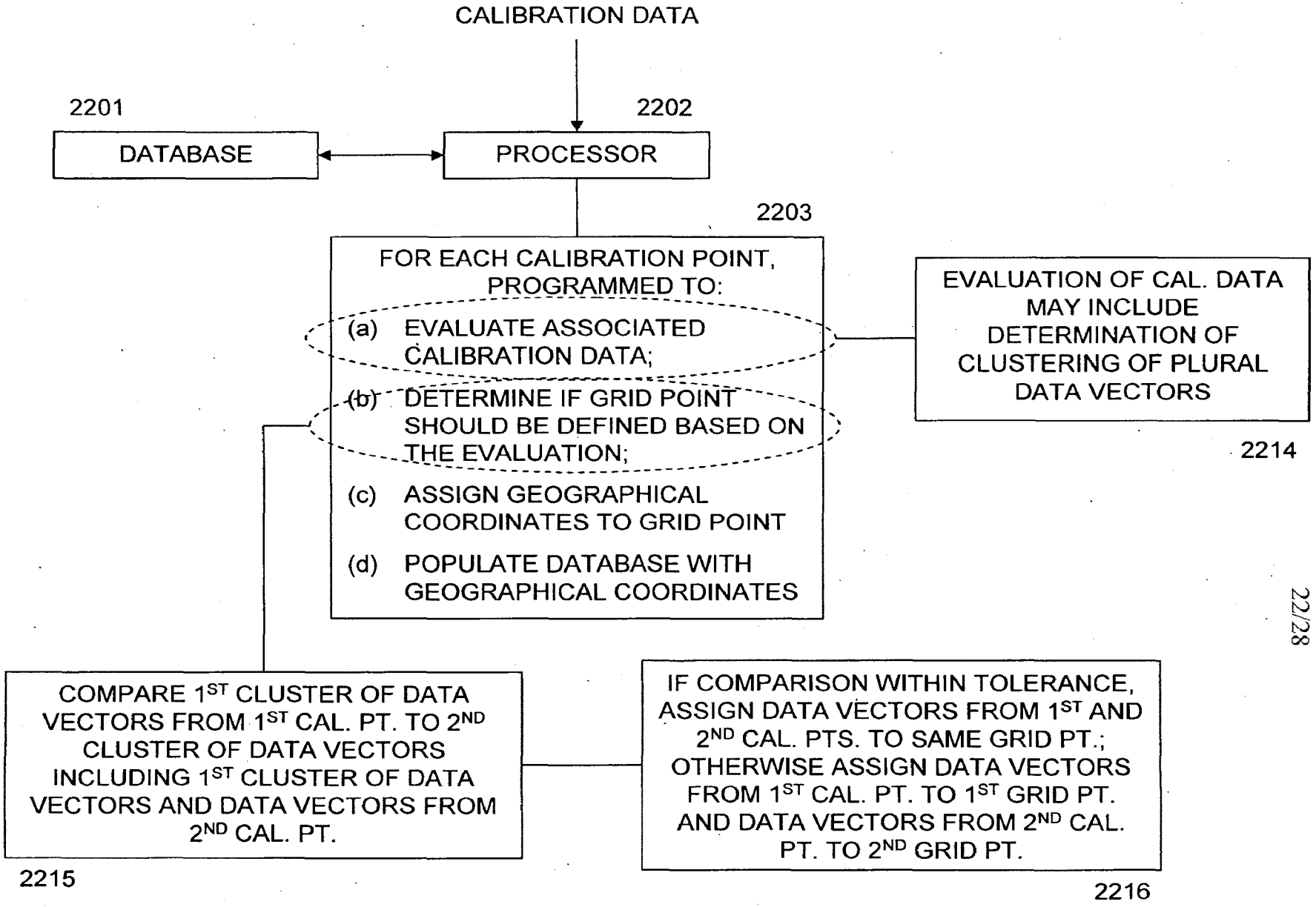

CALIBRATION DATA
2201
2202
DATABASE
PROCESSOR
2203
FOR EACH CALIBRATION POINT, PROGRAMMED TO:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
(d) POPULATE DATABASE WITH GEOGRAPHICAL COORDINATES
EVALUATION OF CAL. DATA MAY INCLUDE DETERMINATION OF CLUSTERING OF PLURAL DATA VECTORS
2214
COMPARE 1ST CLUSTER OF DATA VECTORS FROM 1ST CAL. PT. TO 2ND CLUSTER OF DATA VECTORS INCLUDING 1ST CLUSTER OF DATA VECTORS AND DATA VECTORS FROM 2ND CAL. PT.
2215
IF COMPARISON WITHIN TOLERANCE, ASSIGN DATA VECTORS FROM 1ST AND 2ND CAL. PTS. TO SAME GRID PT.; OTHERWISE ASSIGN DATA VECTORS FROM 1ST CAL. PT. TO 1ST GRID PT. AND DATA VECTORS FROM 2ND CAL. PT. TO 2ND GRID PT.
2216

FIGURE 22

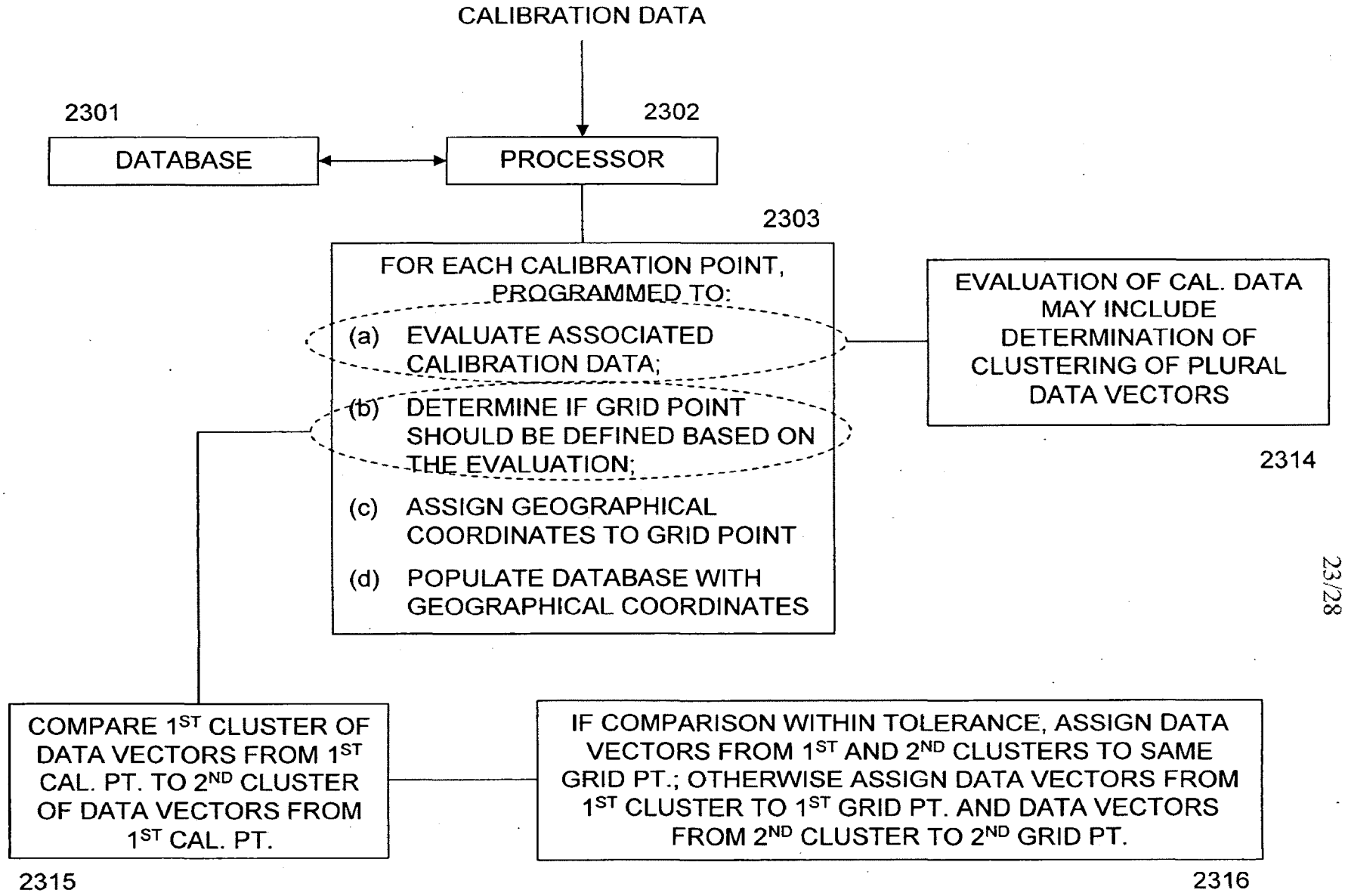

CALIBRATION DATA
2301
2302
DATABASE
PROCESSOR
2303
FOR EACH CALIBRATION POINT, PROGRAMMED TO:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
(d) POPULATE DATABASE WITH GEOGRAPHICAL COORDINATES
EVALUATION OF CAL. DATA MAY INCLUDE DETERMINATION OF CLUSTERING OF PLURAL DATA VECTORS
2314
COMPARE 1ST CLUSTER OF DATA VECTORS FROM 1ST CAL. PT. TO 2ND CLUSTER OF DATA VECTORS FROM 1ST CAL. PT.
2315
IF COMPARISON WITHIN TOLERANCE, ASSIGN DATA VECTORS FROM 1ST AND 2ND CLUSTERS TO SAME GRID PT.; OTHERWISE ASSIGN DATA VECTORS FROM 1ST CLUSTER TO 1ST GRID PT. AND DATA VECTORS FROM 2ND CLUSTER TO 2ND GRID PT.
2316

FIGURE 23

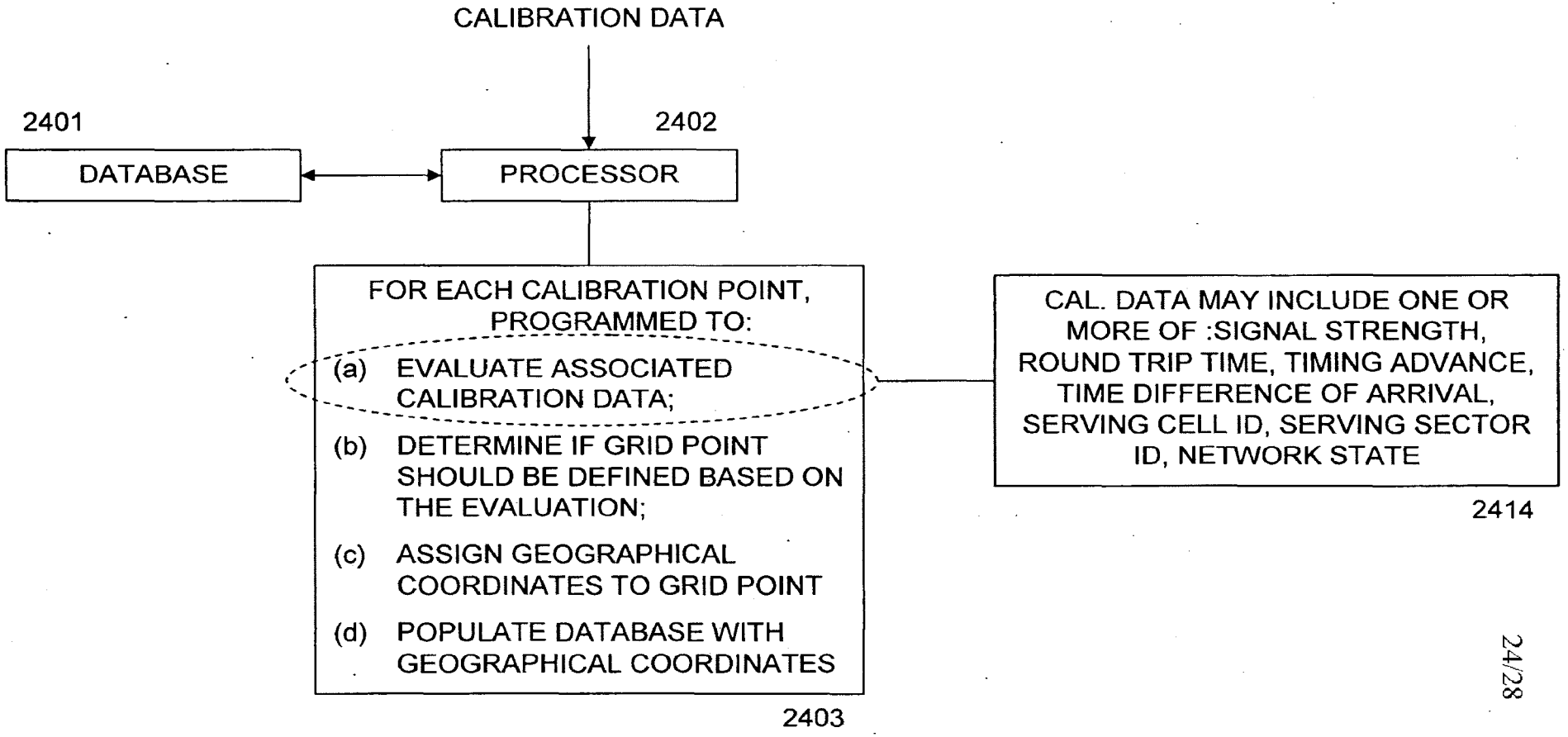

CALIBRATION DATA
2401
2402
DATABASE
PROCESSOR
FOR EACH CALIBRATION POINT, PROGRAMMED TO:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
(d) POPULATE DATABASE WITH GEOGRAPHICAL COORDINATES
2403
CAL. DATA MAY INCLUDE ONE OR MORE OF :SIGNAL STRENGTH, ROUND TRIP TIME, TIMING ADVANCE, TIME DIFFERENCE OF ARRIVAL, SERVING CELL ID, SERVING SECTOR ID, NETWORK STATE
2414

FIGURE 24

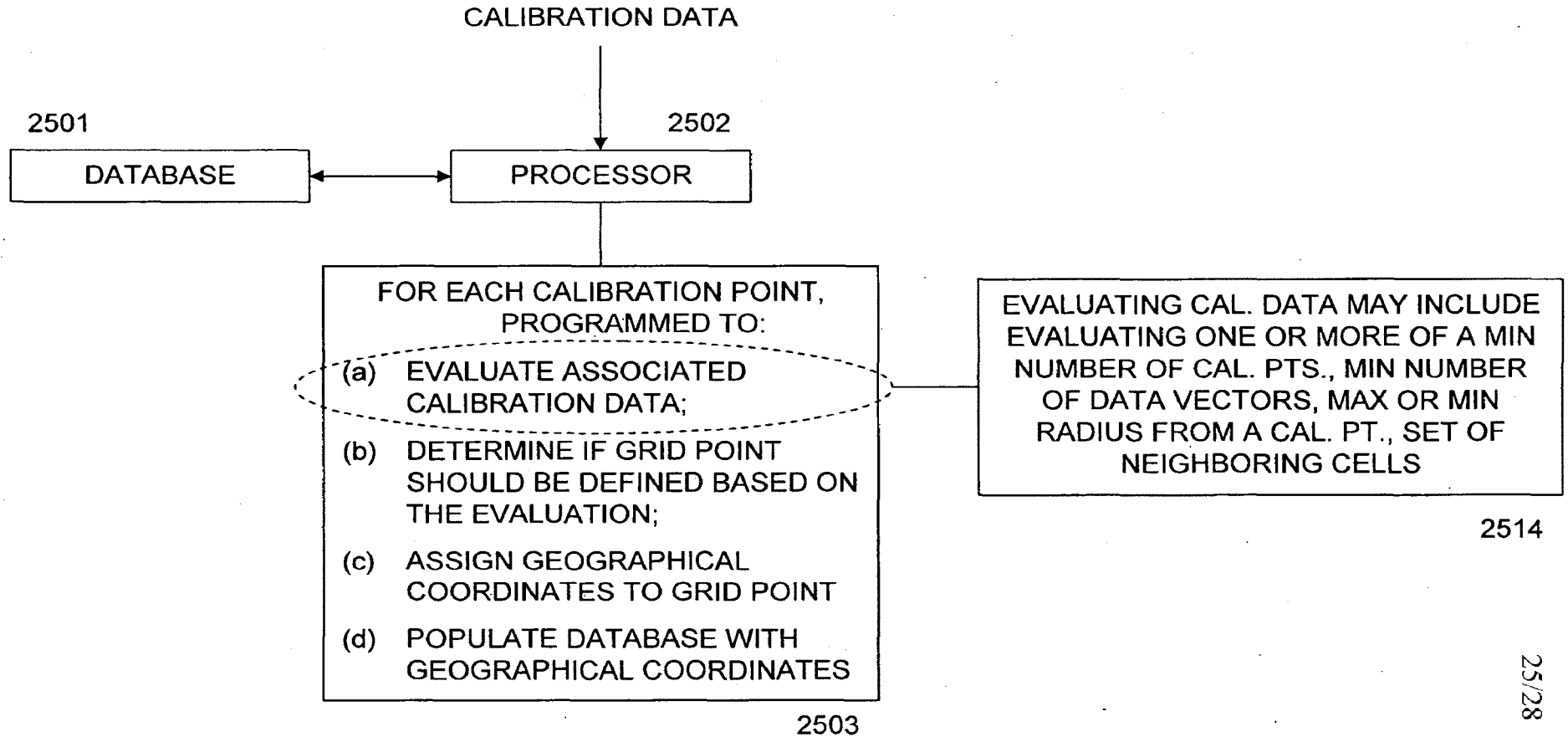

CALIBRATION DATA
2501
2502
DATABASE
PROCESSOR
FOR EACH CALIBRATION POINT, PROGRAMMED TO:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
(d) POPULATE DATABASE WITH GEOGRAPHICAL COORDINATES
2503
EVALUATING CAL. DATA MAY INCLUDE EVALUATING ONE OR MORE OF A MIN NUMBER OF CAL. PTS., MIN NUMBER OF DATA VECTORS, MAX OR MIN RADIUS FROM A CAL. PT., SET OF NEIGHBORING CELLS
2514

FIGURE 25

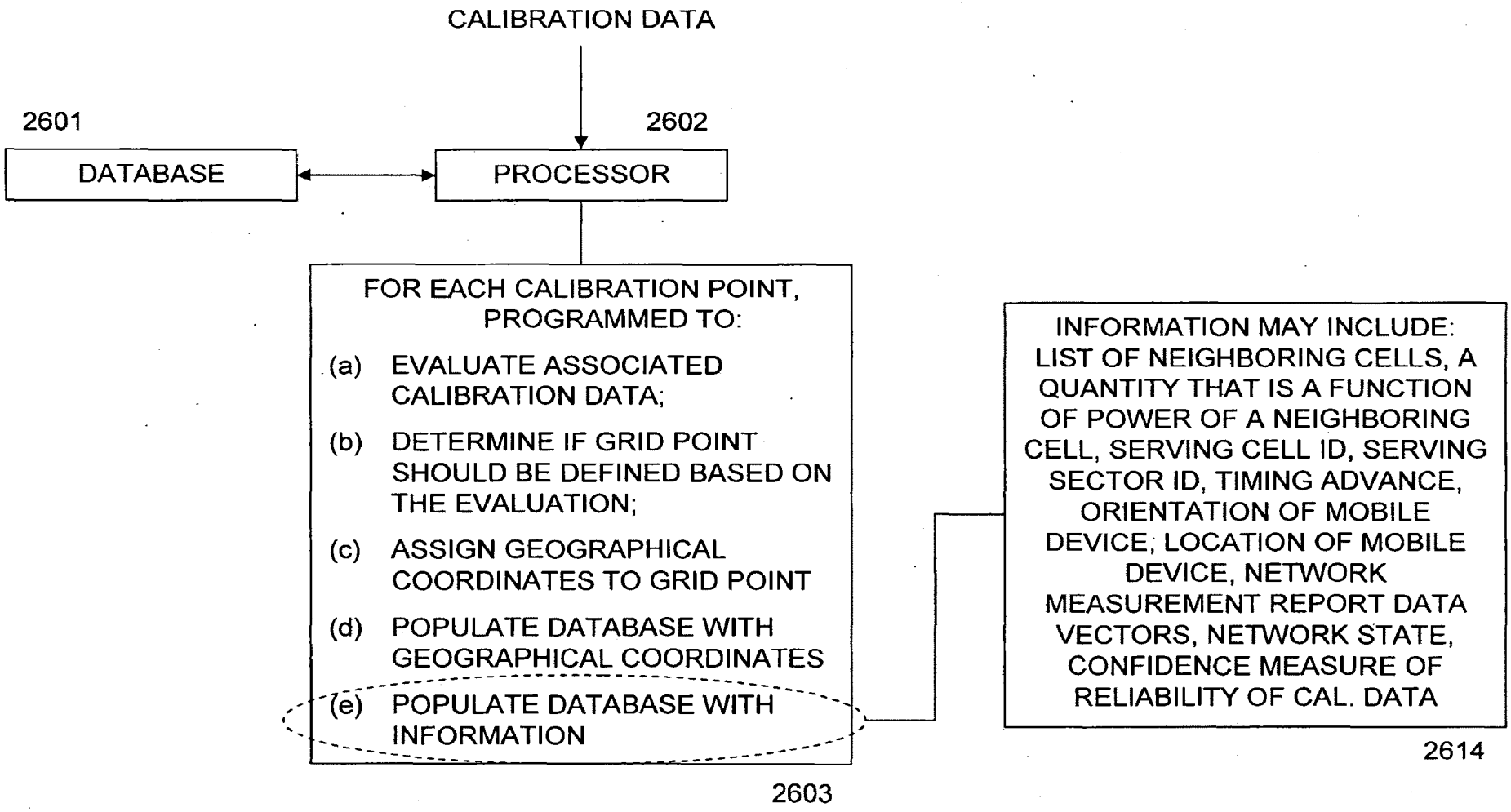

CALIBRATION DATA
2601
2602
DATABASE
PROCESSOR
FOR EACH CALIBRATION POINT, PROGRAMMED TO:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
(d) POPULATE DATABASE WITH GEOGRAPHICAL COORDINATES
(e) POPULATE DATABASE WITH INFORMATION
2603
INFORMATION MAY INCLUDE: LIST OF NEIGHBORING CELLS, A QUANTITY THAT IS A FUNCTION OF POWER OF A NEIGHBORING CELL, SERVING CELL ID, SERVING SECTOR ID, TIMING ADVANCE, ORIENTATION OF MOBILE DEVICE; LOCATION OF MOBILE DEVICE, NETWORK MEASUREMENT REPORT DATA VECTORS, NETWORK STATE, CONFIDENCE MEASURE OF RELIABILITY OF CAL. DATA
2614

FIGURE 26

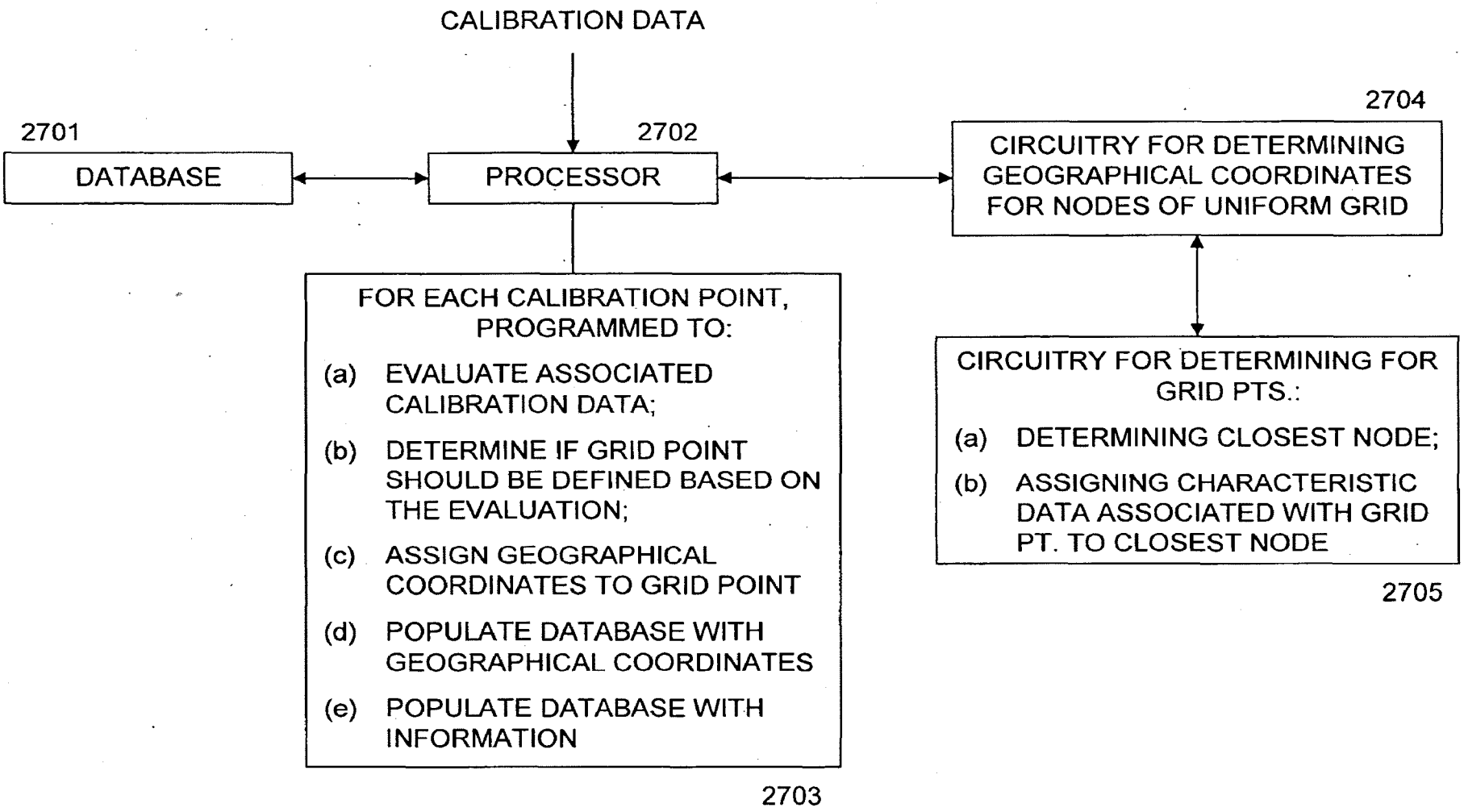

CALIBRATION DATA
2701
DATABASE
2702
PROCESSOR
2704
CIRCUITRY FOR DETERMINING GEOGRAPHICAL COORDINATES FOR NODES OF UNIFORM GRID
FOR EACH CALIBRATION POINT, PROGRAMMED TO:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
(d) POPULATE DATABASE WITH GEOGRAPHICAL COORDINATES
(e) POPULATE DATABASE WITH INFORMATION
2703
CIRCUITRY FOR DETERMINING FOR GRID PTS.:
(a) DETERMINING CLOSEST NODE;
(b) ASSIGNING CHARACTERISTIC DATA ASSOCIATED WITH GRID PT. TO CLOSEST NODE
2705

FIGURE 27

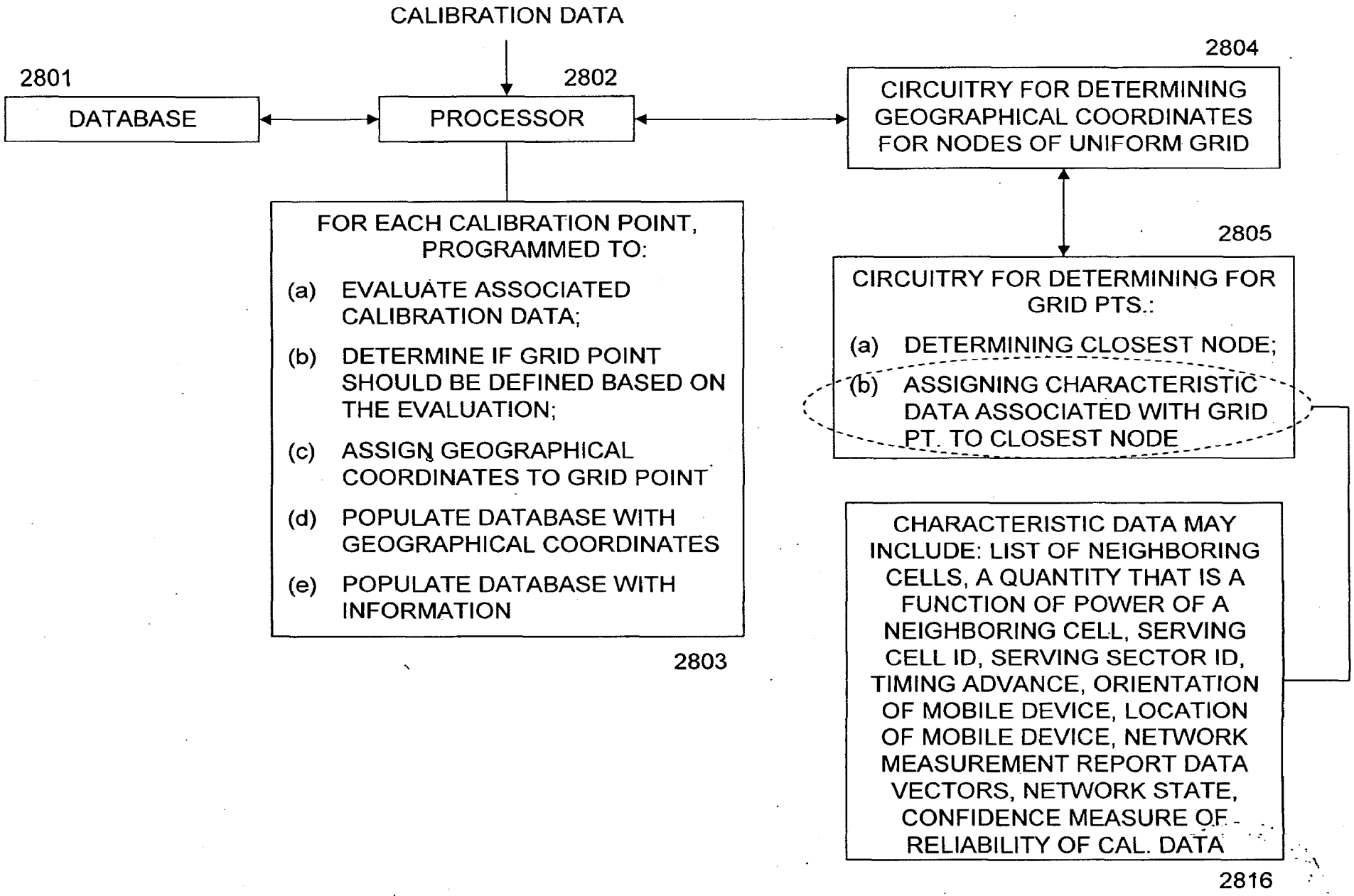

CALIBRATION DATA
2801
DATABASE
2802
PROCESSOR
2804
CIRCUITRY FOR DETERMINING GEOGRAPHICAL COORDINATES FOR NODES OF UNIFORM GRID
FOR EACH CALIBRATION POINT, PROGRAMMED TO:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
(d) POPULATE DATABASE WITH GEOGRAPHICAL COORDINATES
(e) POPULATE DATABASE WITH INFORMATION
2803
2805
CIRCUITRY FOR DETERMINING FOR GRID PTS.:
(a) DETERMINING CLOSEST NODE;
(b) ASSIGNING CHARACTERISTIC DATA ASSOCIATED WITH GRID PT. TO CLOSEST NODE
CHARACTERISTIC DATA MAY INCLUDE: LIST OF NEIGHBORING CELLS, A QUANTITY THAT IS A FUNCTION OF POWER OF A NEIGHBORING CELL, SERVING CELL ID, SERVING SECTOR ID, TIMING ADVANCE, ORIENTATION OF MOBILE DEVICE, LOCATION OF MOBILE DEVICE, NETWORK MEASUREMENT REPORT DATA VECTORS, NETWORK STATE, CONFIDENCE MEASURE OF RELIABILITY OF CAL. DATA
2816

FIGURE 28

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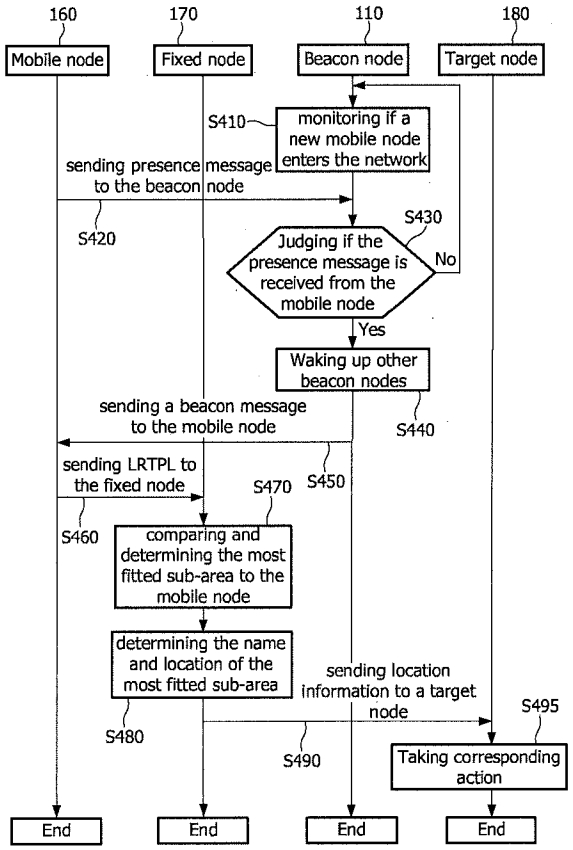
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[Continued on next page]

(54) Title: METHOD, APPARATUS AND SYSTEM FOR LOCALIZATION IN A WIRELESS NETWORK



(57) Abstract: A method, apparatus and system for localization in wireless network are disclosed in the present invention for localizing one mobile node in a wireless network. The method comprises the steps of: acquiring a transmission power level, which is related to location of the mobile node; comparing the transmission power level with a location mapping information, wherein the location mapping information comprises at least a known location and its corresponding transmission power level; determining the location of the mobile node, according to the comparison result. The present invention can achieve broader applications for localization, and make the localization result for a mobile node more accurate and more efficient, since it utilizes the transmission power level to localize a mobile node, which makes the localization results insensitive to the influence of the complex environment.

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METHOD, APPARATUS AND SYSTEM FOR LOCALIZATION IN A WIRELESS NETWORK

FIELD OF THE INVENTION

The invention relates to a wireless network, in particularly, to a method, apparatus and system for localizing a mobile node in a wireless network.

BACKGROUND OF THE INVENTION

In a wireless network, Radio Signal Strength (RSS) is widely used as an approach to measure the distance between nodes, for instance, a wireless sensor network (WSN) may generally include several sensor nodes, each of which normally has the capability to perform short-haul wireless communication and communicates with each other via Radio Frequency information. Based on the Radio Path Loss model, the distance between two sensor nodes can be calculated. In theory, if the distances between a mobile node and three stationary nodes are known, the location of the mobile node can be calculated in 3-D coordinate system with 3-D coordinates of three stationary nodes.

However, since the wireless signal is liable to suffering interferences, thereby being not stable and even erroneous, it is unreliable to use RSS to measure the distance between two nodes. A solution is to combine TOF (Time of Flight) method with RSS, namely utilizing the propagation speed of wireless signal and the relay-time between transmitter and receiver, to measure the distance between two nodes.

However, the TOF method also has some shortcomings: firstly, TOF method requires accurate time synchronization, which requires extra effort of WSN to maintain synchronization information; and in real applications, it will consume the limited resources of WSN; secondly, for indoor distance measurement, the complex situation of reflection wave caused by walls and furniture considerably degrades the accuracy of TOF.

In conclusion, a method and apparatus for localization in wireless network with stable measurement result insensitive to indoor complex environmental interference is therefore needed.

OBJECT AND SUMMARY OF THE INVENTION

The present invention provides a method, apparatus and system for localization in wireless network, which achieves stable measurement result insensitive to indoor

environment.

According to an embodiment of the present invention, a method for localizing a mobile node in a wireless network is provided, wherein the method comprises the steps of: acquiring a transmission power level, which is related to location of the mobile node; comparing the transmission power level with a location mapping information, wherein the location mapping information comprises at least a known location and its corresponding transmission power level; and determining the location of the mobile node, according to the comparison result.

According to another embodiment of the present invention, an apparatus for localizing a mobile node in a wireless network is provided, wherein the apparatus comprises: an acquiring device, for acquiring a transmission power level, which is related to location of the mobile node; a comparing device, for comparing the transmission power level with a location mapping information, which comprises of at least a known location and its corresponding transmission power level; and a determining device, for determining the location of the mobile node according to the comparison result.

According another embodiment of the present invention, a wireless network system for localizing a mobile node in the wireless network is provided, wherein the wireless network system comprises: at least a receiving device, for receiving a group of localization messages with at least two localization messages from the mobile node, wherein the group of localization messages includes a transmission power level respectively different from each other; an acquiring device, for acquiring a lower transmission power level in the group of localization messages, and the transmission power level is related to the location of the mobile node; a comparing device, for comparing the transmission power level and a location mapping information, which comprises at least a known location and its corresponding transmission power level; and a determining device, for determining the location of the mobile node according to the comparison result.

According another embodiment of the present invention, a wireless network system for localizing a mobile node in the wireless network is provided, wherein the wireless network system comprises: at least a transmitting device, for sending a group of localization messages with at least two localization messages, wherein the group of localization messages includes a transmission power level respectively different from each other; an acquiring device, for acquiring a lower transmission power level in the group of localization messages, and the transmission power level is related to the location of the

mobile node; a comparing device, for comparing the transmission power level with a location mapping information, which comprises at least a known location and its corresponding transmission power level; and a determining device, for determining the location of the mobile node according to the comparison result.

In conclusion, a method, apparatus and system for localization in wireless networks proposed in the present invention can achieve broader applications for localization, and make the localization for mobile node more accurate and more efficient since it utilizes the transmission power level message to localize mobile nodes, which makes the localization results insensitive to the influence of complex environment.

Other objects and attainments together with a fuller understanding of the invention will become apparent and appreciated by referring to the following description and claims taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram illustrating a sensor network according to an embodiment of the present invention;

Figure 2 is a schematic diagram in statistics format illustrating all beacon messages received by a mobile node according to an embodiment of the present invention;

Figure 3 is a flowchart illustrating a method for disposing a sensor network according to an embodiment in the present invention;

Figure 4 is a flowchart illustrating a method for localizing a mobile node in a sensor network according to an embodiment of the present invention;

Figure 5 is a functional block diagram of a fixed node in a sensor network according to an embodiment of the present invention.

Figure 6 is a schematic diagram illustrating a sensor network according to another embodiment of the present invention;

Figure 7 is a schematic diagram illustrating a sensor network according to another embodiment in the present invention.

Throughout the drawing figures, like reference numerals will be understood to refer to like parts and components.

DETAILED DESCRIPTION OF THE INVENTION

Next, the embodiments of the present invention will describe in detail in conjunction with figures.

Figure 1 is a schematic diagram illustrating a sensor network according to an embodiment of the present invention, and the sensor network includes four beacon nodes 110,120,130 and 140, each of the beacon nodes may be a sensor, which broadcasts beacon message at different transmission power level every one second respectively, for instance, as shown in figure 1, the beacon node 110, 120, 130 and 140 broadcast beacon messages at transmission power level from 1 to 4 separately, and the transmission power level is included in corresponding broadcasted beacon message.

One beacon message is comprised of two parts, beacon node ID and transmission power level, and the transmission power level denotes the transmission power level when a beacon transmits the beacon message. For instance, the beacon message sent by the beacon node 110 with beacon ID = 1 at transmission power level 2 is shown in table 1:

Table 1

Beacon ID	Transmission power level
1	2

Besides, the whole area within the radio coverage of WSN includes many sub-areas partitioned by users, sub-area 151, 152, 153, 154,155 and 156. The sub-areas can be partitioned based on the functional areas in a specific application environment, which could be an area where users require for behavior monitoring performed by the WSN, such as an office. Sub-areas can also be appropriately partitioned according to the number and locations of beacon nodes 110,120,130 and 140.

Each of sub-areas 151,152,153,154,155 and 156 has one location respectively which is different from each other, so that one mobile node 160 that enters each of above sub-areas can utilize the location of the sub-area where the node resides to carry out localization, in other word, the mobile node 160 can implement localization according to the location of the sub-area closest to itself.

Figure 2 shows the schematic diagram in statistic format illustrating all beacon messages received by a mobile node according to an embodiment of the present invention. For example, there are 4 beacon nodes in a WSN, then for a specific mobile node in the WSN, the beacon message with lowest received transmission power level (LRTPL) 2, 2, 3 and 4 are received from the beacon nodes with beacon ID 1,2,3,4 at each fixed interval

respectively. The final statistic result is shown in table 2.

Table 2:

beacon ID	LRTPL
1	2
2	2
3	3
4	4

Figure 3 shows the flowchart of a method for disposing a sensor network according to an embodiment of the present invention. Firstly, at step S310, a user disposes sensor nodes as beacon nodes in a application environment, which could be an area where the user requires for the sensor network to perform user's behavior monitoring, e.g. an office. The number and location of the beacons can be determined according to the size of the application environment and the partition of the functional areas (e.g., office desk area, demonstration area beside whiteboard.)

And then, at step S320, the user sets the relating parameters of the beacons. The parameters may include: Timer_interval, denoting the desired time interval between two adjacent beacon messages sent from a beacon node); Min_power_level, denoting the lowest transmission power level of a beacon node; Max_power_level, denoting the highest transmission power level of a beacon node; Power_level_interval, denoting the increasing amplitude between two adjacent transmission power levels of a beacon node, etc.

Subsequently, at step S330, according to locations and parameters of above beacon nodes, the user partitions the whole application environment into several sub-areas, which may be partitioned according to the functional areas in the application environment, e.g. the office desk functional area, demonstration area beside whiteboard. In different functional areas, the user will take on different behaviors, e.g. standing up, sitting down, typing or making a phone call in office desk functional area. Partitioning sub-areas according to the functional areas in the application environment can make the judgment on the user's behaviors more accurate.

At step S340, the user starts the test by using a mobile node to receive the beacon messages from each of beacon nodes in each sub-area, so as to obtain the LRTPL of beacon message from each of beacon nodes in each sub-area.

The LRTPL's location mapping information of each corresponding beacon node

shown in figure 1 is listed in table 3.

Table 3

Sub-area	Beacon ID	LRTPL 1	Percentage	LRTPL 2	Percentage
1	1	2	80%	3	20%
	2	2	60%	3	40%
	3	3	20%	4	80%
	4	3	30%	4	70%
2	1	3	90%	4	10%
	2	2	70%	3	30%
	3	3	85%	4	15%
	4	3	10%	4	90%
3	1	2	75%	3	25%
	2	2	30%	3	70%
	3	3	70%	4	30%
	4	3	20%	4	80%
4	1	3	85%	4	15%
	2	3	10%	4	90%
	3	1	20%	2	80%
	4	3	60%	4	40%
5	1	3	75%	4	25%
	2	3	80%	4	20%
	3	3	90%	4	10%
	4	3	85%	4	15%
6	1	3	10%	4	80%
	2	3	75%	4	10%
	3	2	20%	3	60%
	4	1	20%	2	80%

Since the beacon message may be not well-received due to some unexpected reasons, the node in the same location will receive the beacon message with two different transmission power levels sent from the same beacon. The values of LRTPL have

statistical property, for instance, sub-area 1 receives two beacon messages sent from the beacon 110 (beacon ID is 1) in certain time period: the LRTPL value of one beacon message is 2 and the LRTPL value of another beacon message is 3, in which the percentage of the number of beacon messages with LRTPL value 2 is 80%, with LRTPL value 3 is 20%. When determining the LRTPL value corresponding to each of sub-areas, only the LRTPL with larger percentage is referenced, for instance, the LRTPL value corresponding to Beacon ID 1 in sub-area 1 is 2.

At step S350, the LRTPL of each sub-area is analyzed. According to the information in table 2, the LRTPL corresponding to each beacon node in each sub-area will be finally obtained after analysis. For example, the LRTPL value corresponding to the beacon 110 (Beacon ID 1) in sub-area 1 is 2, the LRTPL value corresponding to the beacon 120 (Beacon ID 2) is 2, etc.

At step S360, the user judges whether each sub-area has different localization information, if so, then stores each LRTPL corresponding to each sub-area into a database at step S370.

Finally, at step S380, all location mapping information (table 3) will be stored in the data base, and the location mapping information may include the name of each sub-area, corresponding functional areas and their corresponding transmission power levels, etc.

At above step S360, if the judgment result is no, namely, at least two sub-areas have the same localization information, then at step 390, the user readjusts the relating parameters of beacon nodes, and further at step S395, readjusts the location of beacon nodes, then repeats procedures from step S330 to step S350 until each sub-area has unique localization information.

Figure 4 shows a flowchart illustrating the method for localizing a mobile node in a sensor network according to an embodiment of the present invention.

Firstly, at step S410, beacon node 110 monitors whether new mobile node (e.g. one user carrying sensor) enters the WSN. If the sensor network comprises multiple beacon nodes, the beacon node 110 among which can be selected as monitoring node, which monitors if new mobile node enters the WSN by monitoring whether the presence information is received from the mobile node.

Before the monitoring beacon node receives presence information from the mobile node, other beacon nodes could be in "hibernation" state; after receiving the presence information, the monitoring beacon node "wakes up" other beacon nodes

Then, at step S420, a mobile node 160 enters into the sensor network, and then sends a presence message, which is used to inform the beacon node 110 that the mobile node 160 needs to be localized. Moreover, the presence message may also include the ID information of the mobile node 160, such as the personal ID information of the user carrying sensors, so that the corresponding ID authentication can be carried out firstly when the mobile node 160 enters the sensor network.

At step S430, the beacon node 110 judges whether it receives the presence message sent from the mobile node 160, if so, then the beacon node 110 "wakes up" other beacon nodes at step S440, otherwise, the beacon 110 continues judging whether it receives the presence message sent from the mobile node 160.

At step S450, the beacon node 110 sends beacon message to the mobile node 160, which includes the ID of the beacon node and the transmission power level for transmitting the beacon message. For instance, beacon node 110 with beacon ID 1 broadcasts the beacon message at different transmission power levels ranging from 1 to 4. The higher the transmission power level is, the broader range can the beacon message be broadcasted. The LRTPL needed for receiving the beacon message at the location of the mobile node160 is 2, that is for beacon node 110, the LRTPL of the mobile node is 2.

At step S460, after receiving the beacon message, the mobile node 160 sends the LRTPL corresponding to each beacon node to a fixed node 170 in the sensor network, which is used to compare the similarity between LRTPL of the mobile node 160 and the LRTPL of each sub-area in location mapping information table (table 3). Each sub-area's LRTPL is pre-stored in a data base included in the fixed node. (as step S370 shown in figure 4)

At step S470, fixed node 170 uses Euclidean distance to calculate the similarity between the LRTPL of mobile node and that of each sub-area.

$$L = \arg\min_i \{ \sum_j \left(RPL_j - \sum_k (PL_{ijk} * PER_{ijk}) \right)^2 \}$$

Wherein, i denotes the ith known sub-area L_i; j denotes the jth beacon node B_j; k=1 or 2, denote two different LRTPL values; PER_{ijk} denotes the percentage of each LRTPL; PL_{ijk} denotes the LRTPL corresponding to the beacon node B_j; RPL_j denotes the LRTPL of the mobile node with respect to the jth beacon node; arg min_i denotes the sub-area No. i

with minimum $L = \arg\min_i \{\sum_j \left(RPL_j - \sum_k (PL_{ijk} * PER_{ijk}) \right)^2 \}$ value, namely the most fitted sub-area to the location of mobile node 110.

At step S480, according to the pre-stored name information of each sub-area and the name information of their corresponding functional areas, fixed node 170 obtains the name of the most fitted (i.e the closest) sub-area to the mobile node 160 (e.g. sub-area 3) and the name of corresponding functional area (e.g. office desk area). In this way, the sensor network can know the functional area where the user resides and the possible behaviors taken by the user in the functional area so that the sensor network can make more accurate judgment for the user behaviors.

At step S490, fixed node 170 will send the calculated location of the mobile node 160 (e.g. coordinate (89.235), the name of the sub-area corresponding to mobile node 160 and the name of corresponding functional areas, to a target node 180, which can be connected with an equipment (e.g. a lamp) to control the equipment.

At step S495, according to received above information, target node 180 can acquire the location of the mobile node, the name of corresponding sub-area and the name of corresponding functional area, and then take activities accordingly, e.g. increasing the brightness of the lamp.

Figure 5 shows the schematic diagram illustrating the functional block of a fixed node in a sensor network according to an embodiment of the present invention.

The fixed node 500 comprises an acquiring device 510, for acquiring the LRTPL of the beacon message sent from each of beacon node to a mobile node in the sensor network (as shown in figure 2);

The fixed node 500 further comprises a storage device 540, for storing the LRTPL location mapping information for each sub-area with known location with respect to each beacon node in the sensor network (as shown in table 3), name of each sub-area and the sub-area information of corresponding functional area name. Moreover, the storage device 540 is also used to store the user ID information of a mobile node and cipher information, etc.

The fixed node 500 further comprises a comparing device 522 and a determining device 524, in which the comparing device 522 is used to compare the similarity between the LRTPL of a mobile node acquired by the acquiring device 510 and the LRTPL location

mapping information of each sub-area with respect to each beacon node stored in the storage device 540, so as to obtain the most fitted sub-area to the mobile node 160. The comparing method can be referred to the illustration of step S570 in figure 5.

Based on the comparison result and the name, location and name of corresponding functional areas of each sub-area stored in the storage device 540, the determining device 524 determines the specific location of the mobile node 160.

The fixed node 500 also comprises an actuator 530, which could be connected with an equipment (e.g. a lamp) in cable or wireless way. After processor 520 calculates out the location of the mobile node, the fixed node can control the equipment to make corresponding adjustment through actuator 530. (e.g. increasing the brightness of the lamp)

It is to be understood by those skilled in the art that the actuator 500 can be also included in another node independent from the fixed node 500, and receive the location information of the mobile node sent from the fixed node 500, and also control an equipment(e.g. a lamp) according to the location information.

The fixed node 500 further comprises a transmitting device 580 and a receiving device 590, in which transmitting device 590 is used to broadcast the calculated location information of the mobile node in the sensor network.

It is to be understood by those skilled in the art that each functional module contained in the fixed node 500 in the present invention can also be allocated in each different node (e.g. each beacon node or target node) in the sensor network in integrated or distributed manner, for instance, full functions of the fixed node 500 can also be realized in each beacon node or target node. It is evident that the functions of the fixed node 500 can also be fulfilled by the mobile node.

The method and apparatus for localization in a wireless network according to an embodiment of the present invention can be applied in an office environment equipped with sensor network, through the sensor carried by the user (namely a mobile node), can the location of the user be calculated out. Also, according to the location of the user, the identification of frequent activities of the user in the area can be fulfilled, and furthermore, intelligently adjusting and controlling indoor lighting system can also be achieved according to user's behavior status.

Figure 6 is a schematic diagram illustrating a sensor network according to another embodiment of the present invention.

As shown in figure 6, according to another embodiment of the present invention, the sensor network may comprise a beacon node 110 as minimum, which broadcasts the beacon message at four different transmission power levels ranging from 1 to 4, and then the value of LRTPL received at mobile node 160 is 2. Correspondingly, a user uses the mobile node to perform the test to receive the beacon message sent from beacon node 110 in sub-area 151,153,154 and 156, so as to obtain the beacon message's LRTPL received from each beacon node in each sub-area.

For example, the LRTPL of each beacon node corresponding to each sub-area is shown in table 4

Table4:

Sub-area	Beacon ID	LRTPL 1	percentage	LRTPL 2	Percentage
1	1	1	80%	2	20%
3	1	2	75%	3	25%
4	1	3	85%	4	15%
6	1	3	10%	4	80%

Then, following the method illustrated in figure 4, we can use Euclidean distance to calculate the similarity between the LRTPL of mobile node and that of sub-area, and get the most fitted sub-area to the mobile node 160 (sub-area 156), so as to determine the location of the mobile node 160.

Figure 7 is a schematic diagram illustrating a sensor network according to another embodiment of the present invention.

As shown in Figure 7, it is to be understood by those skilled in the art that the method and apparatus for localization in wireless network as disclosed in this invention can also be used by the mobile node 160 to be localized, wherein the mobile node 160 can broadcast the location information at different transmission power levels (e.g. from 1 to 4), and beacon node 110, 120,130 and 140, as receiving devices, receive the LRTPL of the location information with value 2, 2, 3 and 4 respectively, same as in table 2.

Accordingly, when disposing such kind of sensor network, a user uses one mobile node to perform the message-sending test in each sub-area to obtain the LRTPL of each sub-area. Following the same way can the data shown in figure 3 be obtained. Then, following the method shown in figure 4, Euclidean distance is used to calculate the

similarity between the LRTPL of mobile node and that of sub-area to obtain the most fitted sub-area to the mobile node 160 (sub-area 156), thereby determining the location of the mobile node 160.

It is to be understood by those skilled in the art that the method and apparatus for localization in wireless network as disclosed in this invention can not only be applied in sensor network, but also be made of various modifications without departing from the spirit and scope of the invention so as to be applied in other kinds of wireless networks, e.g. Blue Tooth Piconet, etc.

It is to be understood by those skilled in the art that the method and apparatus for localization in wireless network as disclosed in this invention can be made of various modifications without departing from the spirit and scope of the invention as defined by the appended claims.

CLAIMS:

1. A method for localizing a mobile node in a wireless network, comprising the steps of:

(a) acquiring a transmission power level, which is related to location of the mobile node;

(b) comparing the transmission power level with a location mapping information, wherein the location mapping information comprises at least a known location and its corresponding transmission power level; and

(c) determining the location of the mobile node, according to the comparison result.

2. The method according to claim 1, further comprising the step of:

receiving a group of localization messages with at least two localization messages from a signal source, wherein the group of localization messages includes a transmission power level respectively different from each other;

wherein the step (a) comprises the step of: acquiring a lower transmission power level in the group of localization messages, and the transmission power level is related to the location of the mobile node.

3. The method according to claim 2, further comprising the steps of:

receiving a group of localization messages with at least two localization messages from another different signal source, wherein the group of localization messages includes a transmission power level respectively different from each other;

wherein the step (a) comprises the step of: acquiring a lower transmission power level in the group of localization messages, and the transmission power level is related to the location of the mobile node.

4. The method according to claim 1, further comprising the step of:

acquiring the location mapping information, which comprises at least a known location and its corresponding transmission power level.

5. The method according to claim 1, further comprising the step of:

sending a location message of the mobile node to a target node, which can control an equipment according to the location message.

6. The method according to claim 1, wherein

the known location is a sub-area, and

the step (c) comprises the step of: determining a most fitted sub-area to the acquired transmission power level.

7. The method according to claim 6, wherein the step (c) further comprises the step of:

determining a name of the sub-area.

8. The method according to claim 6, wherein the step (c) further comprises the step of:

determining a functional area of the sub-area.

9. An apparatus for localizing a mobile node in a wireless network, comprising:

an acquiring device, for acquiring a transmission power level, which is related to location of the mobile node;

a comparing device, for comparing the transmission power level with a location mapping information, which comprises of at least a known location and its corresponding transmission power level; and

a determining device, for determining the location of the mobile node according to the comparison result.

10. The apparatus according to claim 9, wherein the determining device is used to determine the most fitted sub-area to the transmission power level of the mobile node.

11. The apparatus according to claim 9, further comprising a storage device, for storing the location mapping information, which includes at least a known location and its corresponding transmission power level.

12. The apparatus according to claim 11, wherein the storage device is used to store user's ID of the mobile node and cipher information.

13. The apparatus according to claim 9, further comprising an actuator, for controlling an equipment according to the location of the mobile node.

14. A wireless network system for localizing a mobile node in the wireless network, comprising:

at least a receiving device, for receiving a group of localization messages with at least two localization messages from the mobile node, wherein the group of localization messages includes a transmission power level respectively different from each other;

an acquiring device, for acquiring a lower transmission power level in the group of localization messages, and the transmission power level is related to the location of the mobile node;

a comparing device, for comparing the transmission power level and a location mapping information, which comprises at least a known location and its corresponding transmission power level; and

a determining device, for determining the location of the mobile node according to the comparison result.

15. A wireless network system for localizing a mobile node in the wireless network, comprising:

at least a transmitting device, for sending a group of localization messages with at least two localization messages, wherein the group of localization messages includes a transmission power level respectively different from each other;

an acquiring device, for acquiring a lower transmission power level in the group of localization messages, and the transmission power level is related to the location of the mobile node;

a comparing device, for comparing the transmission power level with a location mapping information, which comprises at least a known location and its corresponding transmission power level; and

a determining device, for determining the location of the mobile node according to the comparison result.

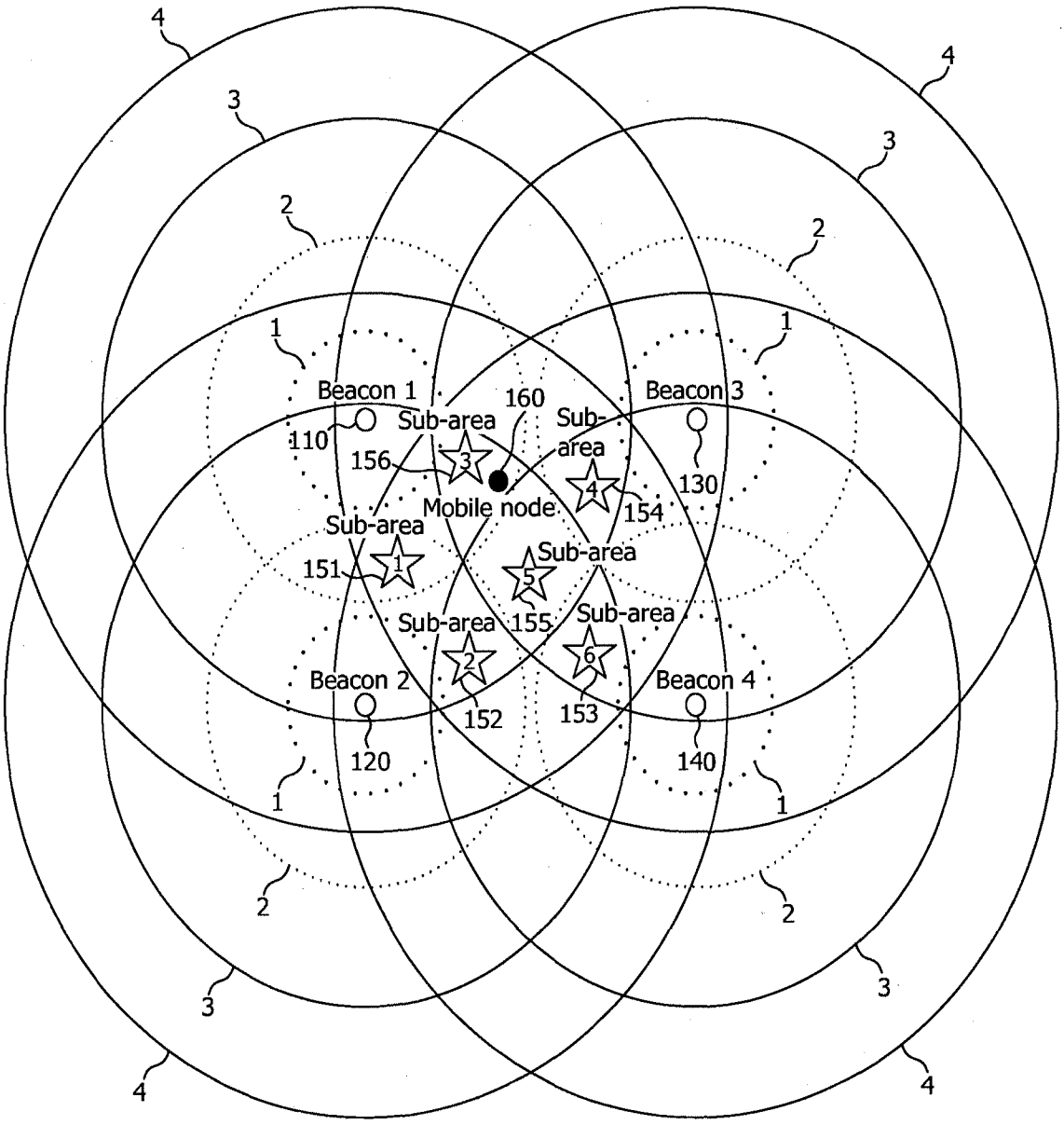

4
3
2
1
Beacon 1
110
Sub-area
3
156
160
Mobile node
Sub-area
4
154
Beacon 3
130
Sub-area
151
1
Sub-area
5
Sub-area
155
Sub-area
2
6
152
153
Beacon 2
120
Beacon 4
140

FIG. 1

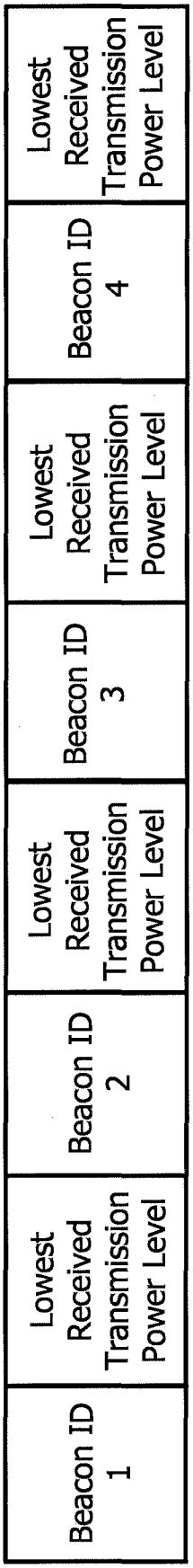

Beacon ID 1
Lowest Received Transmission Power Level
Beacon ID 2
Lowest Received Transmission Power Level
Beacon ID 3
Lowest Received Transmission Power Level
Beacon ID 4
Lowest Received Transmission Power Level

FIG. 2

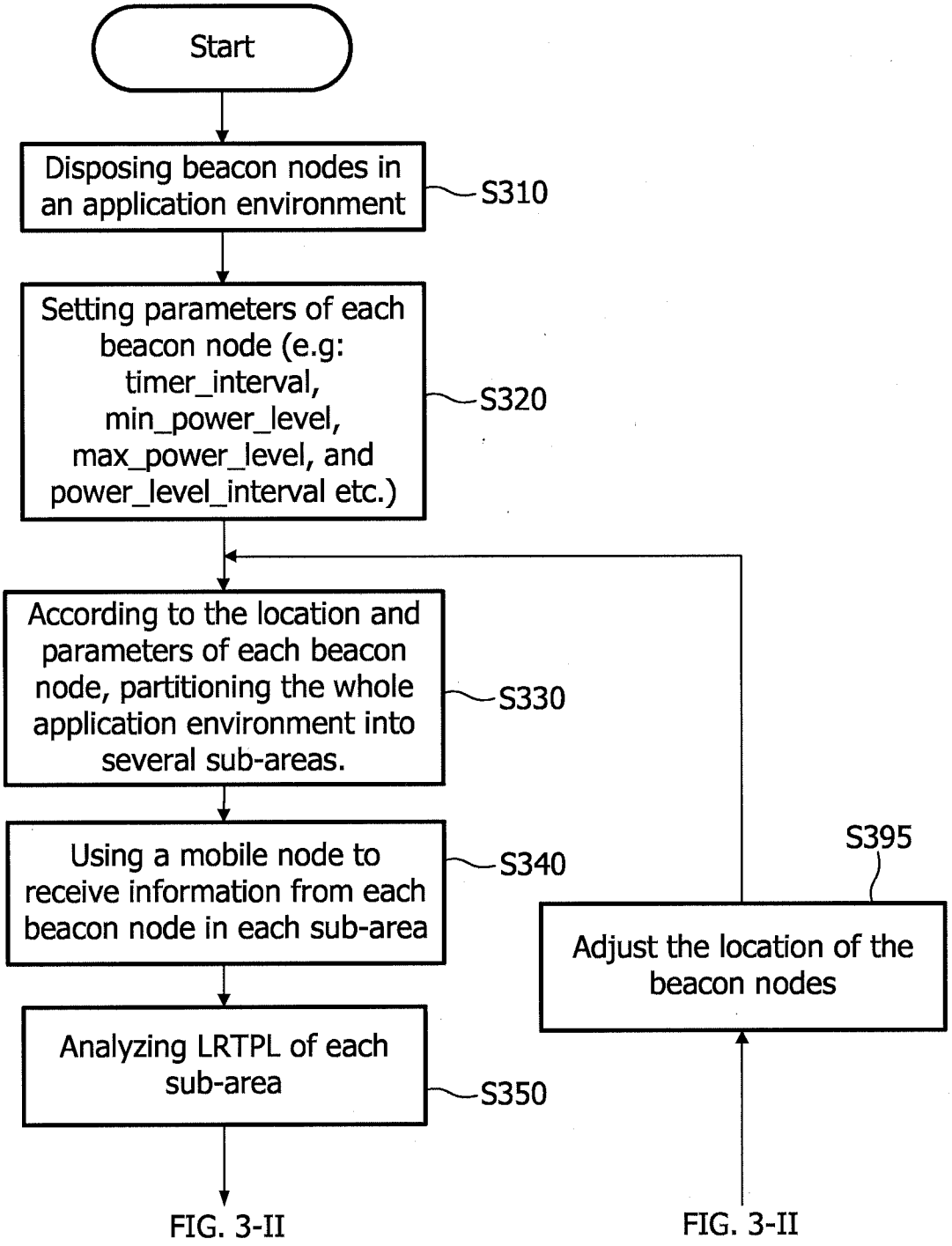

Start
Disposing beacon nodes in an application environment
S310
Setting parameters of each beacon node (e.g: timer_interval, min_power_level, max_power_level, and power_level_interval etc.)
S320
According to the location and parameters of each beacon node, partitioning the whole application environment into several sub-areas.
S330
Using a mobile node to receive information from each beacon node in each sub-area
S340
Analyzing LRTPL of each sub-area
S350
FIG. 3-II
S395
Adjust the location of the beacon nodes
FIG. 3-II

FIG. 3-I

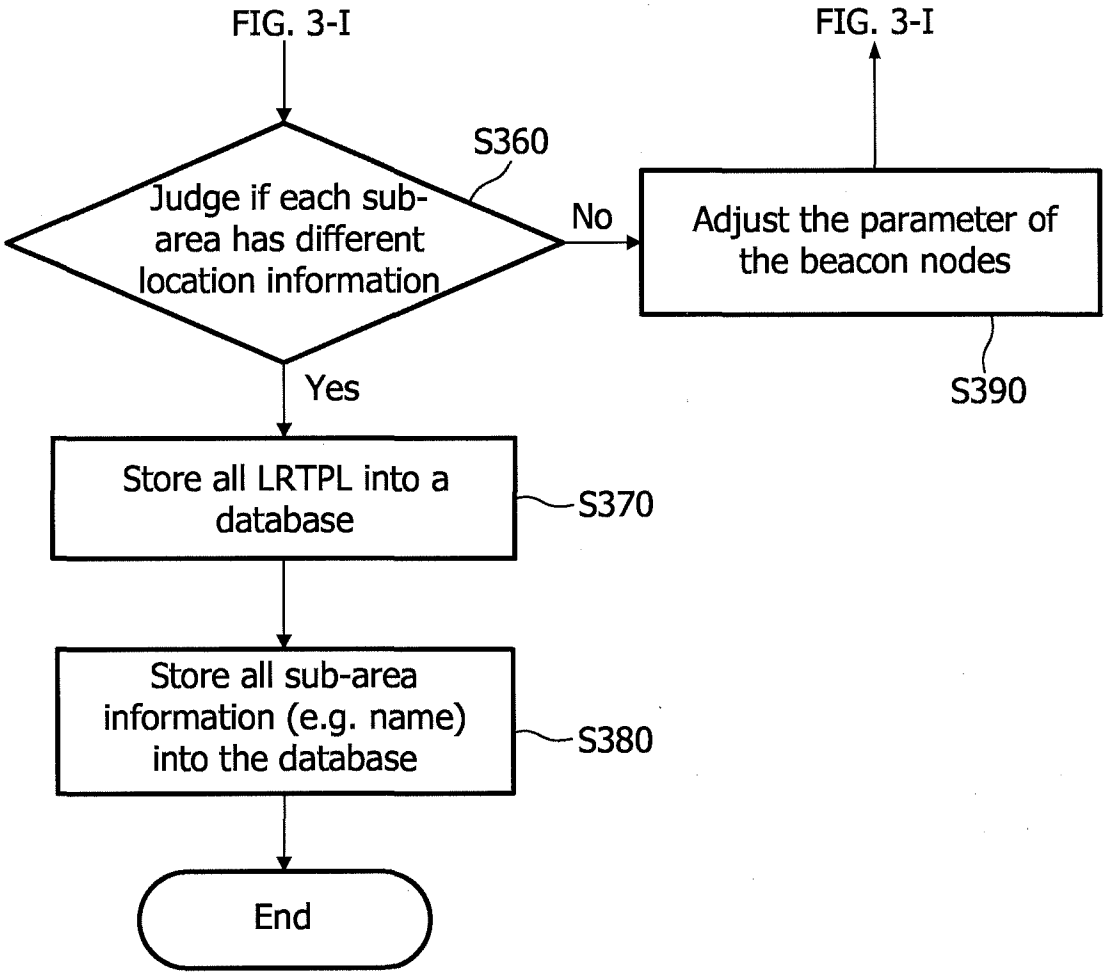

FIG. 3-I
FIG. 3-I
S360
Judge if each sub-area has different location information
No
Adjust the parameter of the beacon nodes
S390
Yes
Store all LRTPL into a database
S370
Store all sub-area information (e.g. name) into the database
S380
End

FIG. 3-II

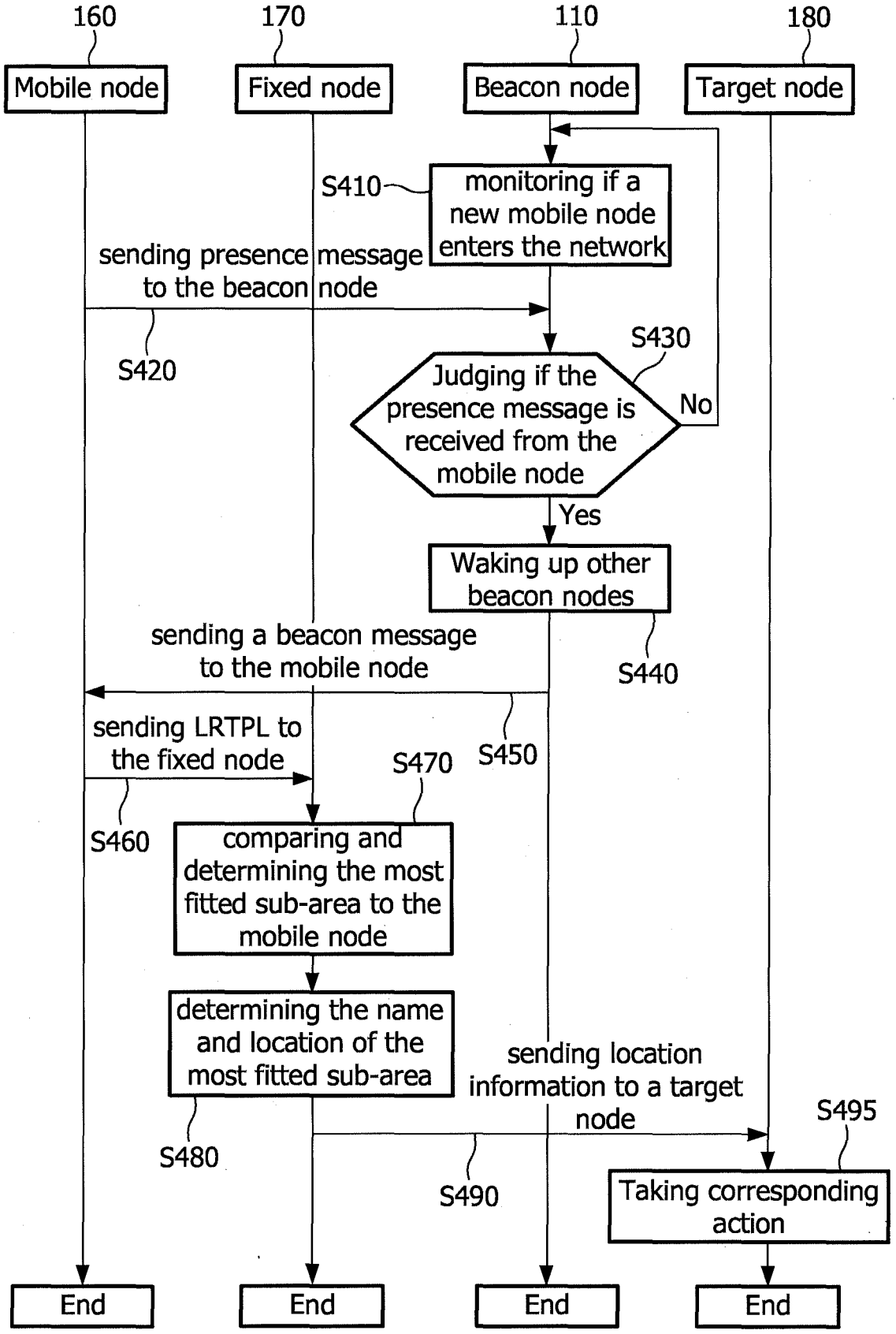

160
170
110
180
Mobile node
Fixed node
Beacon node
Target node
S410
monitoring if a new mobile node enters the network
sending presence message to the beacon node
S420
S430
Judging if the presence message is received from the mobile node
No
Yes
Waking up other beacon nodes
S440
sending a beacon message to the mobile node
sending LRTPL to the fixed node
S450
S460
S470
comparing and determining the most fitted sub-area to the mobile node
determining the name and location of the most fitted sub-area
S480
sending location information to a target node
S490
S495
Taking corresponding action
End
End
End
End

FIG. 4

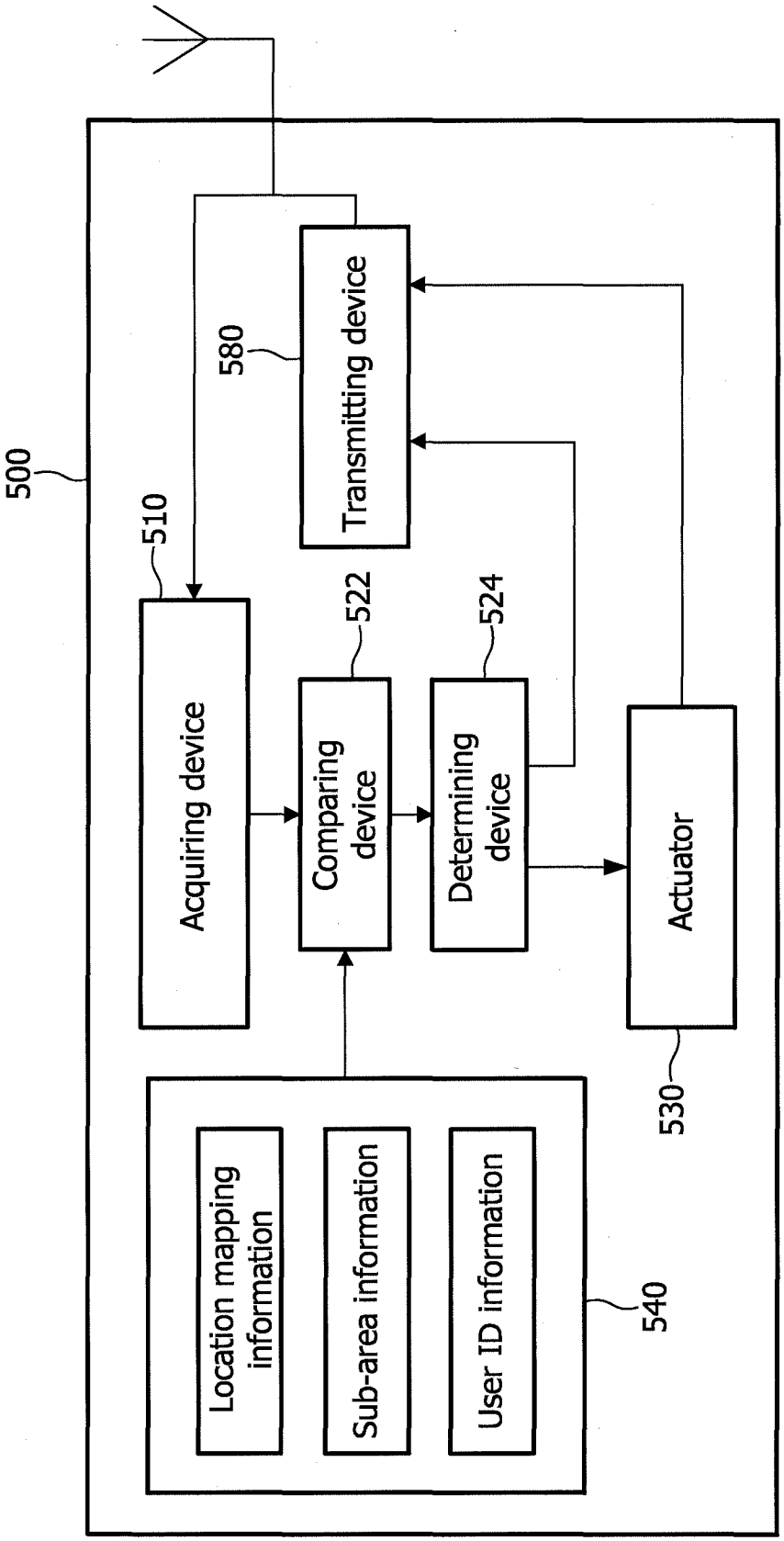

500
510
Acquiring device
522
Comparing device
524
Determining device
580
Transmitting device
530
Actuator
540
Location mapping information
Sub-area information
User ID information

FIG. 5

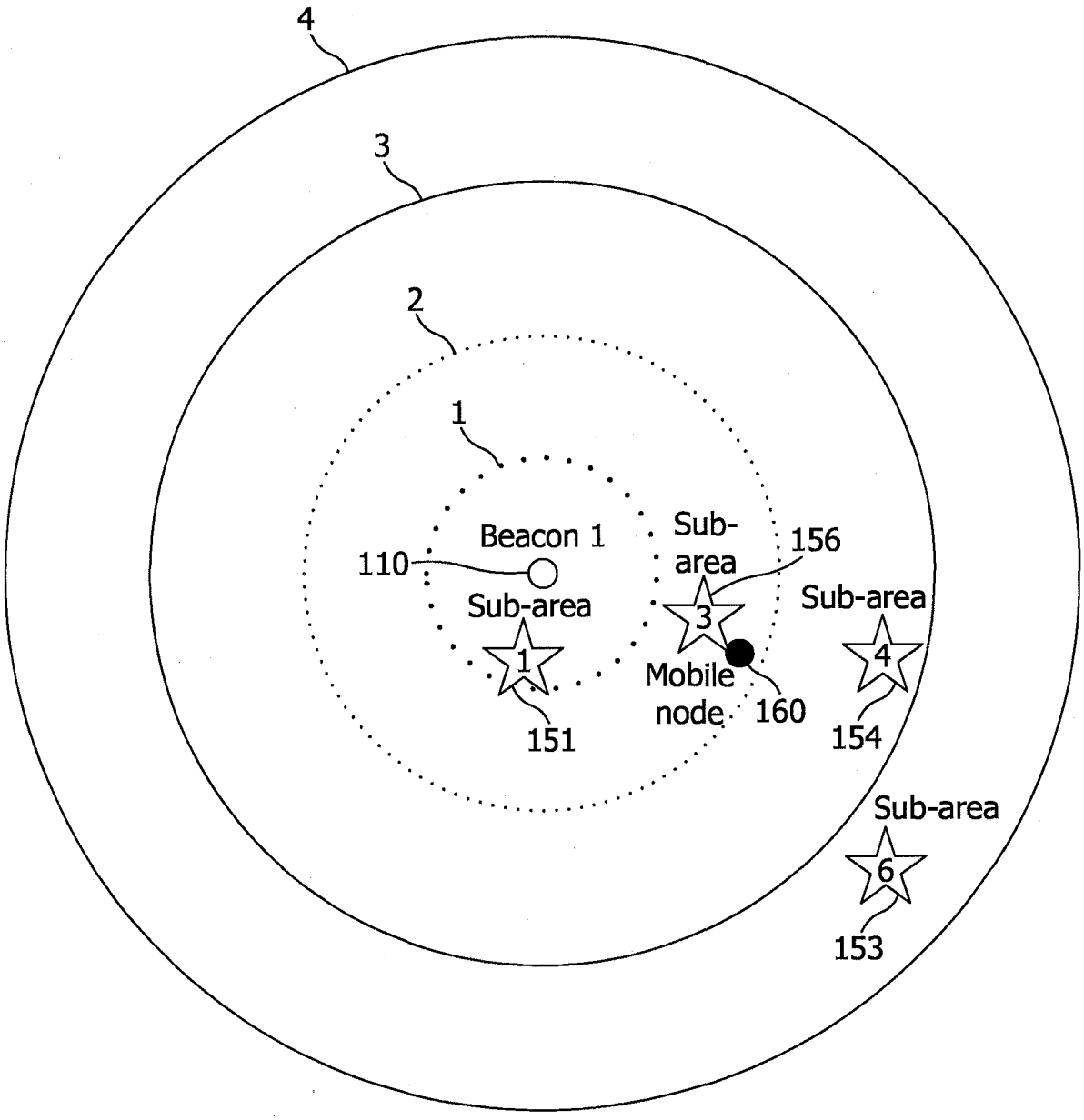

4
3
2
1
Beacon 1
110
Sub-area
1
151
Sub-area
3
156
Mobile node
160
Sub-area
4
154
Sub-area
6
153

FIG. 6

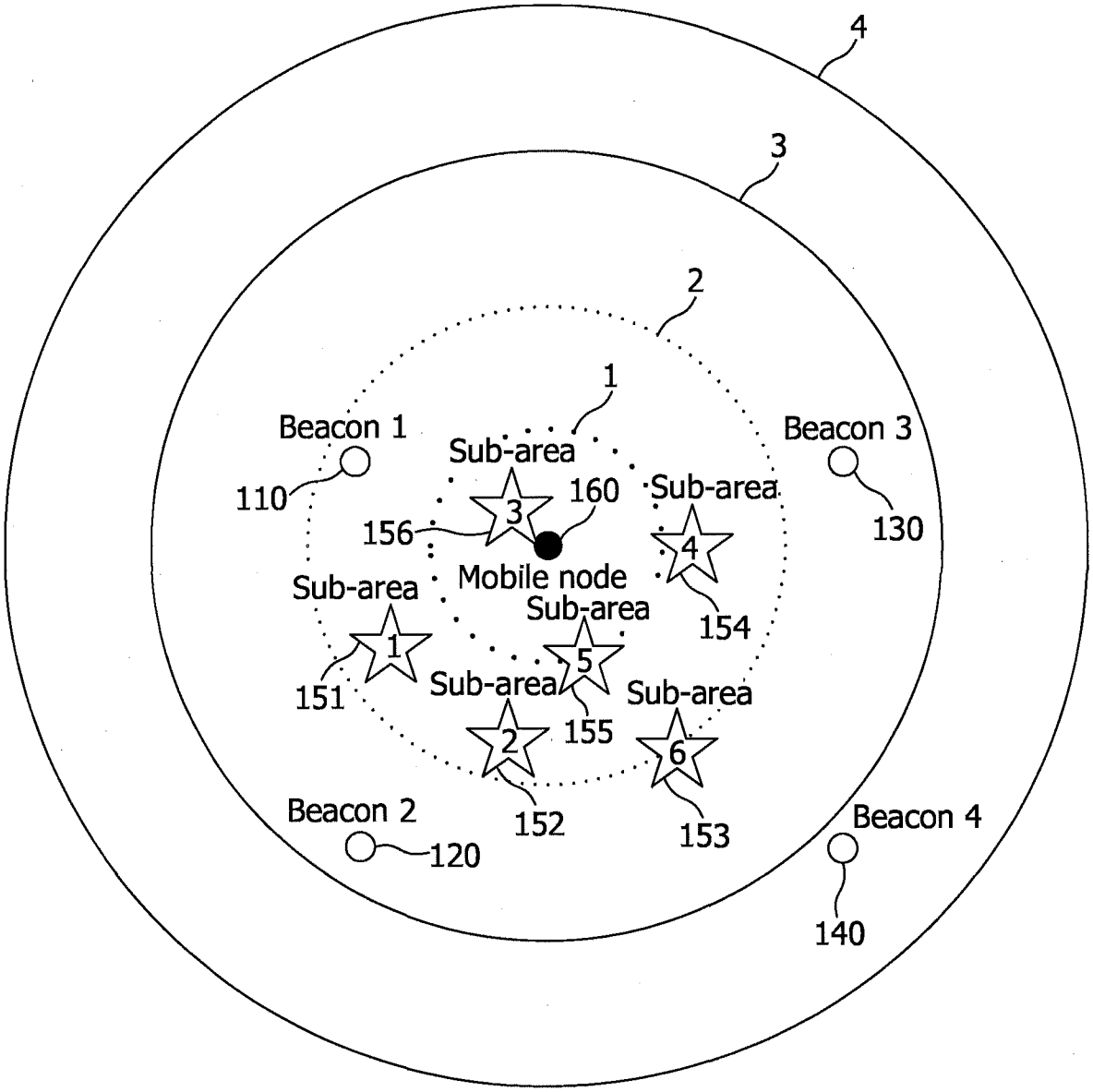

4
3
2
1
Beacon 1
110
Sub-area
3
160
Sub-area
156
4
130
Beacon 3
Mobile node
Sub-area
Sub-area
154
1
5
151
Sub-area
Sub-area
155
2
6
Beacon 2
120
152
153
Beacon 4
140

FIG. 7

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04Q7/38

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 839 560 B1 (BAHL PARAMVIR [US] ET AL) 4 January 2005 (2005-01-04) abstract column 4, line 4 - column 9, line 10	1-15
X	US 2003/220116 A1 (SAGEFALK WILLY [SE] ET AL) 27 November 2003 (2003-11-27) paragraphs [0012] - [0015], [0071] - [0083]	1-15
X	WO 2005/011321 A (POLARIS WIRELESS INC [US]; SPAIN DAVID STEVENSON JR [US]; MARTIN ROBER) 3 February 2005 (2005-02-03) abstract paragraphs [0053] - [0078]	1-15

-/--

[X] Further documents are listed in the continuation of Box C.

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Date of the actual completion of the international search	Date of mailing of the international search report
20 December 2006	29/12/2006

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Falò, Luca

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/064877 A1 (GUM ARNOLD J [US] ET AL) 24 March 2005 (2005-03-24) abstract; claims 6-9 paragraphs [0029] - [0053], [0072]	1-15
A	US 2004/087316 A1 (CACI J CLAUDE [US]) 6 May 2004 (2004-05-06) paragraphs [0029] - [0047]	1-15

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6839560 B1	04-01-2005	US 2005096068 A1	05-05-2005
US 2003220116 A1	27-11-2003	NONE	
WO 2005011321 A	03-02-2005	EP 1647160 A1	19-04-2006
US 2005064877 A1	24-03-2005	AU 2004275387 A1	31-03-2005
		CA 2539340 A1	31-03-2005
		CN 1875290 A	06-12-2006
		EP 1668382 A2	14-06-2006
		KR 20060056390 A	24-05-2006
		WO 2005029120 A2	31-03-2005
US 2004087316 A1	06-05-2004	NONE	

Electronic Acknowledgement Receipt

EFS ID:	22392685
Application Number:	14518868
International Application Number:	
Confirmation Number:	6799
Title of Invention:	System and Method to Collect and Modify Calibration Data
First Named Inventor/Applicant Name:	Martin Alles
Customer Number:	79172
Filer:	Patrick Dennis McPherson/Nicola Kinney
Filer Authorized By:	Patrick Dennis McPherson
Attorney Docket Number:	AND01 083 CONT
Receipt Date:	19-MAY-2015
Filing Date:	20-OCT-2014
Time Stamp:	17:32:34
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		AND01_083CONT_IDS_REF.pdf	9672034 bf509cba66e8536c718d521b042d02fd778ce0d4	yes	110

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	Information Disclosure Statement (IDS) Form (SB08)		1	9	
	Information Disclosure Statement (IDS) Form (SB08)		10	16	
	Information Disclosure Statement (IDS) Form (SB08)		17	23	
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2		AND01_083CONT_REFSpdf.pdf	7188872 9fc494c22811095b5deb4612f609721b8a315cdf	yes	77
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	Foreign Reference		47	67	
	Non Patent Literature		68	71	
	Non Patent Literature		72	72	
	Non Patent Literature		73	77	
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Information:					
3		NPL1GEO1.pdf	4617832 ce7209d5c25d0817acba1963724635fd0cf1e2f0	yes	33
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	Document Description		**Start**	**End**	
	Foreign Reference		1	9	
	Non Patent Literature		10	16	

	Non Patent Literature		17	21	
	Non Patent Literature		22	24	
	Non Patent Literature		25	29	
	Non Patent Literature		30	33	
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Information:					
4	Non Patent Literature	NPL2GEO1.pdf	7573906 c3b3f47a754bad25b8e6e4dc7da9f37ab1e3de61	no	35
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Information:					
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7		NPL1TP3.pdf	10773948 d7b41537e6591052075072cbc00b1454adc33020	yes	49
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9		NPL3TP3.pdf	6137866 32424b4a1716540aa0cd0c66daa2d8565ed150b8	yes	41
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11	Foreign Reference	GB2364617.pdf	2683821 649233089d40a031f7a1a13ea2e12d041f53d7d6	no	40
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12	Foreign Reference	WO0018148.pdf	1543830 1a6f8fcc3258ba36eb6a10e4214cec1c60e2fdac	no	17
Warnings:					
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13	Foreign Reference	WO2008097505.pdf	6031742 c93ab6bb4a41692a4e1f4399c3fb86f638d76095	no	73
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14	Foreign Reference	WO2007015188.pdf	2394516 7e3780dd318ed952e9320f0c449ba7ab577d258e	no	28

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INFORMATION DISCLOSURE STATEMENT BY APPLICANT (**Not for submission under 37 CFR 1.99**)		
	Application Number	14518868
	Filing Date	2014-10-20
	First Named Inventor	Alles et al.
	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

U.S.PATENTS						
Examiner Initial*	Cite No	Patent Number	Kind Code[1]	Issue Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear
	1	7593738	B2	2009-09-22	Anderson	
	2	7440762	B2	2008-10-21	Maloney et al.	
	3	7427952	B2	2008-09-23	Bull et al.	
	4	7340259	B2	2008-03-04	Maloney	
	5	7271765	B2	2007-09-18	Stilp et al.	
	6	7167713	B2	2007-01-23	Anderson	
	7	7023383	B2	2006-04-04	Stilp et al.	
	8	6996392	B2	2006-02-07	Anderson	

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	Application Number	14518868
	Filing Date	2014-10-20
	First Named Inventor	Alles et al.
	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

	9	6876859	B2	2005-04-05	Anderson et al.	
	10	6873290	B2	2005-03-29	Anderson et al.	
	11	6782264	B2	2004-08-24	Anderson	
	12	6771625	B1	2004-08-03	Beal	
	13	6765531	B2	2004-07-20	Anderson	
	14	6661379	B2	2003-12-09	Stilp et al.	
	15	6646604	B2	2003-11-11	Anderson	
	16	6603428	B2	2003-08-05	Stilp	
	17	6563460	B2	2003-05-13	Stilp et al.	
	18	6546256	B1	2003-04-08	Maloney	
	19	6519465	B2	2003-02-11	Stilp et al.	

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	Filing Date	2014-10-20
	First Named Inventor	Alles et al.
	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

	20	6492944	B1	2002-12-10	Stilp	
	21	6483460	B2	2002-11-19	Stilp et al.	
	22	6463290	B1	2002-10-08	Stilp et al.	
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	25	6366241	B2	2002-04-02	Pack	
	26	6351235	B1	2002-02-26	Stilp	
	27	6334059	B1	2001-12-25	Stilp et al.	
	28	6317604	B1	2001-11-13	Kovach Jr. et al.	
	29	6317081	B1	2001-11-13	Stilp	
	30	6288676	B1	2001-09-11	Maloney	

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	First Named Inventor	Alles et al.
	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

	31	6288675	B1	2001-09-11	Maloney	
	32	6285321	B1	2001-09-04	Stilp et al.	
	33	6281834	B1	2001-08-28	Stilp	
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	37	6127975	A	2000-10-03	Maloney	
	38	6119013	A	2000-09-12	Maloney et al.	
	39	6115599	A	2000-09-05	Stilp	
	40	6108555	A	2000-08-22	Maloney et al.	
	41	6101178	A	2000-08-08	Beal	

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	14518868
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	First Named Inventor	Alles et al.
	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

	42	6097336	A	2000-08-01	Stilp	
	43	6091362	A	2000-07-18	Stilp	
	44	6047192	A	2000-04-04	Maloney	
	45	5959580	A	1999-09-28	Maloney et al.	
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	47	5327144	A	1994-07-05	Stilp et al.	
	48	4728959	A	1988-03-01	Maloney	

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	1	20080160952	A1	2008-07-03	Bull et al.	
	2	20080160953	A1	2008-07-03	Mia et al.	

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	Application Number	14518868
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	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

FOREIGN PATENT DOCUMENTS

Examiner Initial*	Cite No	Foreign Document Number[3]	Country Code[2] i	Kind Code[4]	Publication Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear	T[5]
	1	06088472	WO	A1	2006-08-24	Anderson et al.		☐

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NON-PATENT LITERATURE DOCUMENTS

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INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	14518868
	Filing Date	2014-10-20
	First Named Inventor	Alles et al.
	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

CERTIFICATION STATEMENT

Please see 37 CFR 1.97 and 1.98 to make the appropriate selection(s):

☐ That each item of information contained in the information disclosure statement was first cited in any communication from a foreign patent office in a counterpart foreign application not more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e)(1).

OR

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☐ See attached certification statement.

☐ Fee set forth in 37 CFR 1.17 (p) has been submitted herewith.

☒ None

SIGNATURE

A signature of the applicant or representative is required in accordance with CFR 1.33, 10.18. Please see CFR 1.4(d) for the form of the signature.

Signature	/Mark C. Comtois/	Date (YYYY-MM-DD)	2015-05-19
Name/Print	Mark C. Comtois	Registration Number	46285

This collection of information is required by 37 CFR 1.97 and 1.98. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 1 hour to complete, including gathering, preparing and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

PTO/SB/08a (05-07)
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INFORMATION DISCLOSURE STATEMENT BY APPLICANT (**Not for submission under 37 CFR 1.99**)		
	Application Number	14518868
	Filing Date	2014-10-20
	First Named Inventor	Alles et al.
	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

U.S.PATENTS						
Examiner Initial*	Cite No	Patent Number	Kind Code[1]	Issue Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear
	1					
If you wish to add additional U.S. Patent citation information please click the Add button.						
U.S.PATENT APPLICATION PUBLICATIONS						
Examiner Initial*	Cite No	Publication Number	Kind Code[1]	Publication Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear
	1	20080161015	A1	2008-07-03	Maloney et al.	
	2	20020172223	A1	2002-11-21	Stilp et al.	
	3	20080132247	A1	2008-06-05	Anderson et al.	
	4	20080132244	A1	2008-06-05	Anderson et al.	
	5	20080158059	A1	2008-07-03	Bull et al.	

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	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

	6	20080261614	A1	2008-10-23	Mia et al.	
	7	20080261613	A1	2008-10-23	Anderson et al.	
	8	20080261612	A1	2008-10-23	Mia et al.	
	9	20080261611	A1	2008-10-23	Mia et al.	
	10	20080137524	A1	2008-06-12	Anderson et al.	
	11	20080248811	A1	2008-10-09	Maloney et al.	
	12	20070111746	A1	2007-05-17	Anderson et al.	
	13	20070155489	A1	2007-07-05	Beckley et al.	
	14	20090005061	A1	2009-01-01	Ward et al.	
	15	20070155401	A1	2007-07-05	Ward et al.	
	16	20060030333	A1	2006-02-09	Ward et al.	

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
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	Filing Date	2014-10-20
	First Named Inventor	Alles et al.
	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

	17	20030064734	A1	2003-04-03	Stilp et al.	
	18	20060003775	A1	2006-01-05	Bull et al.	

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FOREIGN PATENT DOCUMENTS

Examiner Initial*	Cite No	Foreign Document Number[3]	Country Code[2] i	Kind Code[4]	Publication Date	Name of Patentee or Applicant of cited Document	Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear	T[5]
	1							☐

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NON-PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc), date, pages(s), volume-issue number(s), publisher, city and/or country where published.	T[5]
	1		☐

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EXAMINER SIGNATURE

Examiner Signature		Date Considered	

*EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through a citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

[1] See Kind Codes of USPTO Patent Documents at www.USPTO.GOV or MPEP 901.04. [2] Enter office that issued the document, by the two-letter code (WIPO Standard ST.3). [3] For Japanese patent documents, the indication of the year of the reign of the Emperor must precede the serial number of the patent document. [4] Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST.16 if possible. [5] Applicant is to place a check mark here if English language translation is attached.

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)		
	Application Number	14518868
	Filing Date	2014-10-20
	First Named Inventor	Alles et al.
	Art Unit	2641
	Examiner Name	Mazda Sabouri
	Attorney Docket Number	AND01 083 CONT

CERTIFICATION STATEMENT

Please see 37 CFR 1.97 and 1.98 to make the appropriate selection(s):

☐ That each item of information contained in the information disclosure statement was first cited in any communication from a foreign patent office in a counterpart foreign application not more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e)(1).

OR

☐ That no item of information contained in the information disclosure statement was cited in a communication from a foreign patent office in a counterpart foreign application, and, to the knowledge of the person signing the certification after making reasonable inquiry, no item of information contained in the information disclosure statement was known to any individual designated in 37 CFR 1.56(c) more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e)(2).

☐ See attached certification statement.

☐ Fee set forth in 37 CFR 1.17 (p) has been submitted herewith.

☒ None

SIGNATURE

A signature of the applicant or representative is required in accordance with CFR 1.33, 10.18. Please see CFR 1.4(d) for the form of the signature.

Signature	/Mark C. Comtois/	Date (YYYY-MM-DD)	2015-05-19
Name/Print	Mark C. Comtois	Registration Number	46285

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www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
14/518,868	10/20/2014	Martin Alles	AND01 083 CONT

CONFIRMATION NO. 6799

PUBLICATION NOTICE

79172
Duane Morris LLP
505 9th Street, N.W.
Suite 1000
Washington, DC 20004

OC000000073234794

Title: System and Method to Collect and Modify Calibration Data

Publication No.US-2015-0038167-A1
Publication Date:02/05/2015

NOTICE OF PUBLICATION OF APPLICATION

The above-identified application will be electronically published as a patent application publication pursuant to 37 CFR 1.211, et seq. The patent application publication number and publication date are set forth above.

The publication may be accessed through the USPTO's publically available Searchable Databases via the Internet at www.uspto.gov. The direct link to access the publication is currently http://www.uspto.gov/patft/.

The publication process established by the Office does not provide for mailing a copy of the publication to applicant. A copy of the publication may be obtained from the Office upon payment of the appropriate fee set forth in 37 CFR 1.19(a)(1). Orders for copies of patent application publications are handled by the USPTO's Office of Public Records. The Office of Public Records can be reached by telephone at (703) 308-9726 or (800) 972-6382, by facsimile at (703) 305-8759, by mail addressed to the United States Patent and Trademark Office, Office of Public Records, Alexandria, VA 22313-1450 or via the Internet.

In addition, information on the status of the application, including the mailing date of Office actions and the dates of receipt of correspondence filed in the Office, may also be accessed via the Internet through the Patent Electronic Business Center at www.uspto.gov using the public side of the Patent Application Information and Retrieval (PAIR) system. The direct link to access this status information is currently http://pair.uspto.gov/. Prior to publication, such status information is confidential and may only be obtained by applicant using the private side of PAIR.

Further assistance in electronically accessing the publication, or about PAIR, is available by calling the Patent Electronic Business Center at 1-866-217-9197.

Office of Data Managment, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

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DECLARATION (37 CFR 1.63) FOR UTILITY OR DESIGN APPLICATION USING AN APPLICATION DATA SHEET (37 CFR 1.76)

Title of Invention	SYSTEM AND METHOD TO COLLECT AND MODIFY CALIBRATION DATA

As the below named inventor, I hereby declare that:

This declaration is directed to:

☐ The attached application, or

☒ United States application or PCT international application number 14/518,868

filed on 20 October 2014.

The above-identified application was made or authorized to be made by me.

I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.

I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

WARNING:

Petitioner/applicant is cautioned to avoid submitting personal information in documents filed in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to the USPTO. Petitioner/applicant is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available.

LEGAL NAME OF INVENTOR

Inventor: Martin Alles Date (Optional): 11/30/2014

Signature: Martin Alles

Note: An application data sheet (PTO/SB/14 or equivalent), including naming the entire inventive entity, must accompany this form or must have been previously filed. Use an additional PTO/AIA/01 form for each additional inventor.

This collection of information is required by 35 U.S.C. 115 and 37 CFR 1.63. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 1 minute to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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The above-identified application was made or authorized to be made by me.

I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.

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LEGAL NAME OF INVENTOR

Inventor: John Carlson Date (Optional): 11/7/2014

Signature: [signature]

Note: An application data sheet (PTO/SB/14 or equivalent), including naming the entire inventive entity, must accompany this form or must have been previously filed. Use an additional PTO/AIA/01 form for each additional inventor.

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LEGAL NAME OF INVENTOR

Inventor: George Maher Date (Optional): 11/7/2014

Signature: George C Maher

Note: An application data sheet (PTO/SB/14 or equivalent), including naming the entire inventive entity, must accompany this form or must have been previously filed. Use an additional PTO/AIA/01 form for each additional inventor.

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I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.

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LEGAL NAME OF INVENTOR

Inventor: Selcuk Mazlum Date (Optional): 11/6/2014

Signature: S.Mazlum

Note: An application data sheet (PTO/SB/14 or equivalent), including naming the entire inventive entity, must accompany this form or must have been previously filed. Use an additional PTO/AIA/01 form for each additional inventor.

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Electronic Acknowledgement Receipt

EFS ID:	20918084
Application Number:	14518868
International Application Number:	
Confirmation Number:	6799
Title of Invention:	System and Method to Collect and Modify Calibration Data
First Named Inventor/Applicant Name:	Martin Alles
Customer Number:	79172
Filer:	Mark Charles Comtois/laureen ponder
Filer Authorized By:	Mark Charles Comtois
Attorney Docket Number:	AND01 083 CONT
Receipt Date:	10-DEC-2014
Filing Date:	20-OCT-2014
Time Stamp:	12:32:41
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		AND01083CONTDecs.pdf	604208 7ed2eb3cfdb2b89a8fac6469eb33851ad613016c	yes	4

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Oath or Declaration filed	1	1
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	Oath or Declaration filed	3	3
	Oath or Declaration filed	4	4
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National Stage of an International Application under 35 U.S.C. 371
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New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
14/518,868	10/20/2014	Martin Alles	AND01 083 CONT

CONFIRMATION NO. 6799

79172
Duane Morris LLP
505 9th Street, N.W.
Suite 1000
Washington, DC 20004

NOTICE

OC000000071564123

Date Mailed: 10/28/2014

INFORMATIONAL NOTICE TO APPLICANT

Applicant is notified that the above-identified application contains the deficiencies noted below. No period for reply is set forth in this notice for correction of these deficiencies. However, if a deficiency relates to the inventor's oath or declaration, the applicant must file an oath or declaration in compliance with 37 CFR 1.63, or a substitute statement in compliance with 37 CFR 1.64, executed by or with respect to each actual inventor no later than the expiration of the time period set in the "Notice of Allowability" to avoid abandonment. See 37 CFR 1.53(f).

The item(s) indicated below are also required and should be submitted with any reply to this notice to avoid further processing delays.

- A properly executed inventor's oath or declaration has not been received for the following inventor(s):
  Martin Alles
  John Carlson
  George Maher
  Selcuk Mazlum

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United States Patent and Trademark Office
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www.uspto.gov

APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
14/518,868	10/20/2014	3646	1900	AND01 083 CONT	22	2

CONFIRMATION NO. 6799

79172
Duane Morris LLP
505 9th Street, N.W.
Suite 1000
Washington, DC 20004

FILING RECEIPT

OC000000071564122

Date Mailed: 10/28/2014

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Inventor(s)

Martin Alles, Vienna, VA;
John Carlson, Dulles, VA;
George Maher, Herndon, VA;
Selcuk Mazlum, Leesburg, VA;

Applicant(s)

Andrew LLC, Hickory, NC

Assignment For Published Patent Application

Andrew LLC, Hickory, NC

Power of Attorney: None

Domestic Priority data as claimed by applicant

This application is a CON of 12/026,372 02/05/2008
which claims benefit of 60/899,379 02/05/2007

Foreign Applications for which priority is claimed (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.) - None.
Foreign application information must be provided in an Application Data Sheet in order to constitute a claim to foreign priority. See 37 CFR 1.55 and 1.76.

If Required, Foreign Filing License Granted: 10/27/2014
The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 14/518,868**
Projected Publication Date: 02/05/2015
Non-Publication Request: No

Early Publication Request: No
Title

System and Method to Collect and Modify Calibration Data

Preliminary Class

342

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

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Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

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Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at http://www.uspto.gov/web/offices/pac/doc/general/index.html.

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Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

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PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number: 14/518,868

APPLICATION AS FILED - PART I

FOR	(Column 1) NUMBER FILED	(Column 2) NUMBER EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY FEE($)
BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A			N/A	280
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A			N/A	600
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A			N/A	720
TOTAL CLAIMS (37 CFR 1.16(i))	22 minus 20 =	* 2			OR	x 80 =	160
INDEPENDENT CLAIMS (37 CFR 1.16(h))	2 minus 3 =	*				x 420 =	0.00
APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).						0.00
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))							0.00
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL			TOTAL	1760

APPLICATION AS AMENDED - PART II

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
AMENDMENT A	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE($)	ADDITIONAL FEE($)		RATE($)	ADDITIONAL FEE($)
AMENDMENT B	Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
	Application Size Fee (37 CFR 1.16(s))									
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".
The "Highest Number Previously Paid For" (Total or Independent) is the highest found in the appropriate box in column 1.

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	AND01 083 CONT
	Application Number	
Title of Invention	System and Method to Collect and Modify Calibration Data	

The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76.
This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.

Secrecy Order 37 CFR 5.2

☐ Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)

Inventor Information:

Inventor 1 Remove

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Martin		Alles	

Residence Information (Select One) ◉ US Residency ○ Non US Residency ○ Active US Military Service

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Residence Information (Select One) ◉ US Residency ○ Non US Residency ○ Active US Military Service

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	AND01 083 CONT
	Application Number	
Title of Invention	System and Method to Collect and Modify Calibration Data	

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Residence Information (Select One) (•) US Residency ( ) Non US Residency ( ) Active US Military Service

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Address 2	

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Postal Code	20175	**Country**	US

All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the **Add** button. Add

Correspondence Information:

Enter either Customer Number or complete the Correspondence Information section below.
For further information see 37 CFR 1.33(a).

☐ **An Address is being provided for the correspondence Information of this application.**

Customer Number	79172		
Email Address		Add Email	Remove Email

Application Information:

Title of the Invention	System and Method to Collect and Modify Calibration Data		
Attorney Docket Number	AND01 083 CONT	**Small Entity Status Claimed**	☐
Application Type	Nonprovisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)	8	**Suggested Figure for Publication (if any)**	

Filing By Reference :

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	AND01 083 CONT
	Application Number	
Title of Invention	System and Method to Collect and Modify Calibration Data	

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., "Domestic Benefit/National Stage Information" and "Foreign Priority Information").

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)

☐ **Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not** be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

Representative Information:

Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32).
Either enter Customer Number or complete the Representative Name section below. If both sections are completed the customer Number will be used for the Representative Information during processing.

Please Select One:	◉ Customer Number	○ US Patent Practitioner	○ Limited Recognition (37 CFR 11.9)
Customer Number	79172		

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, or 365(c) or indicate National Stage entry from a PCT application. Providing this information in the application data sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.
When referring to the current application, please leave the application number blank.

Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	Continuation of	12/026372	2008-02-05
Prior Application Status	Expired		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
12/026372	Claims benefit of provisional	60/899379	2007-02-05

Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the **Add** button.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	AND01 083 CONT
	Application Number	
Title of Invention	System and Method to Collect and Modify Calibration Data	

Foreign Priority Information:

This section allows for the applicant to claim priority to a foreign application. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55(d). When priority is claimed to a foreign application that is eligible for retrieval under the priority document exchange program (PDX)[i] the information will be used by the Office to automatically attempt retrieval pursuant to 37 CFR 1.55(h)(1) and (2). Under the PDX program, applicant bears the ultimate responsibility for ensuring that a copy of the foreign application is received by the Office from the participating foreign intellectual property office, or a certified copy of the foreign priority application is filed, within the time period specified in 37 CFR 1.55(g)(1).

Remove

Application Number	Country[i]	Filing Date (YYYY-MM-DD)	Access Code[i] (if applicable)

Additional Foreign Priority Data may be generated within this form by selecting the **Add** button.

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013.
NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

Authorization to Permit Access:

☐ Authorization to Permit Access to the Instant Application by the Participating Offices

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	AND01 083 CONT
	Application Number	
Title of Invention	System and Method to Collect and Modify Calibration Data	

If checked, the undersigned hereby grants the USPTO authority to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the World Intellectual Property Office (WIPO), and any other intellectual property offices in which a foreign application claiming priority to the instant patent application is filed access to the instant patent application. See 37 CFR 1.14(c) and (h). This box should not be checked if the applicant does not wish the EPO, JPO, KIPO, WIPO, or other intellectual property office in which a foreign application claiming priority to the instant patent application is filed to have access to the instant patent application.

In accordance with 37 CFR 1.14(h)(3), access will be provided to a copy of the instant patent application with respect to: 1) the instant patent application-as-filed; 2) any foreign application to which the instant patent application claims priority under 35 U.S.C. 119(a)-(d) if a copy of the foreign application that satisfies the certified copy requirement of 37 CFR 1.55 has been filed in the instant patent application; and 3) any U.S. application-as-filed from which benefit is sought in the instant patent application.

In accordance with 37 CFR 1.14(c), access may be provided to information concerning the date o f filing this Authorization.

Applicant Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Applicant 1

If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.

Clear

○ Assignee	○ Legal Representative under 35 U.S.C. 117	○ Joint Inventor
◉ Person to whom the inventor is obligated to assign.	○ Person who shows sufficient proprietary interest	

If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:

Deceased	
Name of the Deceased or Legally Incapacitated Inventor :	

If the Applicant is an Organization check here. ☒

Organization Name	Andrew LLC

Mailing Address Information For Applicant:

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Country	US	Postal Code	28602
Phone Number		Fax Number	

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	AND01 083 CONT
	Application Number	
Title of Invention	System and Method to Collect and Modify Calibration Data	

Email Address	

Additional Applicant Data may be generated within this form by selecting the Add button.

Assignee Information including Non-Applicant Assignee Information:

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Assignee 1

Complete this section if assignee information, including non-applicant assignee information, is desired to be included on the patent application publication . An assignee-applicant identified in the "Applicant Information" section will appear on the patent application publication as an applicant. For an assignee-applicant, complete this section only if identification as an assignee is also desired on the patent application publication.

If the Assignee or Non-Applicant Assignee is an Organization check here. ☒

Organization Name	Andrew LLC

Mailing Address Information For Assignee including Non-Applicant Assignee:

Address 1	1100 Commscope Place		
Address 2			
City	Hickory	**State/Province**	NC
Country i	US	Postal Code	28602
Phone Number		Fax Number	
Email Address			

Additional Assignee or Non-Applicant Assignee Data may be generated within this form by selecting the Add button.

Signature:

NOTE: This form must be signed in accordance with 37 CFR 1.33. See 37 CFR 1.4 for signature requirements and certifications.

Signature	/Mark C. Comtois/			Date (YYYY-MM-DD)	2014-10-20
First Name	Mark	Last Name	Comtois	Registration Number	46285

Additional Signature may be generated within this form by selecting the Add button.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	AND01 083 CONT
	Application Number	
Title of Invention	System and Method to Collect and Modify Calibration Data	

This collection of information is required by 37 CFR 1.76. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 23 minutes to complete, including gathering, preparing, and submitting the completed application data sheet form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

SYSTEM AND METHOD TO COLLECT AND MODIFY CALIBRATION DATA

CROSS REFERENCES

[0001] The present application is a continuation of U.S. Patent Application No. 12/026,372, entitled "System and Method to Collect and Modify Calibration Data", filed 5 February 2008 which claims priority benefit to and is related to provisional application No. 60/899,379 entitled "Mobile Location Using Network Measurement Reports" filed on February 5, 2007, each of which are hereby incorporated by reference in their entirety.

BACKGROUND

[0002] The use of wireless communication devices such as telephones, pagers, personal digital assistants, laptop computers, etc., hereinafter referred to collectively as "mobile appliances" or "mobiles stations" has become prevalent in today's society. In recent years, at the urging of public safety groups, there has been increased interest in technology which can determine the geographic position or "geo-locate" a mobile station in certain circumstances.

[0003] Estimating the location of a mobile station may require one or more types of calibration data associated with the mobile station (*e.g.,* signal strength, round trip time, time difference of arrival (TDOA), ground truth data, etc.). Determining precise ground truth measurements is important when generating an

accurate calibration database. Without accurate ground truth information, the calibration database will contain significant errors which will in turn be reflected by poor location estimates. Any device used to retrieve ground truth data may produce some degree of signal degradation or drop-out. In the case of a GPS receiver used to collect ground truth data, degradation or drop-out could occur, for example, due to poor satellite visibility or high dilution of precision (DOP).

[0004] Referring to FIG. 1, a vehicle 40 may be configured with a collection device 45 to collect calibration data. Once calibration data has been obtained, it may be stored locally in an internal memory of the collection device 45, or the data may be transmitted to a receiving base station 60, where the data is stored in a calibration database 50.

[0005] The vehicle 40 may include a dead-reckoning device (not shown) to collect data during periods of signal degradation or drop-out. Such devices attempt to calculate the location of the vehicle when GPS location signaling obtained from a GPS satellite 70 becomes unavailable. Dead reckoning operates by estimating a location of a moving vehicle 40 using information, such as, but not limited to, the last accurate GPS location, velocity of the vehicle 40 and may include other known information.

[0006] Dead reckoning schemes often produce data results that may be unsatisfactory when attempting to perform a location estimate. FIG. 2 illustrates an exemplary dead reckoning operation. Referring to FIG. 2, a vehicle's estimated position is illustrated by the line (T) along the street. During a dead reckoning

operation, there may be an increased chance of location error and the vehicle's estimated position (T) may be erroneous with respect to the actual position of the vehicle.

[0007] Current collection procedures utilized to generate a calibration database 50 may also be laborious, time-consuming and expensive. Simplifying the test and measurement equipment (T&M) needed, and the procedures for obtaining calibration data may save time and expenses.

[0008] To increase the accuracy of location estimates, it is important the collected calibration data be as precise as possible. To ensure the integrity of the calibration data after it has been collected, a data modification and/or data replacement algorithm may be implemented to enhance the accuracy of the collected data. Enhancing the collected calibration data may reduce the chances of errors occurring during a subsequent location process. Additionally, generating a calibration database using enhanced collection procedures may simplify the collection process.

[0009] One embodiment of the present subject matter is a method for generating a calibration database that may be used to locate a mobile station. The method may include obtaining location data from a plurality of geographic locations within a region and providing a location information database which includes latitude and longitude information fore each of a plurality of points within the region. The method may also include determining two points in proximity to one of

the plural geographic locations, interpolating between the two points to determine a third point, and entering the location of the third point in the calibration database.

[0010] Another embodiment of the present subject matter is method for generating a calibration database employing a wireless device in a region that contains plural streets and intersections of the plural streets. The method may include obtaining location data of a plurality of geographic locations situated within a region from the wireless device and providing a location information database including latitude and longitude information for each of a plurality of points within the region. The method may also include determining a status of the wireless device, determining from the status a most likely street the wireless device is located for a first one of the plural geographic locations, and determining a first point of the plural points that is in proximity to said first geographic location. The method may then enter the first point in the calibration database.

[0011] Another embodiment of the present subject matter is a system for generating a calibration database. The system may include a first database containing location data obtained at a plurality of geographic locations within a region and a location information database which includes latitude and longitude information for each of a plurality of points in the same region. The system may also include circuitry for determining points in the location information database that are in proximity to a geographical location, circuitry for interpolating between the points to determine a third point, and circuitry for entering the third point in the calibration database.

[0012] Another embodiment of the disclosed subject matter is a system for generating a calibration database in a region with plural streets and intersections using a wireless device. The system may include a wireless device for obtaining location data at geographic locations within a region and a location information database that includes latitude and longitude information for a plurality of points within the region. The system may also include circuitry for determining a status of the wireless device, circuitry for determining from the status which street the wireless device is situated upon for a geographic location, circuitry for determining a first point proximate to the geographic location, and circuitry for entering the first point in the calibration database.

[0013] These and other advantages of the disclosed subject matter over the prior art will be readily apparent to one skilled in the art to which the disclosure pertains from a perusal of the claims, the appended drawings, and the following detailed description of the preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIG. 1 illustrates an exemplary calibration data collection system.

[0015] FIG. 2 illustrates an example of dead reckoning.

[0016] FIG. 3 illustrates an example of location point position estimation.

[0017] FIG. 4 illustrates another example of location point estimation.

[0018] FIG. 5 illustrates a block diagram calibration data collection system.

[0019] FIG. 6 illustrates an exemplary non-uniform grid (NUG) region (R).

[0020] FIG. 7 illustrates a flow diagram according to an exemplary embodiment.

[0021] FIG.8 illustrates a flow diagram according to an embodiment of the present subject matter.

[0022] FIG. 9 illustrates a flow diagram according to another embodiment of the present subject matter.

DETAILED DESCRIPTION

[0023] Ground truth data observed from a data collection device (*i.e.,* a GPS receiver) may be collected and stored in a calibration database and compared to a street database to modify and enhance the calibration data for increased accuracy. Increasing the accuracy of the ground truth data may in turn provide more accurate location results.

[0024] Calibration data may include a set of location data obtained by any of a variety of data collection devices and techniques. Some exemplary collection devices may include a GPS receiver that receives satellite location signals, and a terrestrial geo-location device that measures received signal strengths from base stations or other wireless signaling devices. Assuming a set of location data have been obtained by one or more of types of data collection devices, the location data may be compared to other data sources to determine the degree of data deviation and to ensure the data's integrity.

[0025] In a geographical area that contains multiple streets, highways, etc. having corresponding intersections, there may be a probability of collecting erroneous location point data regardless of the type of data collection device. A street database may be used as a supplemental data source to compare and/or check the integrity of collected location data. The street database may be a compilation of latitude, longitude and other forms of geographical location data, and may also provide ancillary information such as the direction of one-way streets, off-street territories, etc. The street database data may be stored in the same database 50 used to store the collected ground truth data or may be stored in a separate database.

[0026] The precise latitude and longitude positions of streets may be included in the street database. Referring to FIG. 2, if a data collection procedure relied on dead reckoning to determine ground truth data due to a lost GPS satellite signal, the resulting data will have an increased likelihood of producing an off-street and/or erroneous location estimate.

[0027] Location data may be modified using a location information database (*e.g.*, a street database) as an optimum overlay. The location information database may provide a set of latitude and longitude information that can be used as an overlay guide, which may be compared and matched to the collected location data. Determining which street the collection process was conducted on may be a prerequisite for selecting which set of data to use for data enhancing purposes. A set of collected location points may substantially parallel a set of data in a street database, and may provide an accurate overlay for comparison purposes.

Alternatively, the street database may demonstrate inconsistencies between a first street and a nearby street that may require clarification. The location information database may be selected to overlap the geographic area of the respective collected location data. The overlapped region may be designated by coordinates, street, town, Zip code or other geographic area descriptor.

[0028] Checking the integrity of each retrieved ground truth location point may include matching each point to the closest street in the street database. In another example, a set of points may be matched to a particular street based on the proximity of a group of points. A location data point or set of location data points may be represented in a data vector(s), where each data vector has at least one parameter associated with a particular location. Each data vector used for location estimation may have, for example, N components with at least one of its components as the location, and where the other N-l components may apply to other data signal components.

[0029] Referring to FIG. 3, data points x1, x2, x3, x4 and x5 may have been measured by a vehicle driving on the street (S1). Once the measurements at the data points are obtained, a location information database, such as a map database can be used to match the measured data points (x1-x5) to points located on the actual street x1', x2', x3', x4' and x5', which are stored in the street database. In this case, the street (S1) provides a simple way to perform a comparison and adjustment procedure to modify the values of the location data with respect to the location data points.

[0030] Referring to FIG. 4, a map database may include more than one street (S1, S2). In this non-limiting example, a set of measured data points (x1-x7) were measured as having an estimated location, for the most part, near street S1; however, the point x5 was estimated as being mistakenly closer to S2 than the intended street S1. In this case, it may be useful to apply an algorithm different from the closest street algorithm described above with reference to FIG. 3.

[0031] As illustrated in FIG. 4, the location point x5 is located a distance d2 from S1, which is greater than a distance d1 from S2. In this case, relying on the historical and/or future street locations of the previously and subsequently measured data points may provide a way to correctly match x5 to the correct street S1 regardless of the actual closest street to x5. Examining the street mappings of one or more points before and/or after x5 (*e.g.,* x1-x4 before, and x6-x7 after) it may be determined that x5 was intended to be part of S1 and not S2. As a result, the latitude and longitude values corresponding to the intended location of x5 (*i.e.,* x5'), with respect to S1, may be substituted for the measured position of x5.

[0032] Once the street overlay is properly matched to the measured point location data collected over a given region, and the intended street location identified with respect to the measured data points, the location data points originally retrieved from a calibration data collection device may be replaced and/or modified with the data derived from the street database. In addition, various other known methods of enhancing the position data may also be applied to increase the

integrity of the calibration database and provide accurate ground truth measurements.

[0033] Interpolation may also be used as another method to enhance collected ground truth data. If, for example, a collected ground truth data point falls outside of a street location of the street database, the two closest points in the street database may be used in an interpolation operation to determine a third point therebetween. The ground truth of this third point may then be used in subsequent calculations or as a replacement to the ground truth value that was retrieved from the original data collection process.

[0034] Historical ground truth information may also be used to enhance collected ground truth data. By keeping track of a data collection vehicle's directional movements and/or maneuvers, a probability calculation or estimate of the most likely street location may be calculated. For example, once ground truth values have been collected in a given region, these values may be modified or replaced with the ground truth values of the most probable candidate street estimated by a probability calculation of the vehicle's historical movements and maneuvers. This may be useful when attempting to correct ground truth data collected in areas with multiple streets or other obstacles likely to create erroneous ground truth data.

[0035] Ground truth data enhancement algorithms may be used to complement dead-reckoning results when the results are known to be in error. Enhancement algorithms may also be used to produce location data in situations where the dead-

reckoning component of the calibration device/vehicle may be unavailable. Ground truth exclusion criteria may be applied to limit the amount of erroneous data that is stored in the calibration database. If, for example, ground truth data is obtained via a GPS receiver, a predetermined threshold value may be established to require a certain number of visible satellites be available before the ground truth data is accepted.

[0036] A predetermined threshold value may be used to limit the data received from a particular set of measurement devices having a dilution of precision (DOP) beyond an acceptable threshold value. For example, if a group of measuring devices are located too close together then the distances between the measuring devices may be compared to the predetermined threshold, and as a result of the devices being under the acceptable separation distance, the data may be considered unacceptable and disregarded. Similarly, a threshold distance may be established as a minimum distance requirement to limit ground truth collection efforts within a particular distance from a last valid GPS reading. Other methods may also be used to limit the amount of erroneous or unnecessary ground truth data obtained and stored in the calibration database.

[0037] Calibration data collection procedures that utilize autonomous test and measurement (T&M) equipment may simplify the ground truth collection process. Simplifying the T&M equipment and/or creating autonomous procedures for data collection may allow highly mobile vehicles and untrained drivers to perform calibration data collection processes. For example, public transportation vehicles

such as buses or taxi cabs, highly mobile vehicles such as FedEx/UPS trucks, etc., or other types of vehicles that travel often within the calibration area may be prime candidates for installing the T&M equipment and performing the collection process.

[0038] Referring to FIG. 5, autonomous T&M equipment (ATME) 100 may include a wireless terminal 110 that is capable of measuring received signal strengths of serving and neighboring cell base stations and other wireless communication transmissions, a location device that computes the ground truth location of the wireless terminal 110, such as a GPS receiver 120, and a memory 130 that stores the results of the collection efforts.

[0039] ATME 100 may include storage capability to store received signals (*i.e.*, memory 130), such as, signal strength data of the serving and/or neighboring cell base stations or other network information such as cell global identity (CGI), broadcast control channel (BCCH), base station identity code (BSIC), and/or corresponding ground truth location data.

[0040] ATME 100 may be capable of sending data stored in the memory 130 to a server 180 using available baseband and/or broadband wireless data transfer technology such as GPRS, 2G, 2.5G, 3G, 4G, etc. ATME 100 may be in communication with an ATME controller unit 160, which may be located at a serving base station (BS) 140 or another location within the communication range of the ATME 100.

[0041] The controller unit 160 may monitor the statistical sufficiency of the data available for the current location of the ATME 100, and may further implement

tests to measure the statistical sufficiency to determine whether new data should be added to the existing calibration database 150. In addition, the ATME controller 160 may be linked to a non-uniform grid (NUG) or uniform grid (UG) generator permitting grid point generation and/or augmentation to proceed in parallel with the data acquisition from the ATME 100. Grid points (*e.g.,* NUGs) are another way to organize and/or realize information related to a wireless networking environment.

[0042] A NUG is described in detail in co-pending U.S. Patent Application Serial Number 12/068,213, now U.S. Patent No. 8,175,620, entitled "SYSTEM AND METHOD FOR GENERATING NON-UNIFORM GRID POINTS FROM CALIBRATION DATA", the entirety of which is incorporated herein by reference. A NUG may be generated to represent the signal characteristics and calibration data over a given region. FIG. 6 illustrates a geographical region (R) having NUGs represented by NUG1, NUG2 and NUG3. The NUGs represent an area of collected calibration data based on data collected via data collection devices and/or signals transmitted from the mobile stations (MSs) identified within the geographical region of the NUG (*e.g.,* (MS 2 and BS 21 - NUG1), (MS 4, 6, 8 and 10 - NUG2) and (MS 12, 14 and BS 23 - NUG3)). The BS 22 may serve one or more NUGs and may be located outside the region (R) of the identified NUGs. The different NUGs may be separated based on geographical considerations (*e.g.,* mountains, buildings, streets) or varying concentrations of MSs.

[0043] Network measurement reports (NMRs) may be used to represent the current estimated location and/or signal characteristics of a MS. An exemplary

NMR may be represented as a data vector containing measured signal power level parameters (*e.g.,* P1, P2, P3) and may include one or more location parameters (*i.e.,* latitude and longitude).

[0044] An exemplary NMR may be represented by the data vector [P1, P2, P3, LAT1, LONG1, TA1]. The power levels (P1-P3) may represent the power levels of three separate base stations (BSs 21-23) as measured at a particular latitude and longitude location (LAT1, LONG1). TA1 is a non-limiting example timing advance parameter. A NMR may contain any number and type of parameters used to estimate the location of a MS. NMRs may be transmitted from the MS or from other wireless network components to position determining equipment (PDE) 50 or other types of processing units to process the received information, and/or attempt to locate the MS.

[0045] The value of the timing advance (TA) parameter corresponds to the length of time a signal from a MS takes to reach a particular BS. A MS may be configured to transmit data signals at specific timeslot intervals depending on the type of wireless communication protocol employed (*e.g.,* TDMA, GSM, 3GPP etc.). Using the speed of light (c = 3*10^8 m/s) as a reference velocity for the radio waves, the TA parameter may be increased or decreased depending on the distance between the MS and the BS. The TA parameter may need to be adjusted periodically as the distance from the MS to the BS changes.

[0046] If statistically sufficient and/or recent data is available for the current NUG configuration then there would be no reason to overload the existing

calibration database 150 with further data for that location. Thus, a continuous examination of the reported data will allow for selective and judicious insertion of such data into the calibration database 150. The examination of the reported data may be performed by the controller unit 160 and/or one or more of the other network components of the data collection system (*i.e.,* server 180). If after an examination of the currently stored calibration data it is determined that the current level of collected data for a particular region is sufficient, then the current calibration efforts may be paused or stopped until instructed to return to an operating status.

[0047] Depending on the requirements for collecting data from a particular location, it is also envisioned turning the ATME 100 off when, for example, the vehicle containing the ATME 100 is parked, immobilized, or is traversing a region for which acceptable data has already been obtained.

[0048] The ATME 100 may also be used to alert the ATME controller 160 to changes in the wireless network. Changes, such as, a site going down, a new site being enabled or the transmit power changing at an antenna are all examples of changes that may be recognized more readily by the ATME controller 160 when a continuous data stream is arriving from the ATME 100, than if one were to rely on information communicated by a network operator of the location system. The constant communication of the ATME 100 with other network operations components may serve as an early warning device to the location system.

[0049] The ATME 100 may determine its future position based on communication with the ATME controller 160. It may be necessary to predict the future position where the ATME controller 160 is operating within the NUG generation process. In this example, consider the ATME 100 collecting data at a particular location, the ATME 100 passes available NMR data to the ATME controller 160. This NMR data includes, for example, an associated location time-stamp, a velocity stamp and a range of other possible parameters in addition to the usual NMR parameters. The ATME controller 160 may signal to the ATME 100 when it no longer needs data at that particular location, thus permitting the ATME 100 to move out of the current location before resuming data collection.

[0050] Depending on the rate at which the reported data changes, the ATME controller 160 can optionally inform the ATME 100 the desired speed of travel permitted to efficiently collect and/or communicate collection data results without error. With this additional information, an ATME 100 may be sent instructions to a driver to either dwell for longer periods in certain locations or move abruptly out of locations where the reported data is statistically similar. As a result, the dwell-time for such an ATME 100 in a particular region may be optimized so that no time is unnecessarily wasted collecting data in a region where extra NMR data is not required or an increased amount of time spent collecting data in a region where more NMR data may be required.

[0051] Some of the features of an ATME 100 may also be applied to the case where such features are interfaced with a human driver of the vehicle carrying the

ATME 100 equipment. In such a situation, the human driver may be instructed by the controller 160 using voice commands to slow down, speed up, turn at the next intersection, etc. Further, in either the case of a human driver or unmanned communication equipment, regions where data insufficiency or statistical failure exist may be flagged as regions where a return to that area may be needed.

[0052] In a particular traffic situation where the driver has no option but to keep moving even though the data requirement of the ATME controller 160 calls for a slower collection driving velocity, the driver may continue to circle around the region (*e.g.,* block) until the ATME controller 160 indicates to the ATME 100 equipment driver that sufficient data collection has been met.

[0053] In general, the division of labor between fully automated components within this scheme and human enablers for the same purpose may take various forms ranging from a fully automated case to the case where the reporting of NMR data is conducted manually.

[0054] When statistical sufficiency or data sufficiency is met in a particular region, the ATME 100 may randomly proceed to a next region or be guided to a particular region by the ATME controller 160, which may have information on areas where the known data is insufficient or where particular NUGs need to be built or refined. It may be true that, in general, the ATME 100 will spend less time per unit area in a rural setting where the statistical nature of the NMRs change slowly as opposed to an urban setting that has vigorous dynamic NMR changes over short

distances. The total time required to calibrate a particular region may also be reduced for the purpose of a pattern matching location scheme.

[0055] In contrast to the blind acquisition of NMR data by a device which has no knowledge of whether the data being reporting is useful, needed, or in the other extreme, excessive, the intelligent calibration data collection process may increase location system productivity and location estimate accuracy.

[0056] FIG. 7 illustrates a flow diagram 700 of a method to modify location data used to locate a mobile station. A first set of location data may be obtained for a geographical region (operation 701). The first set of location data may be stored in a database (operation 702). The first set of stored location data may be compared to a second set of stored location data (operation 703), which represents an overlapping geographical region of the first set of location data. Next, at least one parameter of the first set of location data may be modified to represent a particular location based on the second set of location data at that particular location (operation 704). The modified parameter may be stored in the database as a replacement to the original parameter of the first set of location data (705). The mobile station may then be located based on the modified first set of location data (706).

[0057] Figure 8 is an illustration of a method for generating a calibration database. Location data may be obtained for a plurality of geographic locations situated within a selected geographic region (801). A location information database having accurate latitude and longitude information for plural points in the same

geographic region may be provided, such as a street database (803). From the plural points in the location information database a first and second point may be determined that are proximate to a location in the location data (805). Using interpolation between the first and second points a third point may be determined (807). The third point may be entered into a calibration database as the location associated with the location data for the geographic location (809).

[0058] Figure 9 is an illustration of a method for generating a calibration database using a wireless device. Location data may be obtained for a plurality of geographic locations situated with in a region having plural streets and intersections (901). In one embodiment the location data may be obtained using a wireless device. A location information database having accurate latitude and longitude information for plural points in the same geographic region may be provided, such as a street database (903). The status of the wireless device may be determined (905), and based upon the status, a most likely street upon which the wireless device is sited may be determined as the geographic location (907). A first point from the location information database may be determined that is in proximity to the first geographic location (909) and the first point may then be entered in the calibration database (911).

[0059] The embodiments described above may be used in base station configurations that include, but are not limited to, predetermined data collected over varying terrain, varying base station configurations, varying cellular communication protocols, etc.

[0060] While preferred embodiments of the present invention have been described, it is to be understood that the embodiments described are illustrative only and the scope of the invention is to be defined solely by the appended claims when accorded a full range of equivalents, many variations and modifications naturally occurring to those skilled in the art from a perusal hereof.

What is claimed is:

1. A method for generating a calibration database, comprising;

receiving at a wireless device an attribute of a signal transmitted by a wireless transmitter to a mobile station in a region;

wirelessly transmitting from said wireless device said attribute to a controller unit;

obtaining location data of a plurality of geographic locations situated within said region, wherein said location data is determined using said wireless device, and wherein said region contains plural streets and intersections of said plural streets;

providing a location information database wherein said location database includes latitude and longitude information for each of a plurality of points within said region;

determining a status of said wireless device;

determining from said status a most likely one of said plural streets upon which said wireless device is sited for a first one of said plural geographic locations;

determining a first point of said plural points that is in proximity to said first geographic location; and

entering said first point in said calibration database and associating the location data for the first one of said plural geographic locations determined by said wireless device with the first point.

2. The method of Claim 1 wherein said attribute is selected from the group consisting of: signal strength, Cell global identity, broadcast control channel, base station identity code.

3. The method of Claim 1 further comprising determining at said controller unit if said location data is statistically sufficient and if so entering said location data into said location information database.

4. The method of Claim 1 further comprising determining at said controller unit if said location data is statistically sufficient and if so entering said location data into a non-uniform grid generator.

5. The method of Claim 1 further comprising sending future positioning information from said controller unit to said wireless device.

6. The method of Claim 5 wherein said future position information includes at least one of a geographic position and a speed.

7. The method of Claim 5 further comprising determining said future positioning information at least in part on information from said location information database.

8. The method of Claim 5 further comprising determining said future positioning information at least in part on information from a non-uniform grid generator.

9. The method of Claim 1 further comprising receiving at said wireless device an attribute of a signal transmitted by the wireless transmitter in communication with a mobile station in a second region.

10. The method of Claim 1 wherein said location database is a street database.

11. The method of Claim 1 wherein said status includes attributes selected from the group consisting of: direction of travel; speed of travel, and change in direction of travel.

12. A system for generating a calibration database, comprising:

a wireless device for determining location data at a plurality of geographic locations situated within a region, wherein said region contains plural streets and intersections of said plural streets, said wireless device receiving an attribute of a signal transmitted by a wireless transmitter to a mobile station in said region;

a wireless device transmitter for transmitting from said wireless device said attribute to a controller unit;

a location information database wherein said location database includes latitude and longitude information for each of a plurality of points within said region;

circuitry for determining a status of said wireless device;

circuitry for determining from said status a most likely one of said plural streets upon which said wireless device is sited for a first one of said plural geographic locations;

circuitry for determining a first point of said plural points that is in proximity to said first geographic location; and

circuitry for entering said first point in said calibration database; and associating the location data for the first one of said plural geographic locations determined by said wireless device with the first point.

13. The system of Claim 12 wherein said attribute is selected from the group consisting of: signal strength, Cell Global identity, broadcast control channel, base station identity code.

14. The system of Claim 12 wherein said controller unit determines if said location data is statistically sufficient and if so, enters said location data into said location information database.

15. The system of Claim 12 wherein said controller unit determines if said location data is statistically sufficient and if so enters said location data into a non-uniform grid generator.

16. The system of Claim 12 wherein said controller unit sends future positioning information to said wireless device.

17. The system of Claim 16 wherein said future positioning information includes at least one of a geographic position and a speed.

18. The system of Claim 16 wherein said future positioning information is determined based at least in part on information from said location information database.

19. The system of claim 16 wherein said future positioning information is determined based at least in part on information from a non-uniform grid generator.

20. The system of Claim 12 wherein said wireless device receives an attribute of a signal transmitted by the wireless transmitter in communication with a mobile station in said second region.

21. The system of Claim 12 wherein said location database is a street database.

22. The system of Claim 12, wherein said status includes attributes selected from the group consisting of: direction of travel; speed of travel, and change in direction of travel.

ABSTRACT

A system and method modifies calibration data used to geo-locate a mobile station. Calibration data measured via a calibration data collection device may contain errors due to the physical limitations of the collection device and/or the collection process. Any data collection device may produce some degree of signal degradation or drop-out. Dead reckoning provides a remedy for signal drop-out, however, it often produces data results that may be unsatisfactory to perform an accurate location estimate. To ensure the integrity of the collected calibration data, a data modification and/or data replacement algorithm may be implemented to enhance the accuracy of the collected data. In addition, current collection procedures used to generate a calibration database may be laborious, time-consuming and expensive. Simplifying the test and measurement equipment needed, and the procedures for obtaining calibration data may save time and expenses.

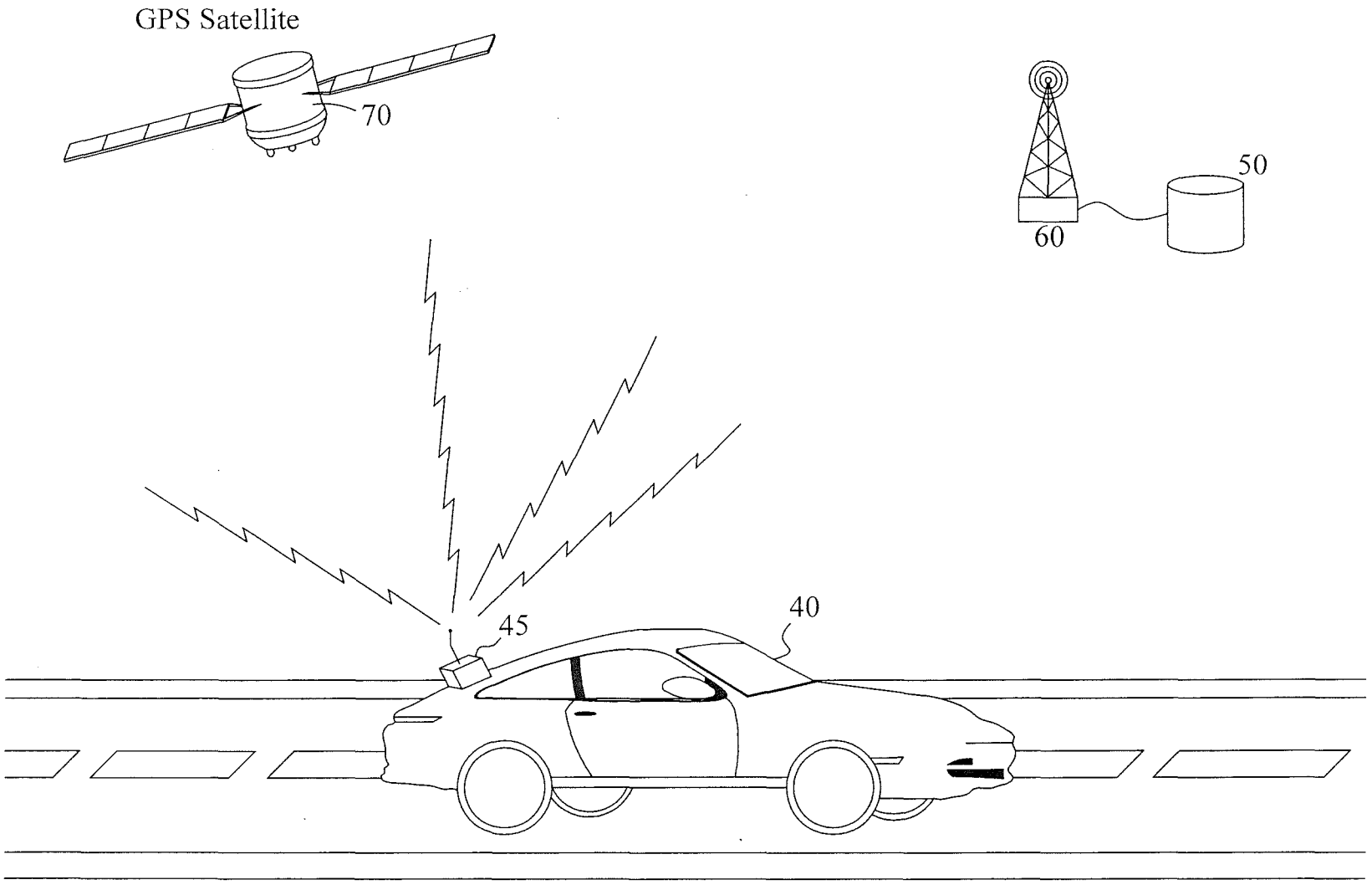


Figure 1
(Prior Art)

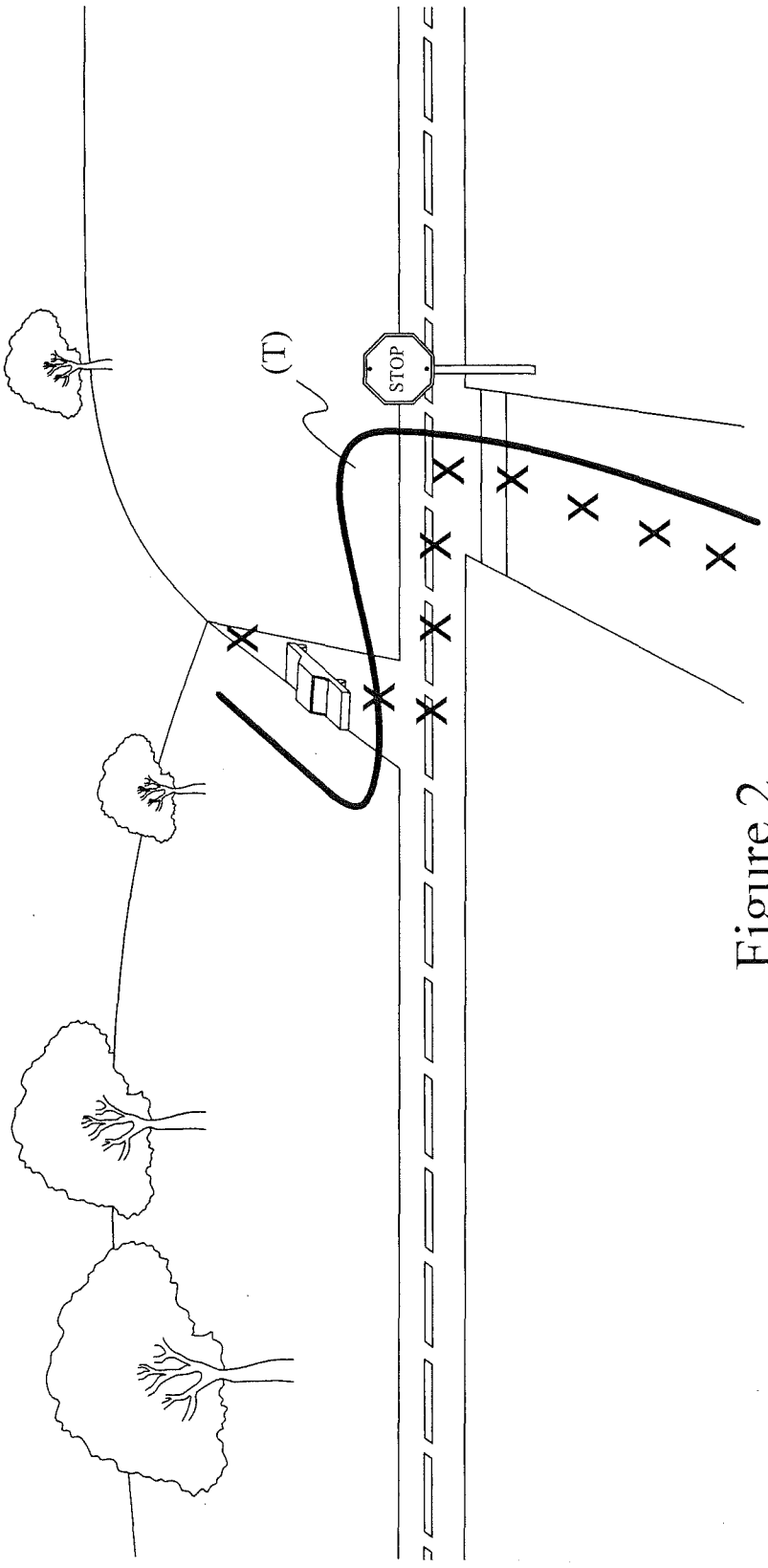


Figure 2
(Prior Art)

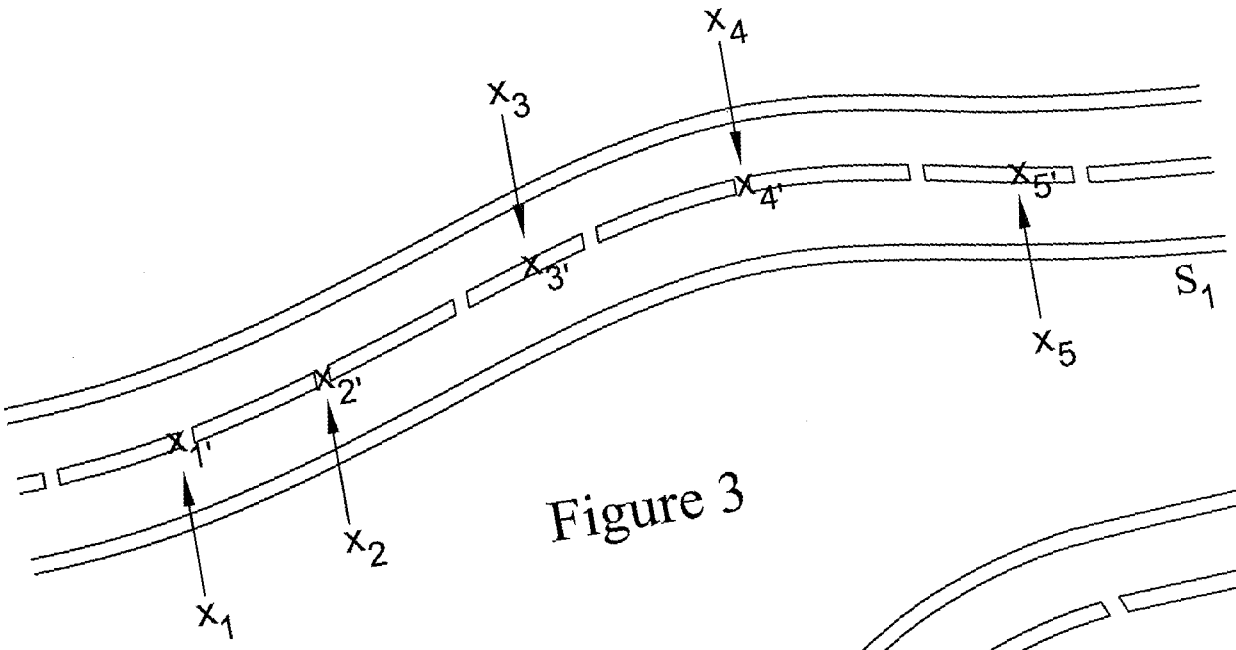


Figure 3

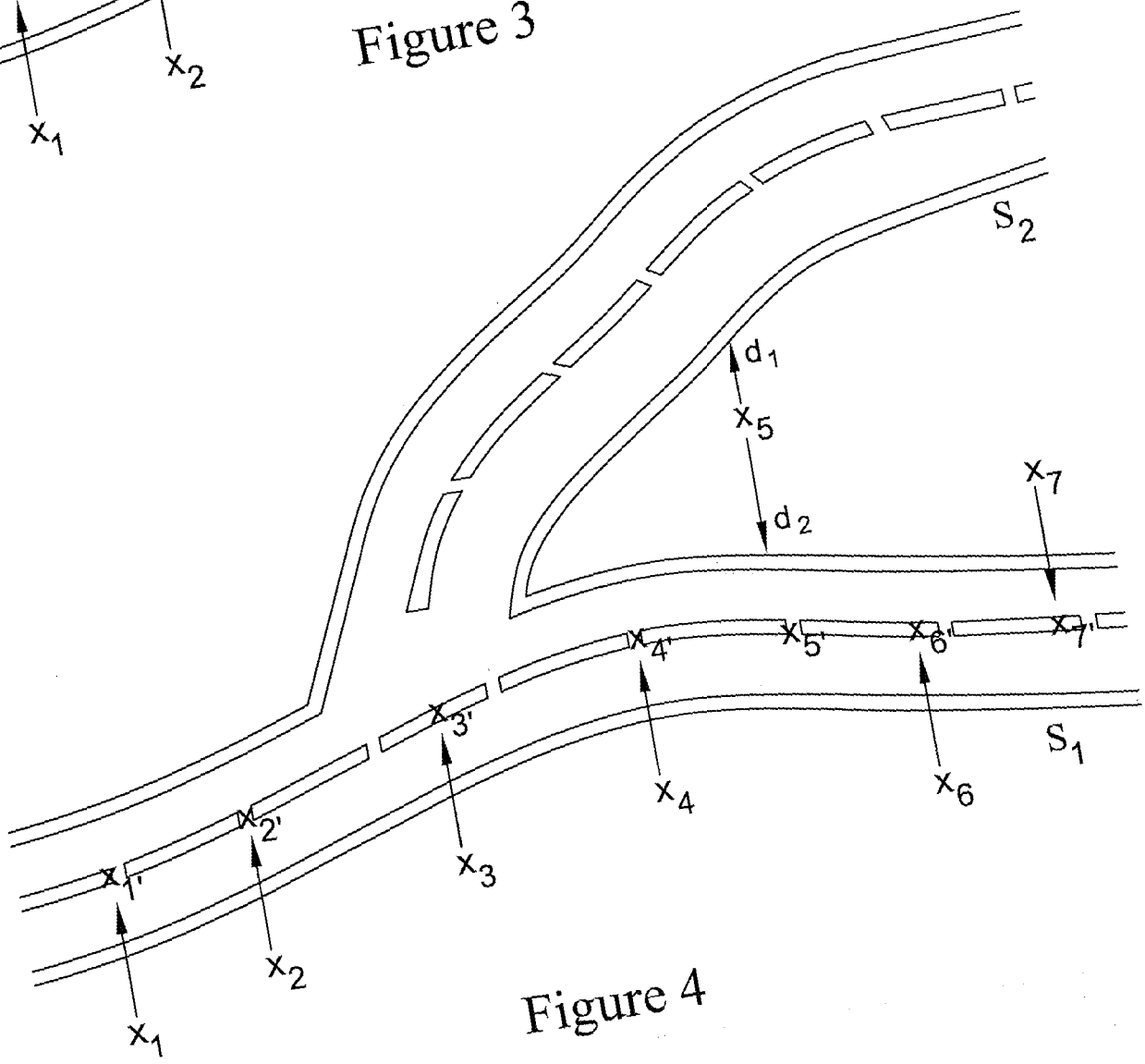


Figure 4

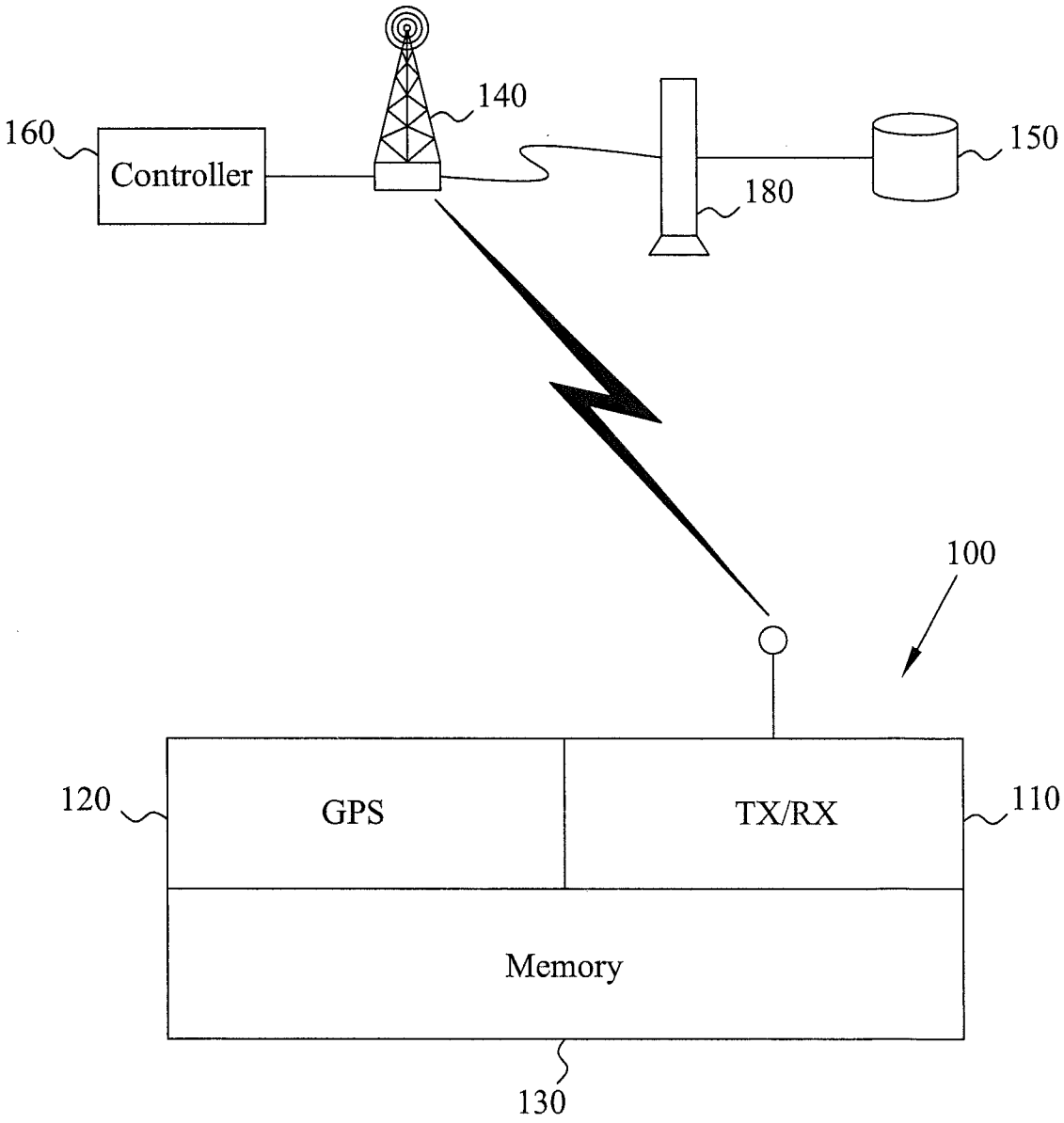


Figure 5

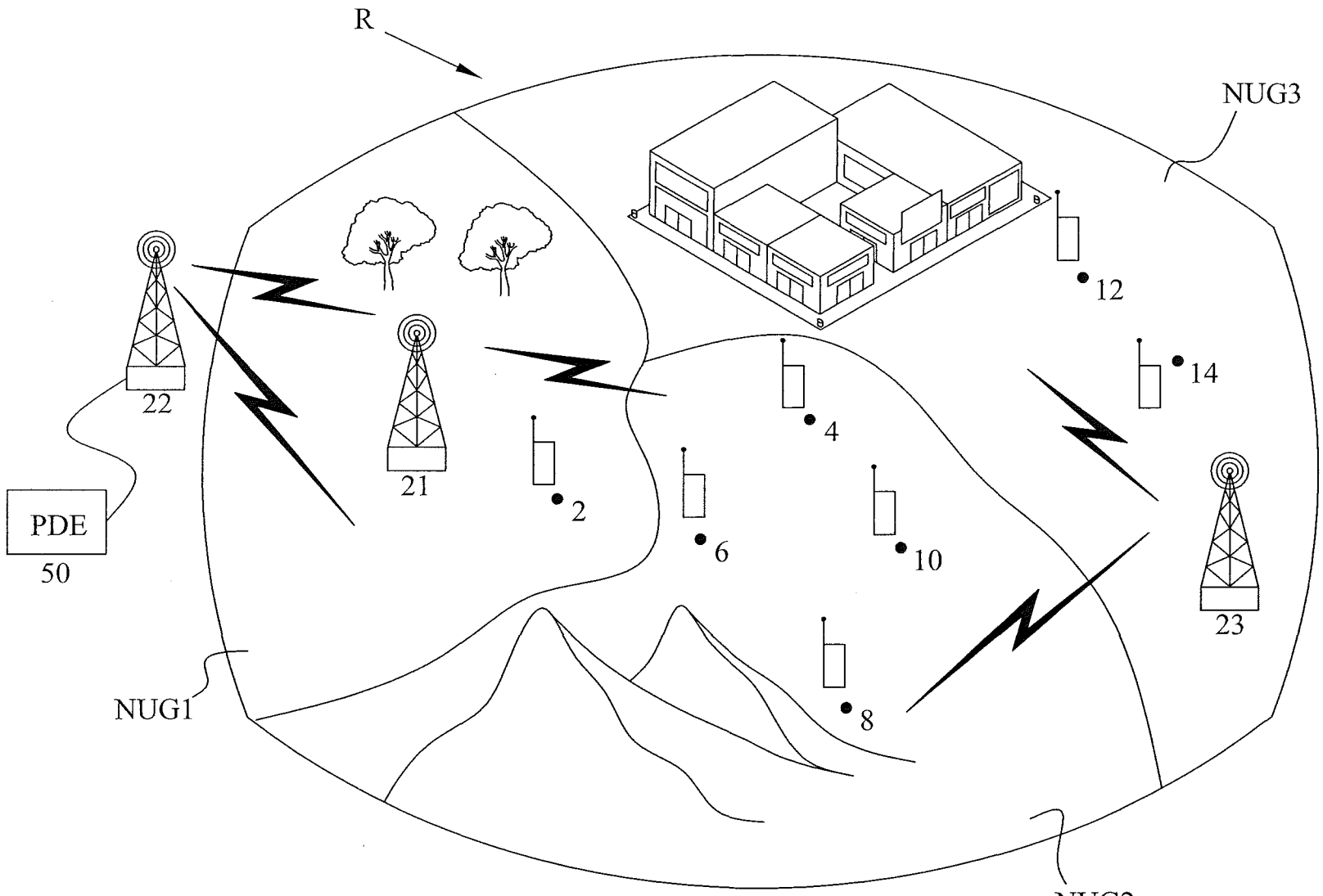


Figure 6

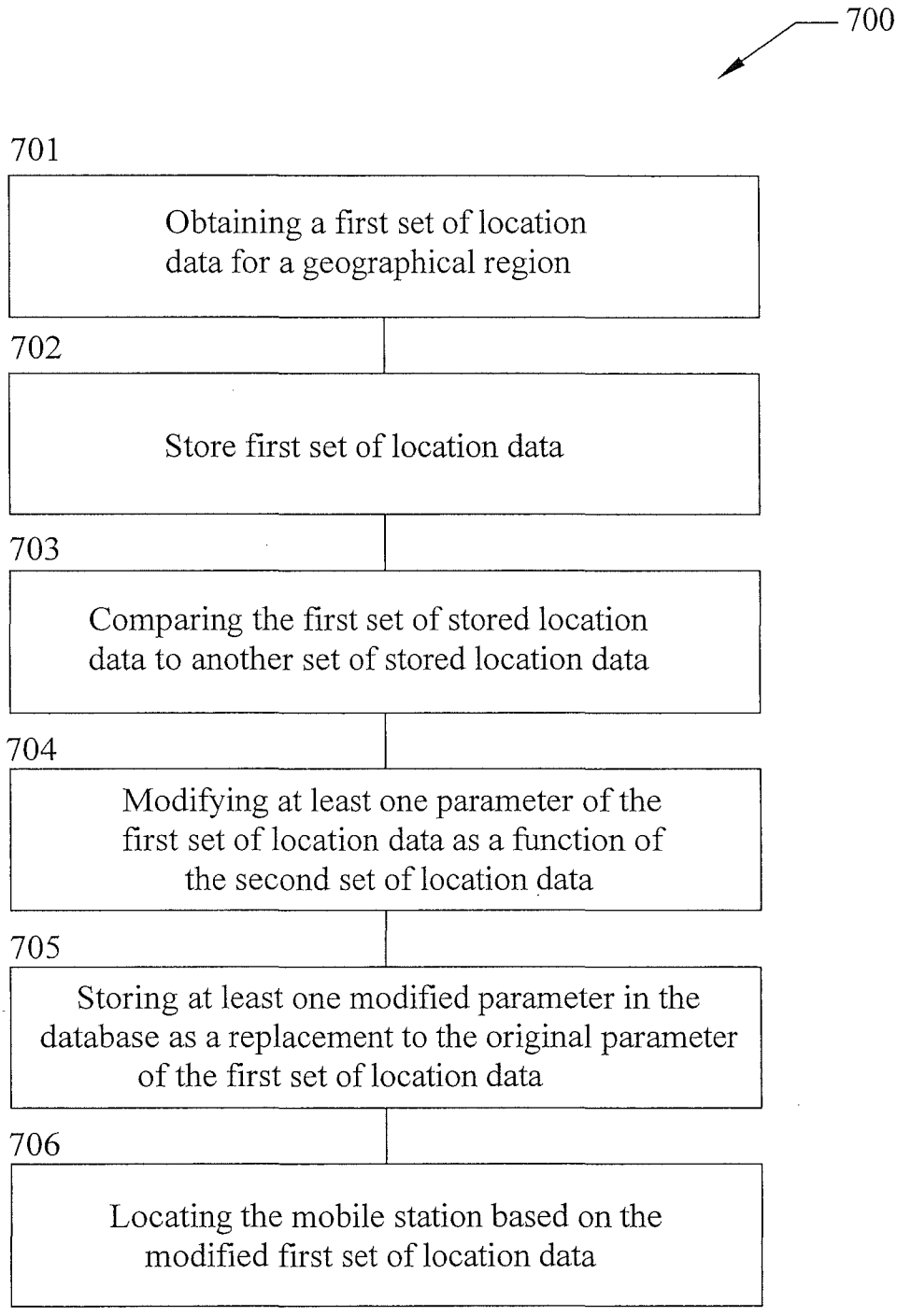

700
701
Obtaining a first set of location data for a geographical region
702
Store first set of location data
703
Comparing the first set of stored location data to another set of stored location data
704
Modifying at least one parameter of the first set of location data as a function of the second set of location data
705
Storing at least one modified parameter in the database as a replacement to the original parameter of the first set of location data
706
Locating the mobile station based on the modified first set of location data

Figure 7

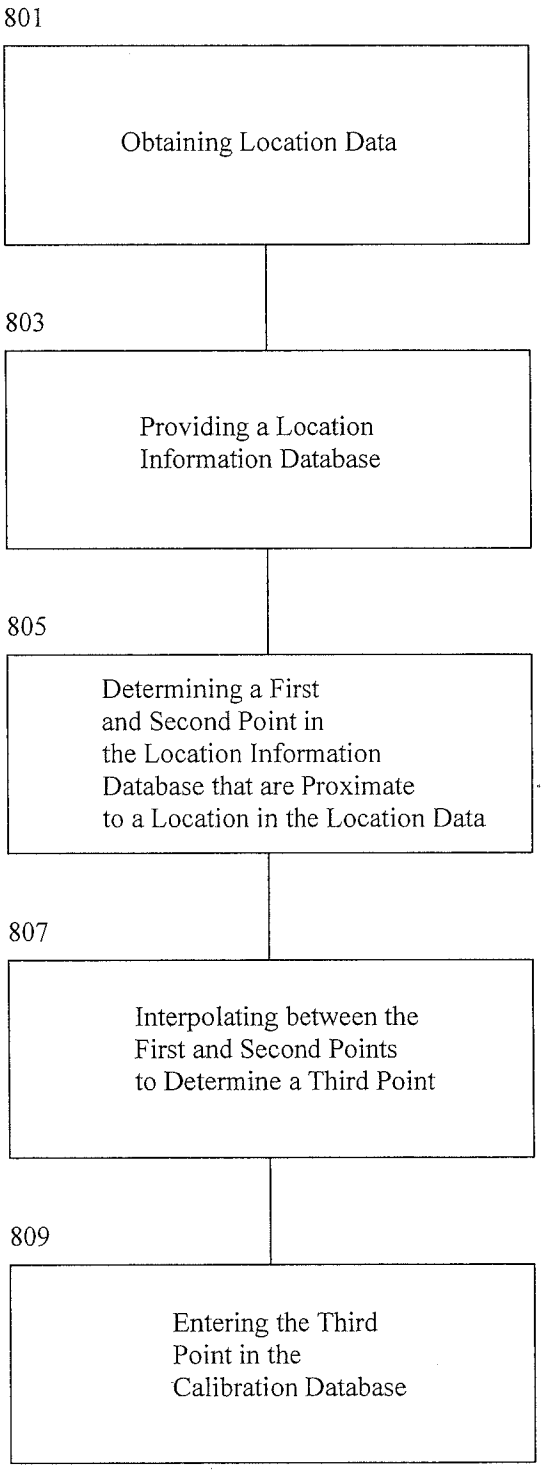

801
Obtaining Location Data
803
Providing a Location Information Database
805
Determining a First and Second Point in the Location Information Database that are Proximate to a Location in the Location Data
807
Interpolating between the First and Second Points to Determine a Third Point
809
Entering the Third Point in the Calibration Database

Figure 8

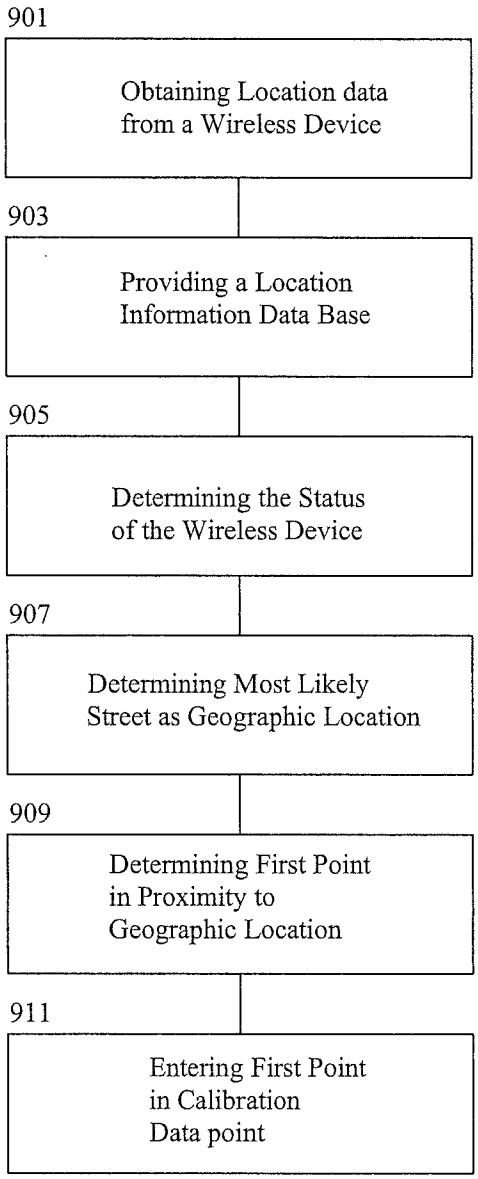

901
Obtaining Location data from a Wireless Device
903
Providing a Location Information Data Base
905
Determining the Status of the Wireless Device
907
Determining Most Likely Street as Geographic Location
909
Determining First Point in Proximity to Geographic Location
911
Entering First Point in Calibration Data point

Figure 9

Electronic Patent Application Fee Transmittal

Application Number:	
Filing Date:	
Title of Invention:	System and Method to Collect and Modify Calibration Data
First Named Inventor/Applicant Name:	Martin Alles
Filer:	Mark Charles Comtois/laureen ponder
Attorney Docket Number:	AND01 083 CONT

Filed as Large Entity

Utility under 35 USC 111(a) Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Utility application filing	1011	1	280	280
Utility Search Fee	1111	1	600	600
Utility Examination Fee	1311	1	720	720
Pages:				
Claims:				
Claims in Excess of 20	1202	2	80	160
Miscellaneous-Filing:				
Petition:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Miscellaneous:				
		Total in USD ($)		**1760**

Electronic Acknowledgement Receipt

EFS ID:	20466405
Application Number:	14518868
International Application Number:	
Confirmation Number:	6799
Title of Invention:	System and Method to Collect and Modify Calibration Data
First Named Inventor/Applicant Name:	Martin Alles
Customer Number:	79172
Filer:	Mark Charles Comtois/laureen ponder
Filer Authorized By:	Mark Charles Comtois
Attorney Docket Number:	AND01 083 CONT
Receipt Date:	20-OCT-2014
Filing Date:	
Time Stamp:	18:16:42
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Deposit Account
Payment was successfully received in RAM	$1760
RAM confirmation Number	5441
Deposit Account	041679
Authorized User	

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1		AND01083CONTApp.pdf	3259639 058196a4f86dac03a456aa9e18bd732f0d15d092	yes	41

Multipart Description/PDF files in .zip description

Document Description	Start	End
Application Data Sheet	1	7
Specification	8	27
Claims	28	32
Abstract	33	33
Drawings-only black and white line drawings	34	41

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