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APPLICATION NO.	ISSUE DATE	PATENT NO.	ATTORNEY DOCKET NO.	CONFIRMATION NO.
12/026,333	07/14/2009	7561104	AND01 082	2910

79172 7590 06/24/2009

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 Customer Service Center of the Office of Patent Publication at (571)-272-4200.

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

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

GOOGLE EXHIBIT 1002
Google v. Geoscope

IR103 (Rev. 11/05)

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 05/29/2009

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.
12/026,333	02/05/2008	Martin Alles	AND01 082	2910

TITLE OF INVENTION: METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT

APPLN. TYPE	SMALL ENTITY	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	NO	$1510	$300	$0	$1810	08/31/2009

EXAMINER	ART UNIT	CLASS-SUBCLASS
PHAN, DAO LINDA	3662	342-451000

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: ANDREW LLC

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

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 credit any overpayment, to Deposit Account Number 04-1679 (enclose an extra copy of this form).

5. **Change in Entity Status** (from status indicated above)

☐ a. Applicant claims SMALL ENTITY status. See 37 CFR 1.27.

☐ b. Applicant is no longer claiming SMALL ENTITY status. See 37 CFR 1.27(g)(2).

NOTE: The Issue Fee and Publication Fee (if required) will not be accepted from anyone other than the applicant; a registered attorney or agent; or the assignee or other party in interest as shown by the records of the United States Patent and Trademark Office.

Authorized Signature /mcc/ Date 10 June 2009

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

This collection of information 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.

Electronic Patent Application Fee Transmittal

Application Number:	12026333
Filing Date:	05-Feb-2008
Title of Invention:	METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT
First Named Inventor/Applicant Name:	Martin Alles
Filer:	Mark Charles Comtois/Jacquetta McBee
Attorney Docket Number:	AND01 082

Filed as Large Entity

Utility under 35 USC 111(a) Filing Fees

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	1510	1510
Publ. Fee- early, voluntary, or normal	1504	1	300	300

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension-of-Time:				
Miscellaneous:				
			Total in USD ($)	**1810**

Electronic Acknowledgement Receipt

EFS ID:	5492712
Application Number:	12026333
International Application Number:	
Confirmation Number:	2910
Title of Invention:	METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT
First Named Inventor/Applicant Name:	Martin Alles
Customer Number:	79172
Filer:	Mark Charles Comtois/Jacquetta McBee
Filer Authorized By:	Mark Charles Comtois
Attorney Docket Number:	AND01 082
Receipt Date:	10-JUN-2009
Filing Date:	05-FEB-2008
Time Stamp:	17:00:29
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Deposit Account
Payment was successfully received in RAM	$1810
RAM confirmation Number	12224
Deposit Account	041679
Authorized User	

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 1.20 (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)	AND01_082_ISSUEFEE.pdf	198113 82ea89b56e993c7ae14a65c81d4b21f44ad73572	no	1
Warnings:					
Information:					
2	Fee Worksheet (PTO-875)	fee-info.pdf	32047 5f730e4e1dabdf6911e54289f386cf8b92190e71	no	2
Warnings:					
Information:					
		Total Files Size (in bytes):	230160		

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
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NOTICE OF ALLOWANCE AND FEE(S) DUE

79172 7590 05/29/2009

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

EXAMINER	
PHAN, DAO LINDA	
ART UNIT	PAPER NUMBER
3662	

DATE MAILED: 05/29/2009

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
12/026,333	02/05/2008	Martin Alles	AND01 082	2910

TITLE OF INVENTION: METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT

APPLN. TYPE	SMALL ENTITY	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	NO	$1510	$300	$0	$1810	08/31/2009

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 SMALL ENTITY status shown above.

If the SMALL ENTITY is shown as YES, verify your current SMALL ENTITY status:

A. If the status is the same, pay the TOTAL FEE(S) DUE shown above.

B. If the status above is to be removed, check box 5b on Part B - Fee(s) Transmittal and pay the PUBLICATION FEE (if required) and twice the amount of the ISSUE FEE shown above, or

If the SMALL ENTITY is shown as NO:

A. Pay TOTAL FEE(S) DUE shown above, or

B. If applicant claimed SMALL ENTITY status before, or is now claiming SMALL ENTITY status, check box 5a on Part B - Fee(s) Transmittal and pay the PUBLICATION FEE (if required) and 1/2 the ISSUE FEE shown above.

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.

PTOL-85 (Rev. 08/07) Approved for use through 08/31/2010.

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 05/29/2009

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.
12/026,333	02/05/2008	Martin Alles	AND01 082	2910

TITLE OF INVENTION: METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT

APPLN. TYPE	SMALL ENTITY	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	NO	$1510	$300	$0	$1810	08/31/2009

EXAMINER	ART UNIT	CLASS-SUBCLASS
PHAN, DAO LINDA	3662	342-451000

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 credit any overpayment, to Deposit Account Number _____ (enclose an extra copy of this form).

5. **Change in Entity Status** (from status indicated above)

❑ a. Applicant claims SMALL ENTITY status. See 37 CFR 1.27.

❑ b. Applicant is no longer claiming SMALL ENTITY status. See 37 CFR 1.27(g)(2).

NOTE: The Issue Fee and Publication Fee (if required) will not be accepted from anyone other than the applicant; a registered attorney or agent; or the assignee or other party in interest as shown by the records of the United States Patent and Trademark Office.

Authorized Signature _____ Date _____

Typed or printed name _____ Registration No. _____

This collection of information 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.

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United States Patent and Trademark Office
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Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
12/026,333	02/05/2008	Martin Alles	AND01 082	2910

79172 7590 05/29/2009

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

EXAMINER
PHAN, DAO LINDA

ART UNIT	PAPER NUMBER
3662	

DATE MAILED: 05/29/2009

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

The Patent Term Adjustment to date is 0 day(s). If the issue fee is paid on the date that is three months after the mailing date of this notice and the patent issues on the Tuesday before the date that is 28 weeks (six and a half months) after the mailing date of this notice, the Patent Term Adjustment will be 0 day(s).

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 Customer Service Center of the Office of Patent Publication at 1-(888)-786-0101 or (571)-272-4200.

PTOL-85 (Rev. 08/07) Approved for use through 08/31/2010.

Notice of Allowability	Application No.	Applicant(s)	
	12/026,333	ALLES ET AL.	
	Examiner	Art Unit	
	Dao L. Phan	3662	

-- 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 *4/2/09*.

2. ☒ The allowed claim(s) is/are *41-54 and 67-73*.

3. ☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).
   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.

4. ☐ A SUBSTITUTE OATH OR DECLARATION must be submitted. Note the attached EXAMINER'S AMENDMENT or NOTICE OF INFORMAL PATENT APPLICATION (PTO-152) which gives reason(s) why the oath or declaration is deficient.

5. ☐ CORRECTED DRAWINGS (as "replacement sheets") must be submitted.
   (a) ☐ including changes required by the Notice of Draftsperson's Patent Drawing Review (PTO-948) attached
      1) ☐ hereto or 2) ☐ to Paper No./Mail Date _____.
   (b) ☐ 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. ☐ Notice of Draftperson's Patent Drawing Review (PTO-948)
3. ☐ Information Disclosure Statements (PTO/SB/08), Paper No./Mail Date _____
4. ☐ Examiner's Comment Regarding Requirement for Deposit of Biological Material
5. ☐ Notice of Informal Patent Application
6. ☐ Interview Summary (PTO-413), Paper No./Mail Date _____ .
7. ☐ Examiner's Amendment/Comment
8. ☒ Examiner's Statement of Reasons for Allowance
9. ☐ Other _____.

/Dao L. Phan/ Primary Examiner, Art Unit 3662	Note: The drawings filed on 2/5/2008 are accepted.

1. The following is an examiner's statement of reasons for allowance claims 41-54 and 67-73: the examiner found no teaching in the prior art that would render obvious the claimed method for determining a location of a mobile station comprising "determining which of said first and second signal characteristics has a greater magnitude; and modifying said observed network measurement data using the greater magnitude signal characteristic", claim 41, "determining a confidence measure for each of the plurality of location estimates; and determining the location of the mobile station based on the plurality of location estimates and the respective confidence measures", claim 67.

2. 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."

3. Any inquiry concerning this communication or earlier communications from the examiner should be directed to Dao L. Phan whose telephone number is (571)272-6976. The examiner can normally be reached on M-F 9:00-5:30.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Thomas Tarcza can be reached on (571)272-6979. 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.

/Dao L. Phan/
Primary Examiner, Art Unit 3662

Index of Claims	Application/Control No.	Applicant(s)/Patent Under Reexamination
	12026333	ALLES ET AL.
	Examiner	**Art Unit**
	Dao L Phan	3662

✓	Rejected	-	Cancelled	N	Non-Elected	A	Appeal
=	Allowed	÷	Restricted	I	Interference	O	Objected

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

CLAIM		DATE								
Final	Original	05/08/2009								
	1	-								
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Index of Claims	Application/Control No.	Applicant(s)/Patent Under Reexamination
	12026333	ALLES ET AL.
	Examiner	**Art Unit**
	Dao L Phan	3662

✓	Rejected	-	Cancelled	N	Non-Elected	A	Appeal
=	Allowed	÷	Restricted	I	Interference	O	Objected

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

CLAIM		DATE								
Final	Original	05/08/2009								
	37	-								
	38	-								
	39	-								
	40	-								
1	41	=								
2	42	=								
3	43	=								
4	44	=								
5	45	=								
6	46	=								
7	47	=								
8	48	=								
9	49	=								
10	50	=								
11	51	=								
12	52	=								
13	53	=								
14	54	=								
	55	-								
	56	-								
	57	-								
	58	-								
	59	-								
	60	-								
	61	-								
	62	-								
	63	-								
	64	-								
	65	-								
	66	-								
15	67	=								
16	68	=								
17	69	=								
18	70	=								
19	71	=								
20	72	=								

Index of Claims	Application/Control No.	Applicant(s)/Patent Under Reexamination
	12026333	ALLES ET AL.
	Examiner	**Art Unit**
	Dao L Phan	3662

✓	Rejected	-	Cancelled	N	Non-Elected	A	Appeal
=	Allowed	÷	Restricted	I	Interference	O	Objected

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

CLAIM		DATE								
Final	Original	05/08/2009								
21	73	=								

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	12026333	ALLES ET AL.
	Examiner	**Art Unit**
	Dao L Phan	3662

ORIGINAL		INTERNATIONAL CLASSIFICATION											
CLASS	SUBCLASS	CLAIMED					NON-CLAIMED				
342	451	G	0	1	S	3 / 02 (2006.01.01)					

CROSS REFERENCE(S)					
CLASS	SUBCLASS (ONE SUBCLASS PER BLOCK)				
342	457				

☐ 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
	1		17		33	9	49		65						
	2		18		34	10	50		66						
	3		19		35	11	51	15	67						
	4		20		36	12	52	16	68						
	5		21		37	13	53	17	69						
	6		22		38	14	54	18	70						
	7		23		39		55	19	71						
	8		24		40		56	20	72						
	9		25	1	41		57	21	73						
	10		26	2	42		58								
	11		27	3	43		59								
	12		28	4	44		60								
	13		29	5	45		61								
	14		30	6	46		62								
	15		31	7	47		63								
	16		32	8	48		64								

NONE		Total Claims Allowed:	
(Assistant Examiner)	(Date)	21	
/Dao L Phan/ Primary Examiner.Art Unit 3662	5/8/09	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	15	10

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	12026333	ALLES ET AL.
	Examiner	**Art Unit**
	Dao L Phan	3662

SEARCHED

Class	Subclass	Date	Examiner
342	357.01, 357.06, 451, 457, 463-465	1/9/09	dp
455	456.6, 457		
Above updated		5/7/09	dp

SEARCH NOTES

Search Notes	Date	Examiner
East text search (See searched history printout)	1/9/09	dp
Updated	5/7/09	dp

INTERFERENCE SEARCH

Class	Subclass	Date	Examiner
PGPub text search - See interference searched printout		5/7/09	dp

EAST Search History

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	211038	magnitude$2	US-PGPUB	OR	OFF	2009/05/07 10:22
L2	900438	measur$6	US-PGPUB	OR	OFF	2009/05/07 10:23
L3	125029	calibrat$5	US-PGPUB	OR	OFF	2009/05/07 10:23
L4	601	(1 and 2 and 3).clm.	US-PGPUB	OR	OFF	2009/05/07 10:24
L5	973496	compare or compares or compared or comparing or comparision$2	US-PGPUB	OR	OFF	2009/05/07 10:25
L6	211	(1 and 2 and 3 and 5).clm.	US-PGPUB	OR	OFF	2009/05/07 10:26
L7	18242	5 same 3	US-PGPUB	OR	OFF	2009/05/07 10:26
L8	2348	7.clm.	US-PGPUB	OR	OFF	2009/05/07 10:26
L9	85	6 and 8	US-PGPUB	OR	OFF	2009/05/07 10:26
L10	55794	confiden$5	US-PGPUB	OR	OFF	2009/05/07 10:29
L11	32	(10 and 2 and 3 and 5).clm.	US-PGPUB	OR	OFF	2009/05/07 10:29

5/7/09 10:32:00 AM
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BIB DATA SHEET

CONFIRMATION NO. 2910

SERIAL NUMBER	FILING or 371(c) DATE	CLASS	GROUP ART UNIT	ATTORNEY DOCKET NO.
12/026,333	02/05/2008 **RULE**	455	3662	AND01 082

APPLICANTS

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

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

This appln claims benefit of 60/899,379 02/05/2007

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

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

02/19/2008

Foreign Priority claimed	☐ Yes ☑ No	☐ Met after Allowance	STATE OR COUNTRY	SHEETS DRAWINGS	TOTAL CLAIMS	INDEPENDENT CLAIMS
35 USC 119(a-d) conditions met	☐ Yes ☑ No					
Verified and Acknowledged	/DAO LINDA PHAN/ Examiner's Signature	Initials	VA	10	73	6

ADDRESS

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

TITLE

METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT

FILING FEE RECEIVED		
4440	FEES: Authority has been given in Paper No._____ to charge/credit DEPOSIT ACCOUNT No._____ for following:	☐ All Fees ☐ 1.16 Fees (Filing) ☐ 1.17 Fees (Processing Ext. of time) ☐ 1.18 Fees (Issue) ☐ Other _____ ☐ Credit

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re the Patent Application of Martin Alles, et al.

Serial No.: 12/026,333 Art Unit: 3662

Filed: February 5, 2008 Examiner: Dao L. Phan

Title: METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE DEVICE

AMENDMENT

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

In response to the Office Action dated February 25, 2009, Applicant submits the following:

Applicant's **Amendment to the Claims** begin on sheet 2 of this paper; and

Applicant's **Remarks** begin on sheet 7 of this paper.

Amendment to the Claims:

Claims 1-40 (Cancelled).

41. (Original) A method for determining a location of a mobile station, comprising:

providing a database of previously-gathered calibration data for a predetermined region in a wireless network, wherein said network includes a first transmitter and a second transmitter;

collecting observed network measurement data including a first signal characteristic from said first transmitter and a second signal characteristic from said second transmitter;

determining which of said first and second signal characteristics has a greater magnitude;

modifying said observed network measurement data using the greater magnitude signal characteristic; and

comparing said modified network measurement data with said database of calibration data to thereby determine the location of the mobile station.

42. (Original) The method of Claim 41 wherein said database comprises previously-gathered calibration data for one or more non-uniform grid points within said region.

43. (Original) The method of Claim 41 wherein said observed network measurement data includes data collected at the mobile station.

44. (Original) The method of Claim 41 wherein said previously-gathered calibration data includes calibration data gathered at a predetermined calibration point within said region wherein said predetermined calibration point is not located within a structure.

45. (Original) The method of Claim 44 wherein said observed network measurement data is collected at a mobile station located within a structure.

46. (Original) The method of Claim 44 wherein said first signal characteristic is signal strength.

47. (Original) The method of Claim 46 wherein said second signal characteristic is signal strength.

48. (Original) The method of Claim 47 wherein the modifying of said calibration data uses a difference between said first or second signal characteristics.

49. (Original) The method of Claim 47 wherein said first signal characteristic is signal strength of a control channel transmitted by said first transmitter and received by said mobile station.

50. (Original) The method of Claim 49 wherein said second signal characteristic is signal strength of a control channel transmitted by said second transmitter and received by said mobile station.

51. (Original) The method of Claim 41, wherein the observed network measurement data includes received signal strength of said transmitters as said mobile station.

52. (Original) The method of Claim 41 wherein said observed network measurement data includes a data set comprising:

$[P_1, P_2..., P_n, TA]$

where:

P_1 represents the signal strength of said first transmitter as measured at said mobile station,

P_2 represents a signal strength of said second transmitter as measured at said mobile station wherein $P_2 > P_1$,

P_n represents a signal strength of a nth transmitter as measured at said mobile station wherein $P_2 > P_n$, and

TA represents a timing advance parameter;

and wherein said modified network measurement data includes a data set comprising:

$[P_2\text{-}P_1, 0, P_2\text{-}P_n, TA]$

where:

$P_2\text{-}P_1$ represents a difference between P_2 and P_1,

0 represents a difference between P_2 and P_2, and

$P_2\text{-}P_n$ represents a difference between P_2 and P_n.

53. (Original) The method of Claim 52 wherein said first transmitter is a serving transmitter for said mobile station and said second and third transmitters are neighboring transmitters.

54. (Original) The method of Claim 52 wherein said third transmitter is not a member of said wireless network.

Claims 55-66 (Cancelled).

67. (Original) A method for determining a location of a mobile station, comprising:

providing a database of previously-gathered outdoor calibration data for a predetermined region in a wireless network;

collecting network measurement data;

comparing said network measurement data with said database of calibration data to thereby determine a plurality of location estimate of the mobile station

determining a confidence measure for each of the plurality of location estimates;

determining the location of the mobile station based on the plurality of location estimates and the respective confidence measures.

68. (Original) The method of Claim 67, wherein the step of determining the location based on the plurality of location estimates and the respective confidence measures comprises selecting the location estimate having the highest respective confidence measure as the location of the mobile station.

69. (Original) The method of Claim 67, wherein the step of determining the location based on the plurality of location estimates and their respective confidence measures comprises weighing the plurality location estimates based on their respective confidence measures and obtaining a weighted average as the location of the mobile.

70. (Original) The method of 67, wherein the confidence measures comprises one or more of the group consisting of a pdf, the Mahalanobis distance, and a distortion measure.

71. (Original) The method of Claim 67, wherein the step of collecting network propagation data further comprises modifying the network propagation data.

72. (Original) The method of Claim 67, wherein the step of comparing said network propagation data with said database of calibration data to thereby determine a plurality of location estimate of the mobile station, further comprises modifying said calibration data prior to the comparison.

73. (Original) The method of Claim 72, wherein the step of comparing said network propagation data with said database of calibration data to thereby determine a plurality of location estimate of the mobile station, further comprises modifying said calibration data prior to the comparison.

REMARKS

Claims 41-54 and 67-73 are pending with entry of this Amendment.

Please cancel Claims 1-40 and 55-66 without prejudice.

Rejections under 35 U.S.C. § 102

On pages 2-4 of the Action, the Office improperly rejected Claims 1-40 and 55-66 under 35 U.S.C. § 102(b) as being unpatentable over Krumm, Stilp or Schantz. While Applicant disagrees with the merits of the rejection, Applicant has cancelled Claims 1-40 and 55-66 solely for the purpose of furthering prosecution in this application and allowing Claims 41-54 and 67-73 to issue. Such a cancellation should not be construed as an acquiescence to the rejection or inferred as an agreement of the Office's understanding of these three references of record.

CONCLUSION

This Amendment has been submitted responsive to the Office Action mailed February 25, 2009. Applicant believes that the present application is now in condition for allowance and such action is earnestly requested.

Should any additional fees be necessary in connection with the filing of this Response, or if a petition for extension of time is required for timely acceptance of the same, such a petition is made and the Office is authorized to charge such fees to **Deposit Account No. 04-1679**.

Respectfully submitted,

/mcc/

Mark C. Comtois
Reg. No. 46,285
Ryan T. Hardee
Reg. No. 57,515

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505 9th Street, N.W., Suite 1000
Washington, D.C. 20004
Telephone: (202) 776-7800
Telecopier: (202) 776-7801

Dated: April 2, 2009

Electronic Acknowledgement Receipt

EFS ID:	5082970
Application Number:	12026333
International Application Number:	
Confirmation Number:	2910
Title of Invention:	METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT
First Named Inventor/Applicant Name:	Martin Alles
Customer Number:	79172
Filer:	Mark Charles Comtois/Jacquetta McBee
Filer Authorized By:	Mark Charles Comtois
Attorney Docket Number:	AND01 082
Receipt Date:	02-APR-2009
Filing Date:	05-FEB-2008
Time Stamp:	13:28:27
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	Amendment/Req. Reconsideration-After Non-Final Reject	AND01_082_AMENDMENT.pdf	544858 a579bf55f2af77071a36d7485fe87675bf0388f5	no	8

Warnings:

Information:

Total Files Size (in bytes):	544858

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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.

PTO/SB/06 (07-06)
Approved for use through 1/31/2007. OMB 0651-0032
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PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number	Filing Date	☐ To be Mailed
12/026,333	02/05/2008	

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	
☐ SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A			N/A	
☐ EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A			N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	minus 20 =	*	X $ =		OR	X $ =	
INDEPENDENT CLAIMS (37 CFR 1.16(h))	minus 3 =	*	X $ =			X $ =	
☐ APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $250 ($125 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).						
☐ MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))							
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL			TOTAL	

APPLICATION AS AMENDED – PART II

AMENDMENT 04/02/2009

	(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 ($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE ($)
Total (37 CFR 1.16(i))	* 21	Minus	** 73	= 0	X $ =		OR	X $52=	0
Independent (37 CFR 1.16(h))	* 2	Minus	***6	= 0	X $ =		OR	X $220=	0
☐ 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	0

AMENDMENT

	(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 ($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE ($)
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 number found in the appropriate box in column 1.

Legal Instrument Examiner:
/NICOLE LOVE-HENSLEY/

This collection of information is required by 37 CFR 1.16. 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, 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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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
12/026,333	02/05/2008	Martin Alles	AND01 082	2910

79172 7590 02/25/2009
Duane Morris LLP
505 9th Street, N.W.
Suite 1000
Washington, DC 20004

EXAMINER
PHAN, DAO LINDA

ART UNIT	PAPER NUMBER
3662	

MAIL DATE	DELIVERY MODE
02/25/2009	PAPER

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
12/026,333	02/05/2008	Martin Alles	AND01 082	2910

79172 7590 02/25/2009
Duane Morris LLP
505 9th Street, N.W.
Suite 1000
Washington, DC 20004

EXAMINER
PHAN, DAO LINDA

ART UNIT	PAPER NUMBER
3662	

MAIL DATE	DELIVERY MODE
02/25/2009	PAPER

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

1. The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

> A person shall be entitled to a patent unless –
>
> (b) the invention was patented or described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of application for patent in the United States.

2. Claims 1-40, 55-66 are rejected under 35 U.S.C. 102(b) as being anticipated by Krumm et al (US 2005/0093745) or Stilp (US 2002/0172223) or Schantz et al (Pat. No. 7,298,314).

Krumm et al teach a system and a method for determining a location of a mobile station including providing (fig. 6) a database of previously-gathered calibration data for a predetermined region in a wireless network; collecting (300; 202; paragraph 0019+) observed network measurement data; modifying 204; 302 the observed network measurement data; and comparing (304; fig. 6 & 8) the modified network measurement data with the database of calibration data to thereby determine the location of a mobile station.

With regard to claims 41-54, Krumm et al teach a method for determining a location of a mobile station including providing (fig. 6) a database of previously-gathered calibration data for a predetermined region in a wireless network; collecting (300; 202; paragraph 0019+) observed network measurement data from each of a plurality of transmitters including a signal characteristic from each one of plural transmitters; determining (par. 0095) an average value for select ones of the signal characteristics; modifying (204; 302) the observed network measurement data using the average

value; and comparing (304; fig. 6 & 8) the modified network measurement data with the database of calibration data to thereby determine the location of the mobile station.

Stilp teaches a system and a method for determining a location of a mobile station including providing (paragraph 0121) a database of previously-gathered calibration data for a predetermined region in a wireless network; collecting 10-2A observed network measurement data; modifying (10-3; fig. 2D) the observed network measurement data; and comparing (WLS; paragraph 0121; fig. 4) the modified network measurement data with the database of calibration data to thereby determine the location of the mobile station.

With regard to claims 41-54, Stilp teaches a method for determining a location of a mobile station including providing (paragraph 0121) a database of previously-gathered calibration data for a predetermined region in a wireless network; collecting 10-2A observed network measurement data from each of a plurality of transmitters including a signal characteristic from each one of plural transmitters; determining (par. 0018, 0117) an average value for select ones of the signal characteristics; modifying (10-3; fig. 2D) the observed network measurement data using the average value; and comparing (WLS; paragraph 0121; fig. 4) the modified network measurement data with the database of calibration data to thereby determine the location of the mobile station.

Schantz et al teach a system and a method for determining a location of a mobile station including providing (col 3, lines 1-3) a database of previously-gathered calibration data for a predetermined region in a wireless network; collecting (2306; fig. 2) observed network measurement data; modifying 2310 the observed network

measurement data; and comparing (2102, 2316, 2318; abstract; col 3, lines 4+) the modified network measurement data with the database of calibration data to thereby determine the location of a mobile station.

With regard to claims 41-54, Schantz et al teach a method for determining a location of a mobile station including providing (col 3, lines 1-3) a database of previously-gathered calibration data for a predetermined region in a wireless network; collecting (2306; fig. 2) observed network measurement data from each of a plurality of transmitters including a signal characteristic from each one of plural transmitters; determining (2310, 2404, 2406; fig. 24) an average value for select ones of the signal characteristics; modifying 2310, 2312, 2316 the observed network measurement data using the average value; and comparing (2102, 2316, 2318; abstract; col 3, lines 4+) the modified network measurement data with the database of calibration data to thereby determine the location of the mobile station.

3. Claims 41-54, 67-73 are allowed.

4. Any inquiry concerning this communication or earlier communications from the examiner should be directed to Dao L. Phan whose telephone number is (571)272-6976. The examiner can normally be reached on M-F 9:00-5:30.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Thomas Tarcza can be reached on (571)272-6979. 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.

/Dao L. Phan/
Primary Examiner, Art Unit 3662

Notice of References Cited	Application/Control No. 12/026,333	Applicant(s)/Patent Under Reexamination ALLES ET AL.	
	Examiner Dao L. Phan	Art Unit 3662	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
*	A	US-7,298,314	11-2007	Schantz et al.	342/125
*	B	US-2002/0172223	11-2002	Stilp, Louis A.	370/480
*	C	US-2005/0093745	05-2005	Krumm et al.	342/465
	D	US-			
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Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	12026333	ALLES ET AL.
	Examiner	Art Unit
	Dao L Phan	3662

SEARCHED			
Class	Subclass	Date	Examiner
342	357.01, 357.06, 451, 457, 463-465	1/9/09	dp
455	456.6, 457		

SEARCH NOTES		
Search Notes	Date	Examiner
East text search (See searched history printout)	1/9/09	dp

INTERFERENCE SEARCH			
Class	Subclass	Date	Examiner

EAST Search History

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	463827	calibrat$5	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 12:59
L2	3951895	compare or compared or compares or comparing or comparison$2	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:01
L3	69488	2 same 1	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:02
L4	5443905	locate or locates or located or location $2 or locating	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:05
L5	42480	3 and 4	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:06
L6	1272	geo-locat$4	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:07
L7	2092	geolocat$4	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:07

L8	1363	geo adj locat$4	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:07
L9	5444061	4 or 6 or 7 or 8	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:07
L10	42480	9 and 3	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:08
L11	1698696	measurement$2	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:11
L12	30795	11 and 10	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:11
L13	256151	2 same 11	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:12
L14	17907	13 and 12	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:13
L15	108932	11 same 1	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:13

L16	14423	14 and 15	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:14
L17	445577	determin$6 with 9	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:16
L18	94087	calculat$6 with 9	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:16
L19	255083	comput$6 with 9	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:17
L20	642305	17 or 18 or 19	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:17
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L22	126198	2 with 11	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:19
L23	3706	22 and 21	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:20

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L25	2357	24 and 23	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:21
L26	62551	11 with 1	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:23
L27	2051	26 and 25	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:23
L28	72392	signal adj strength $2	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:24
L29	121832	power adj level$2	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:24
L30	181708	28 or 29	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:24
L31	327	30 and 27	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	OFF	2009/01/09 13:25

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	Application Number	12026333
	Filing Date	2008-02-05
	First Named Inventor	Martin ALLES, et al.
	Art Unit	2617
	Examiner Name	Unassigned
	Attorney Docket Number	AND01 082

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
/D.P./	1	6871077	B2	2005-03-22	Kennedy	

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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
/D.P./	1	20060030333	A1	2006-02-09	Ward, et al.	
/D.P./	2	20050243936	A1	2005-11-03	Agrawala, et al.	
/D.P./	3	20060240843	A1	2006-10-26	Spain, et al.	

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/D.P./	1	2000034799	WO	A1	2000-06-15	Hilsenrath, et al.		☐

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	Filing Date	2008-02-05
	First Named Inventor	Martin ALLES, et al.
	Art Unit	2617
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ATTORNEY DOCKET NO. AND01 082

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re the Patent Application of Martin ALLES, et al.

Serial No.: 12/026,333 Art Unit: 2617

Filed: 05 February 2008 Examiner: Unassigned

Title: **METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT**

TRANSMITTAL

Commissioner for Patents
P.O. Box 1450
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Transmitted herewith is an Information Disclosure Statement pursuant to 37 CFR §1.56 in connection with the above-identified application .

[X] No fee required:

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No fees are believed to be due with this submission. However, should any fees be required, the Commissioner is hereby authorized to charge such required fees to **Deposit Account No. 04-1679.**

Respectfully submitted,

/mcc/

Mark C. Comtois Reg. No. 46,285

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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
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	2	20050243936	A1	2005-11-03	Agrawala, et al.	
	3	20060240843	A1	2006-10-26	Spain, et al.	

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	1	2000034799	WO	A1	2000-06-15	Hilsenrath, et al.		☐

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	Art Unit	2617
	Examiner Name	Unassigned
	Attorney Docket Number	AND01 082

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Name/Print	Mark C. Comtois	Registration Number	46,285

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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : G01S 3/02

A1

(11) International Publication Number: WO 00/34799

(43) International Publication Date: 15 June 2000 (15.06.00)

(21) International Application Number: PCT/US99/24493

(22) International Filing Date: 19 October 1999 (19.10.99)

(30) Priority Data:

09/205,557	4 December 1998 (04.12.98)	US
09/231,256	15 January 1999 (15.01.99)	US
09/275,655	24 March 1999 (24.03.99)	US

(71) Applicant *(for all designated States except US)*: U.S. WIRELESS CORPORATION [US/US]; Suite 200, 2303 Camino Ramon, San Ramon, CA 95483 (US).

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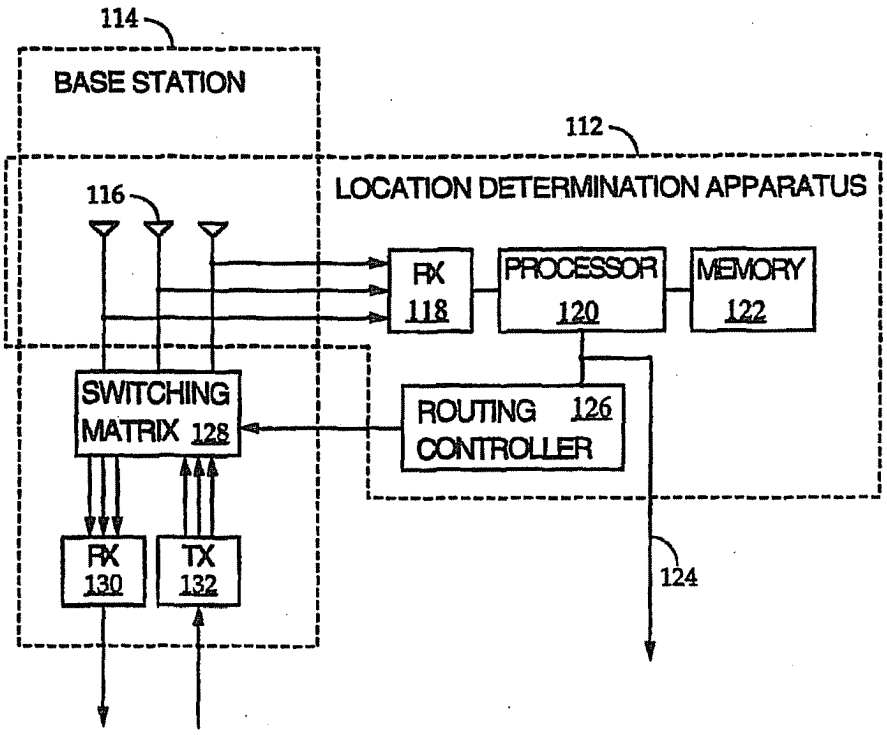
(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, 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), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(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 signal 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 $\mathbf{S}_1,\ldots,\mathbf{S}_N$. According to one matching technique, the likely locations of the mobile having signature $\mathbf{S}$ are the locations $k(1),k(2),\ldots,k(M)$ such that $D(\mathbf{S},\mathbf{S}_{k(j)}) > h$ for $j=1,\ldots M,$, 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 $\mathbf{w}_1,\ldots,\mathbf{w}_N$. 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 $p \times q$ 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 $\tau^{(1)},\ldots,\tau^{(q)}$ 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 $\{C^{(j)}(\tau_i) : j=1,\ldots p;\ i=1,\ldots,L\}$. 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 $\Delta t_i = |t_i - t_{i+1}|$ 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 $p \times p$ signal covariance matrix, $\mathbf{R}$, which is normalized such that $\mathrm{Tr}\,\mathbf{R} = 1$. 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 $\mathbf{x}(t)$ 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 $p \times p$ 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 $\mathbf{R}_{t_0}, \mathbf{R}_{t_1}, \mathbf{R}_{t_2}, \ldots, \mathbf{R}_{t_n}$ 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 $\mathbf{R}_{t_0}, \mathbf{R}_{t_1}, \mathbf{R}_{t_2}, \ldots, \mathbf{R}_{t_n}$. 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 $\overline{\mathbf{R}}_{t_n}$ is calculated by evaluating

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

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, $\overline{\mathbf{R}}_{t_n}$ is calculated recursively by evaluating

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

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 $\overline{\mathbf{R}}_{t_{n-1}}$. This is a recursive definition since the covariance matrix $\overline{\mathbf{R}}_{t_{n-1}}$ is similarly calculated from

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

Thus, one may write

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

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 $\overline{\mathbf{R}}_{t_{n-1}}$ and $\mathbf{R}_{t_n}$:

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

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 $\lambda_1,\ldots,\lambda_m$. 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 **WA=I**. Using **W** and the sampled signals, one then resolves the q multipath signal parts and calculates their relative time delays, $\tau^{(1)},\ldots,\tau^{(q)}$. 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 $\tau^{(1)},\ldots,\tau^{(q)}$ 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 $\tau=[\tau^{(1)},\ldots,\tau^{(q)}]^T$. In addition, a CDMA implementation also provides the code correlation data represented as a matrix $\mathbf{C}=[\mathbf{C}^{(1)T},\ldots,\mathbf{C}^{(p)T}]^T$, where $\mathbf{C}^{(j)}=[C^{(j)}(\tau_1),\ldots,C^{(j)}(\tau_L)]^T$. The subspaces $\mathbf{U}^{(1)},\ldots,\mathbf{U}^{(q)}$, 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 $\mathbf{R}^{(1)},\ldots,\mathbf{R}^{(q)}$ 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 $S_k=\{\mathbf{U}_k^{(1)},...,\mathbf{U}_k^{(q)};\ \mathbf{R}_k^{(1)},...,\mathbf{R}_k^{(q)}\}$, 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

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

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

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

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

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

Solving this for $\delta\theta$ we obtain

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

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:

$$|\mathbf{v}_t| = \alpha\, \delta\theta/\delta t\,, \tag{14}$$

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 $|\mathbf{v}_t|$ 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 $Tr(\mathbf{R})$, $Tr(\delta\mathbf{R})$, and $Tr(\delta\mathbf{R}\ \delta\mathbf{R}^H)$, 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 $\mathfrak{R}=\{\mathbf{R}_1,\ldots,\mathbf{R}_N\}$ and a set of N corresponding locations $\mathfrak{D}=\{\mathbf{d}_1,\ldots,\mathbf{d}_N\}$. The raw calibration data for a single trajectory is conveniently represented as a single set of ordered pairs, $\mathfrak{T}=\{(\mathbf{R}_1,\mathbf{d}_1),\ldots,(\mathbf{R}_N,\mathbf{d}_N)\}$ 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 $\mathfrak{T}_1,\ldots,\mathfrak{T}_M$. In the case where only covariance matrix information is measured, each file $\mathfrak{T}_m$ contains a temporally sequential list of ordered pairs $(\mathbf{R}_1,\mathbf{d}_1),\ldots,(\mathbf{R}_{N(m)},\mathbf{d}_{N(m)})$, 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 $\mathbf{d}_1,\ldots,\mathbf{d}_K$ 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, $\mathbf{S}_k=\{\mathbf{U}_k^{(1)},\ldots,\mathbf{U}_k^{(q)};\ \mathbf{R}_k^{(1)},\ldots,\mathbf{R}_k^{(q)}\}$. The temporal delay signature preferably is $\tau_k=[\tau_k^{(1)},\ldots,\tau_k^{(q)}]^T$, and the code correlation signature is $\mathbf{C}_k=[\mathbf{C}_k^{(1)T},\ldots,\mathbf{C}_k^{(p)T}]^T$. 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 $Tr\{\mathbf{P}_i\mathbf{R}_k\} = \mathbf{p}_i^T\mathbf{r}_k$, 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 $\mathbf{P}_{\mathbf{W}_s} = \mathbf{W}_S\mathbf{W}_S^H$. 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 $\mathbf{a}(\theta_1),\ldots,\mathbf{a}(\theta_L)$ for a set of L directions $\theta_1,\ldots,\theta_L$ 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 $\mathbf{S}$ that includes a signal covariance matrix $\mathbf{R}$ and a signal subspace $\mathbf{U}$. In another embodiment, the signature includes a signal covariance matrix and signal subspace for each of q multipath parts of the signal, i.e., $\mathbf{S}=\{\mathbf{U}^{(1)},\ldots,\mathbf{U}^{(q)};\ \mathbf{R}^{(1)},\ldots,\mathbf{R}^{(q)}\}$. 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 $\mathbf{R}^{(1)},\ldots,\mathbf{R}^{(q)}$ 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, $\mathbf{C}=[\mathbf{C}^{(1)T},\ldots,\mathbf{C}^{(p)T}]^T$, 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 $\mathbf{C}=[\mathbf{C}^{(1)T},\ldots,\mathbf{C}^{(p)T}]^T$ and a calibrated correlation signature $\mathbf{C}_k=[\mathbf{C}_k^{(1)T},\ldots,\mathbf{C}_k^{(p)T}]^T$ 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

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

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

$k(1),\ldots,k(M)$ such that $\{D(\mathbf{S},\mathbf{S}_{k(1)}),\ldots,D(\mathbf{S},\mathbf{S}_{k(M)})\}$ is the set of M largest values in the set $\{D(\mathbf{S},\mathbf{S}_1),\ldots,D(\mathbf{S},\mathbf{S}_N)\}$. 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 $k(1),k(2),\ldots,k(M)$ such that for $j=1,\ldots M$, $D(\mathbf{S},\mathbf{S}_{k(j)}) > h$, 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

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

The vector **w** characterizes how the spatial signature **S** compares to the entire set of calibrated spatial signatures $\mathbf{S}_1,\ldots,\mathbf{S}_N$. This vector **w** can be thought of as describing a "spectrum" of the signature **S** with respect to the entire set of calibrated signatures $\mathbf{S}_1,\ldots,\mathbf{S}_N$. 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 $\mathbf{w}_1,\ldots,\mathbf{w}_N$ by

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

The vector $\mathbf{w}_k$ characterizes how the calibrated signature $\mathbf{S}_k$ compares to the entire set of calibrated spatial signatures $\mathbf{S}_1,\ldots,\mathbf{S}_N$. 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

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

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 $\mathbf{w}_1,\ldots,\mathbf{w}_N$ is performed by evaluating $G(\mathbf{w},\mathbf{w}_k)$ for $k=1,\ldots,N$. 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 $\mathbf{R}_1,\ldots,\mathbf{R}_N$. One then obtains a set of N angular energy distribution functions $B_1(\theta),\ldots,B_N(\theta)$ 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 θ=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 $k(1),\ldots,k(M)$ 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:

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

or

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

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 $\mathbf{R}$, 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.

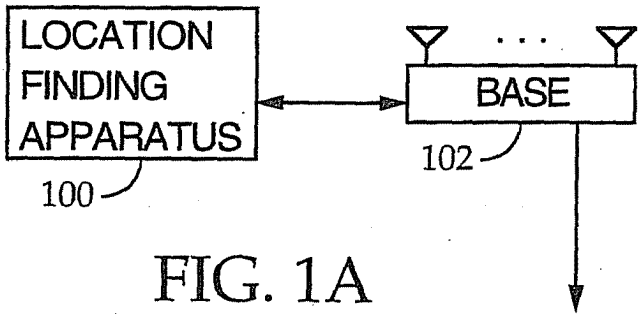


FIG. 1A

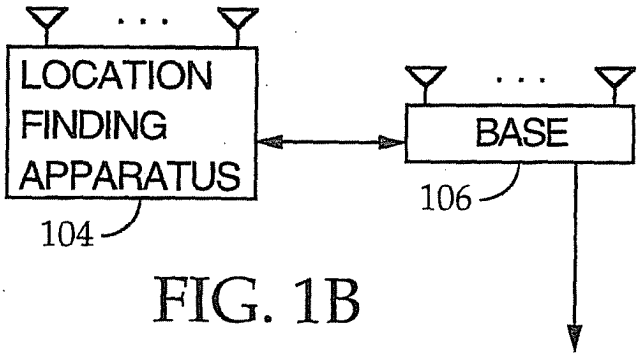


FIG. 1B

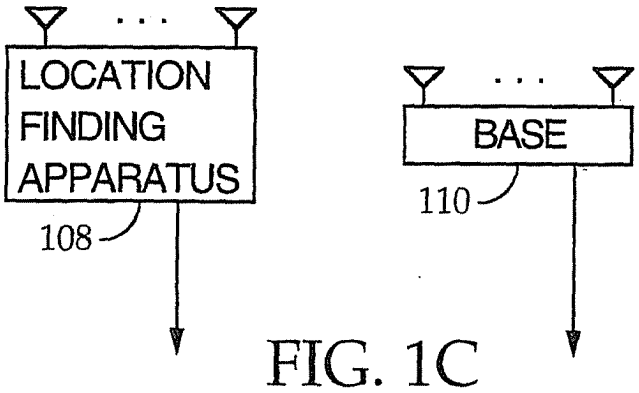
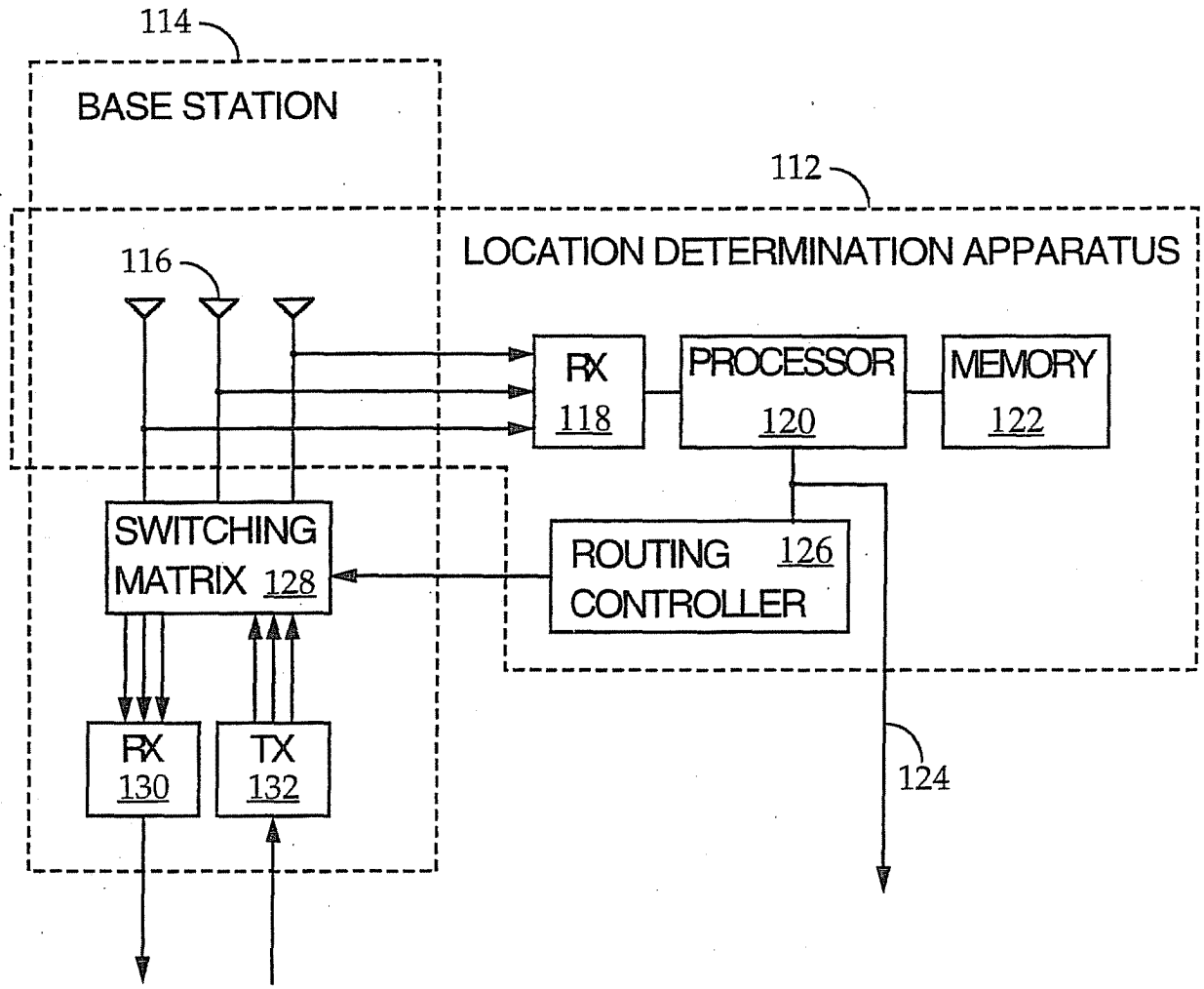


FIG. 1C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SWITCHING
MATRIX 128
ROUTING 126
CONTROLLER
RX
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FIG. 2

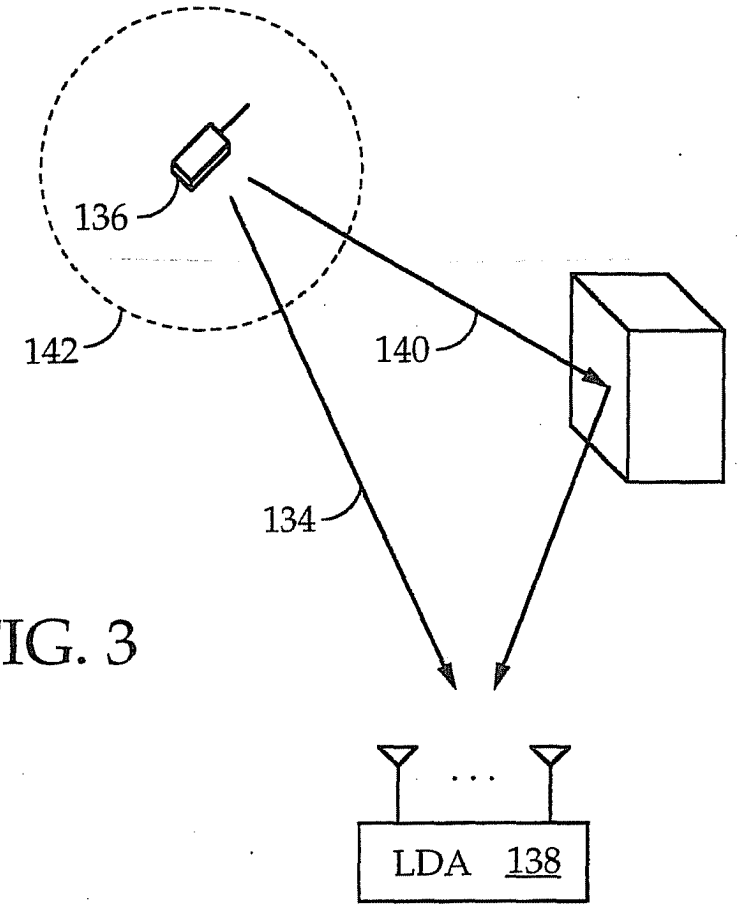
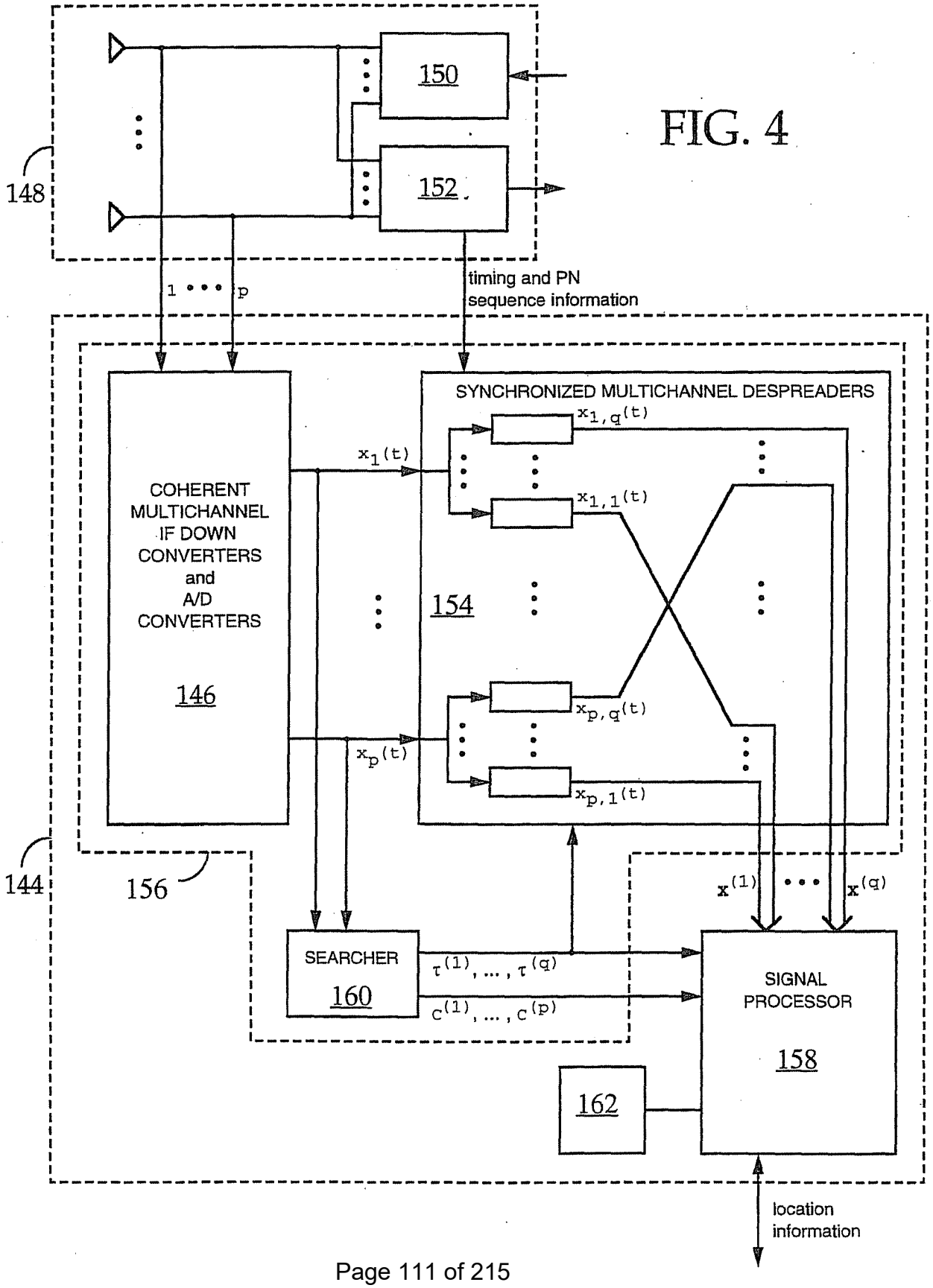


FIG. 3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152
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$x_{1,1}(t)$
154
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$x_p(t)$
$x_{p,1}(t)$
144
156
$x^{(1)}$ • • • $x^{(q)}$
SEARCHER
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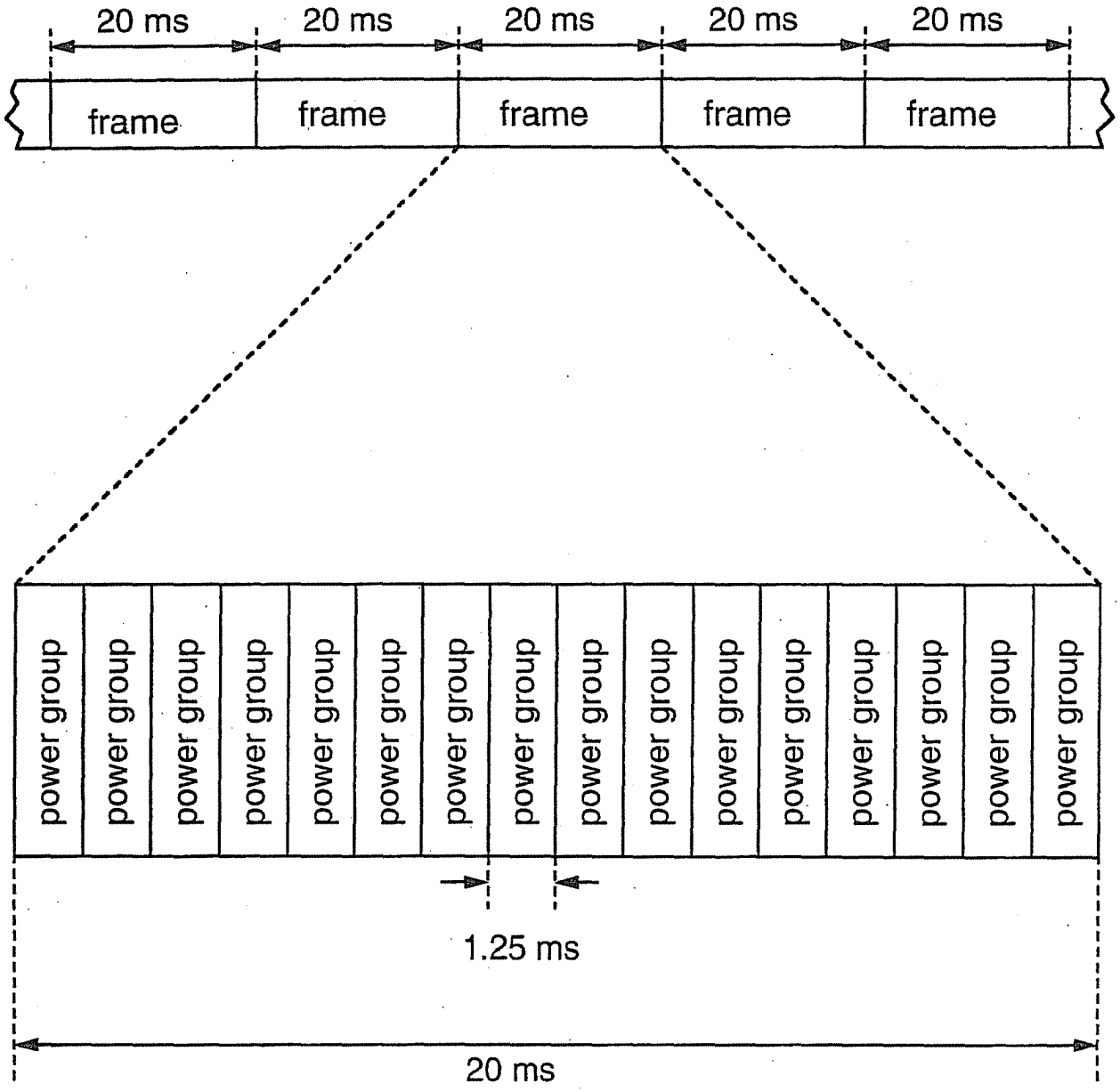
$c^{(1)}, \ldots, c^{(p)}$
SIGNAL PROCESSOR
158
162
location information

FIG. 4

FIG. 5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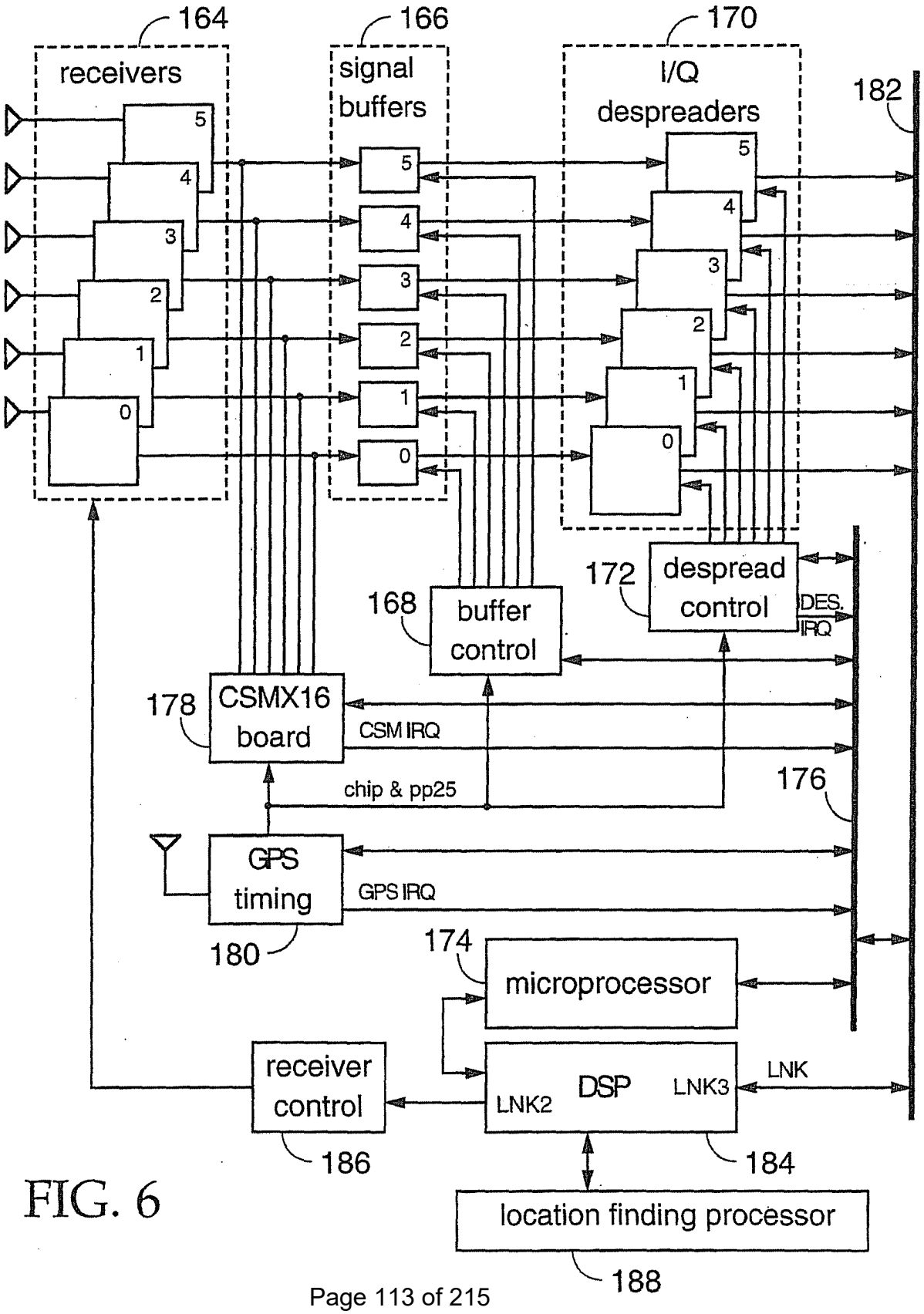
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despread control
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CSMX16 board
CSM IRQ
chip & pp25
176
GPS timing
GPS IRQ
180
174
microprocessor
receiver control
DSP
LNK2
LNK3
LNK
186
184
location finding processor
188

FIG. 6

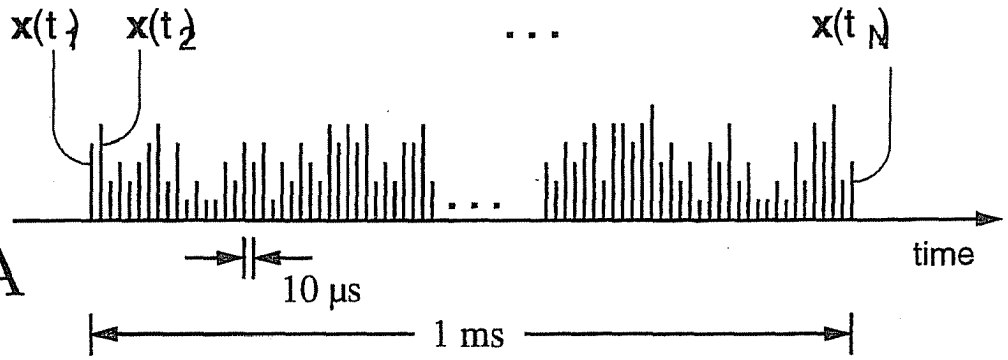


FIG. 7A

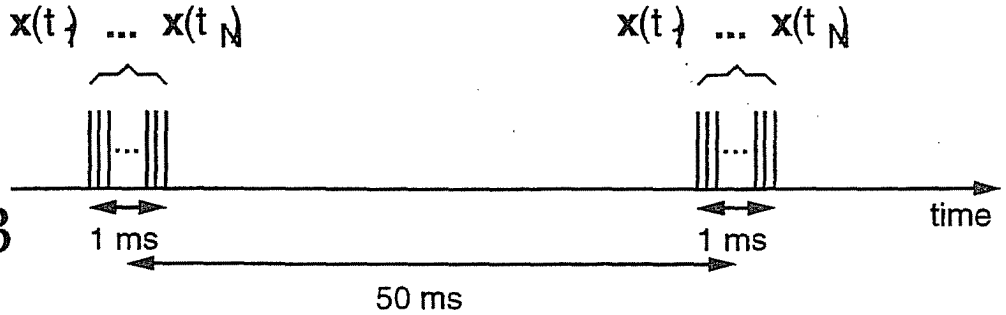


FIG. 7B

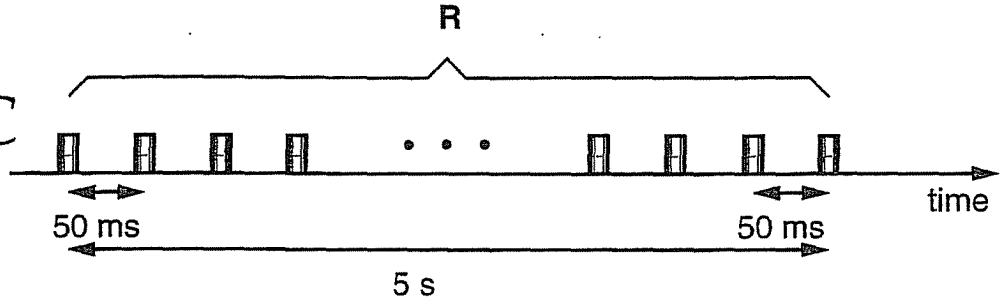


FIG. 7C

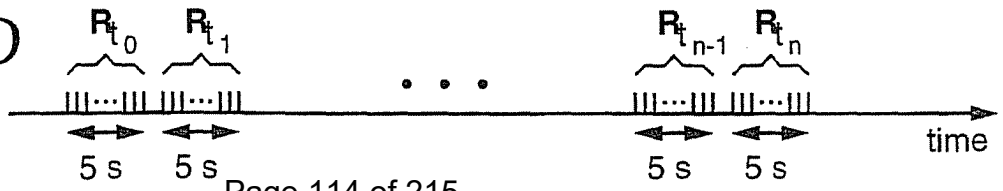


FIG. 7D

FIG. 8A

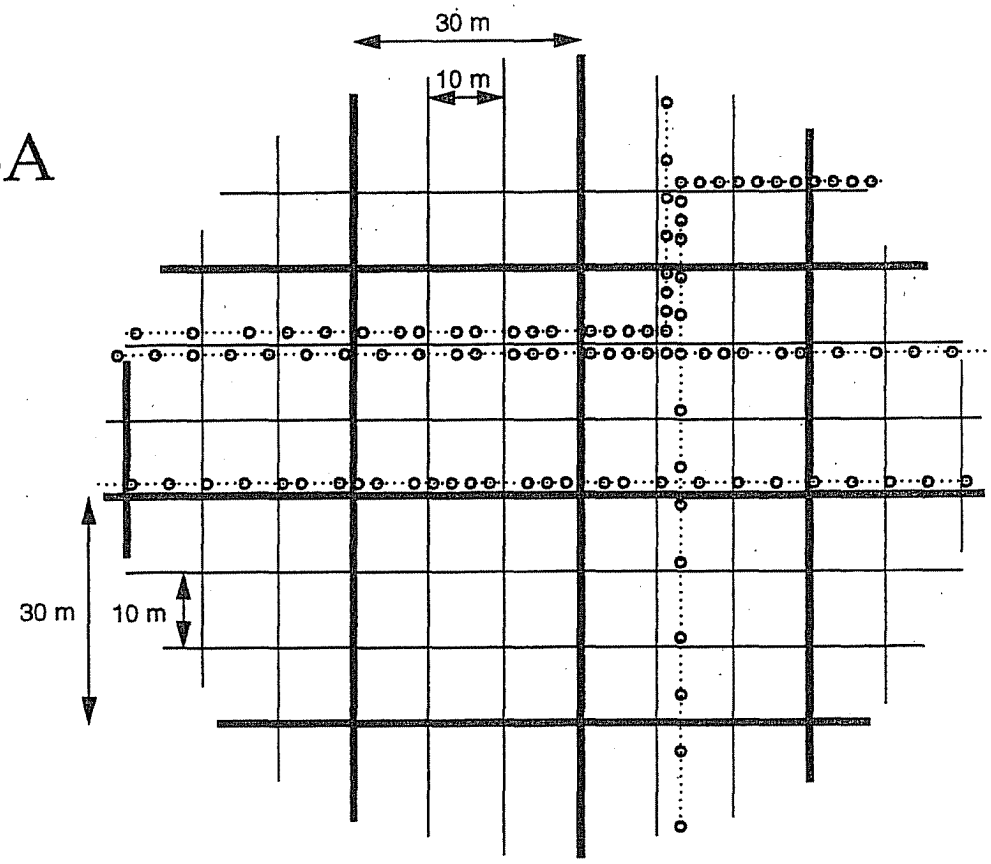
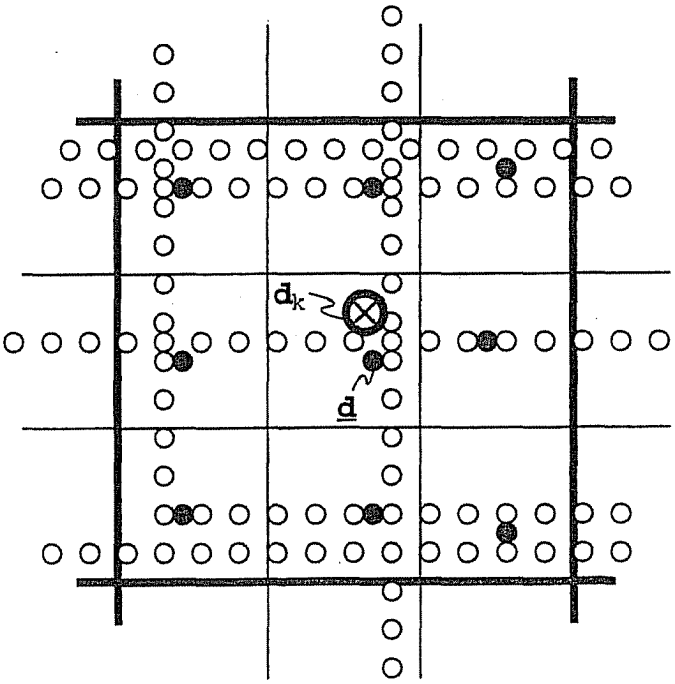


FIG. 8B



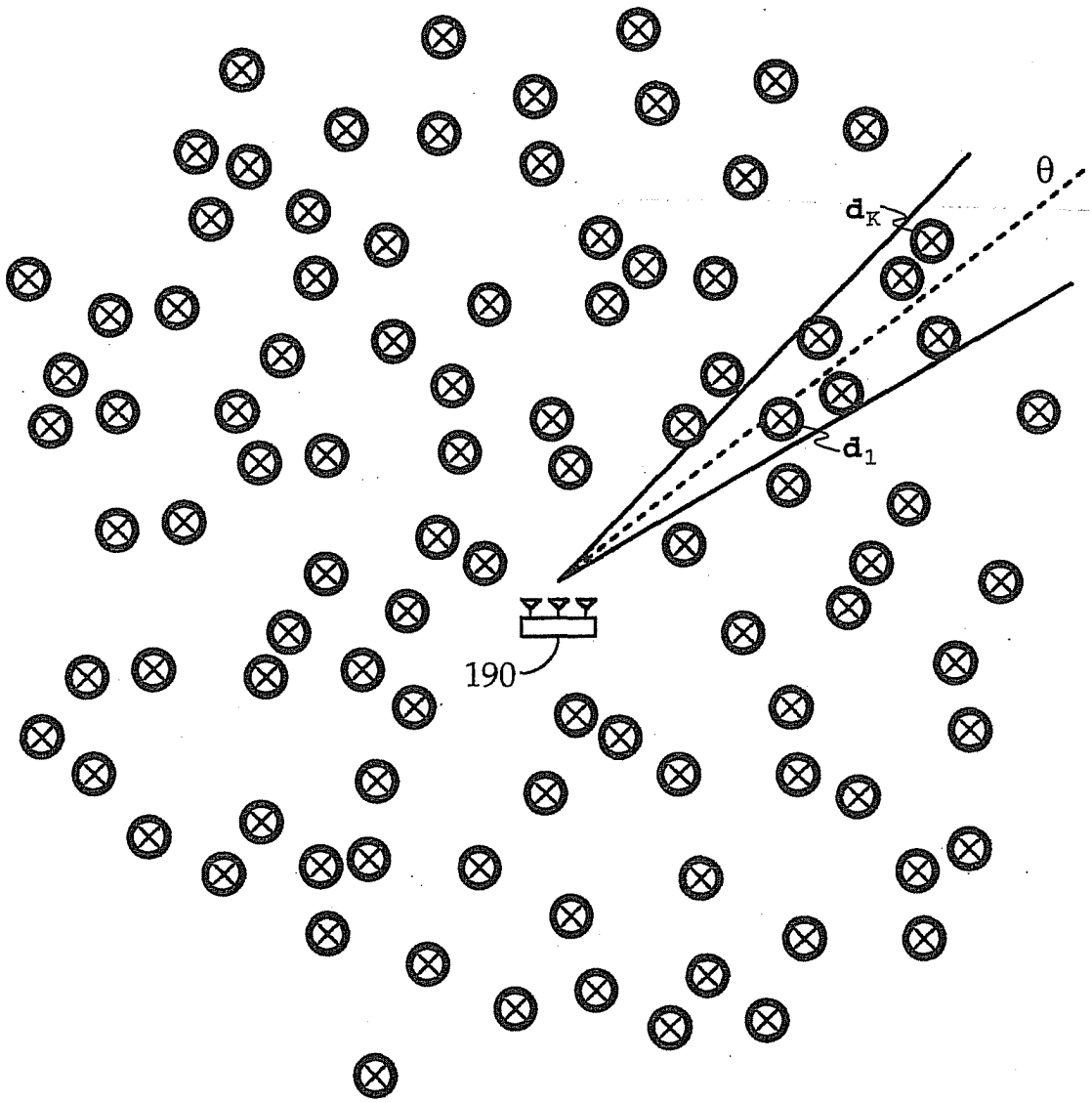


FIG. 9

FIG. 10

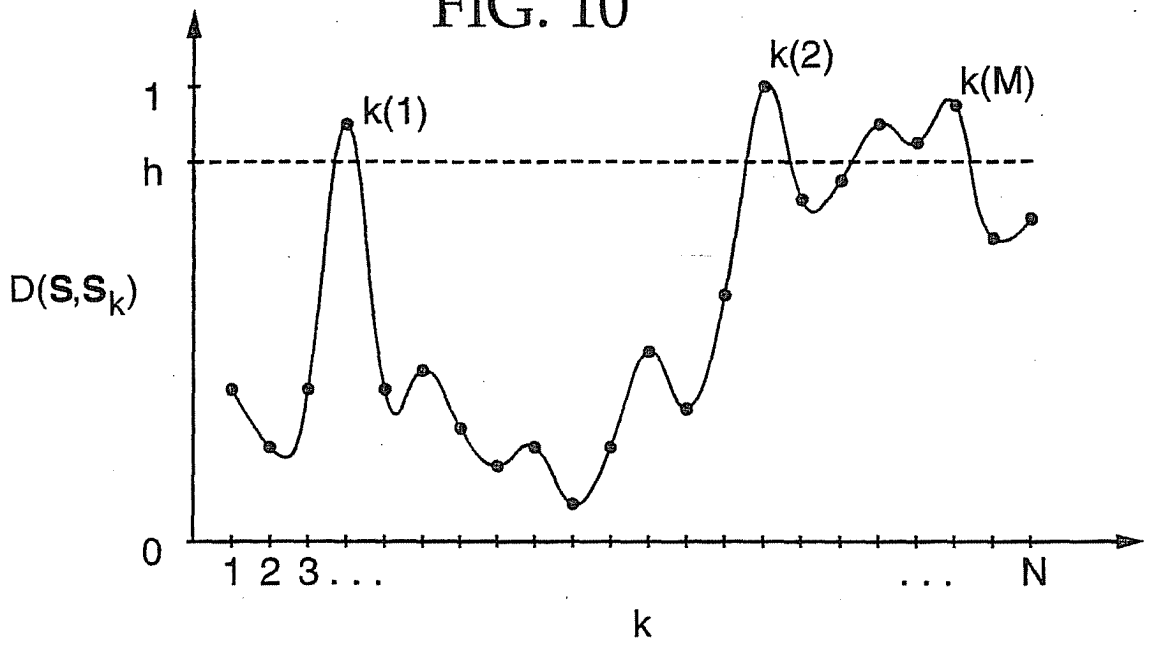
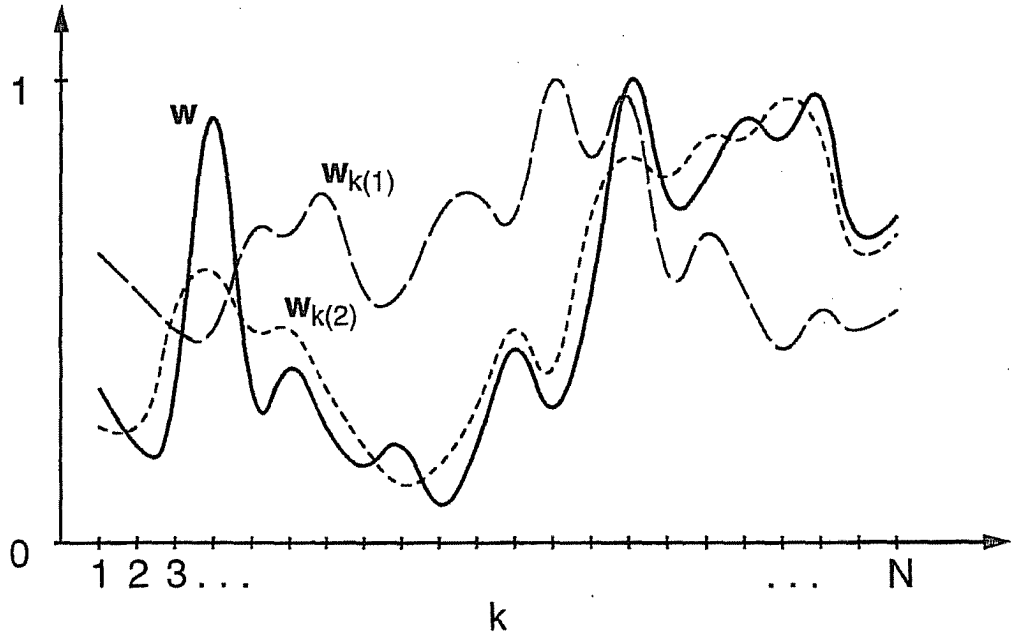


FIG. 11



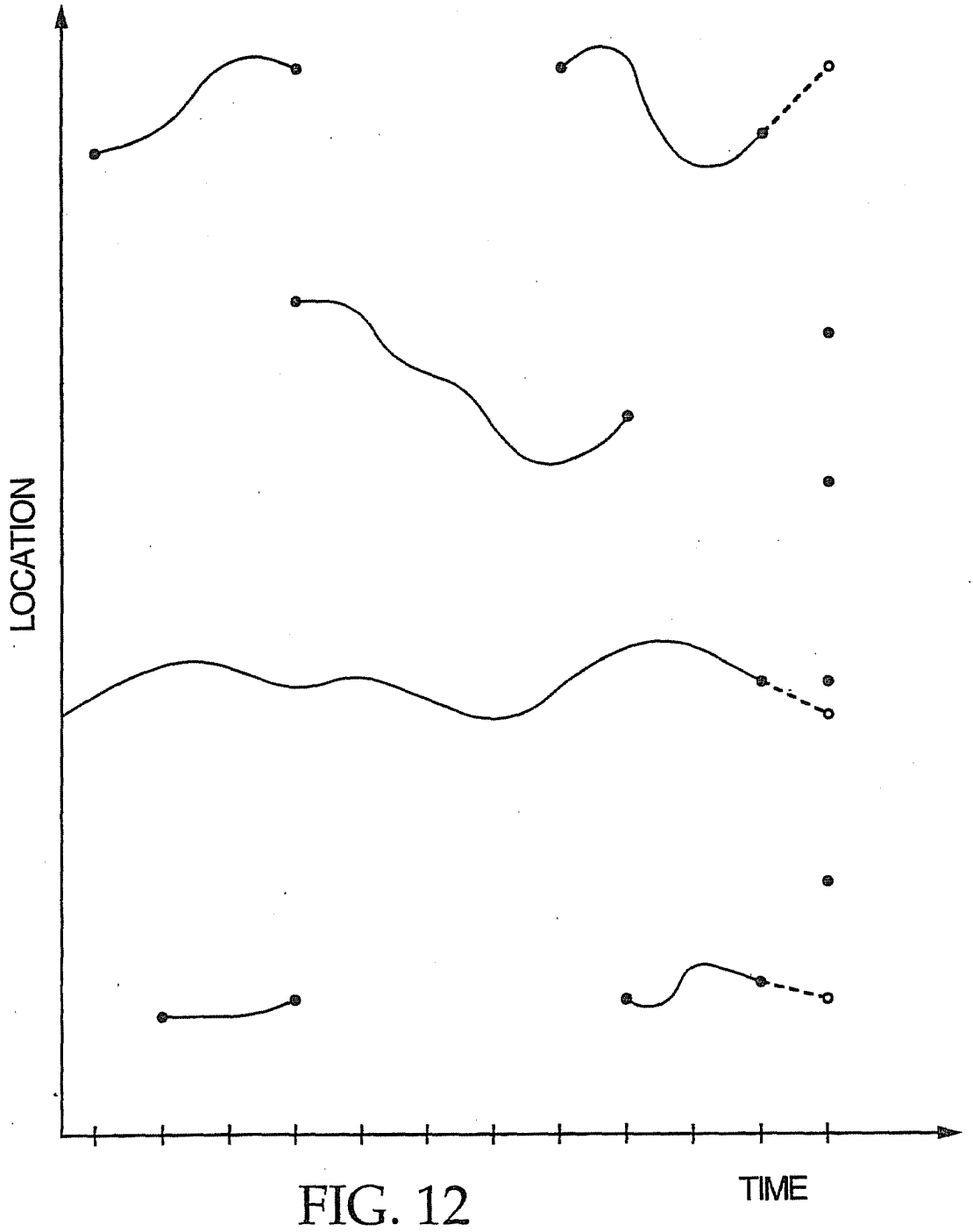


FIG. 12

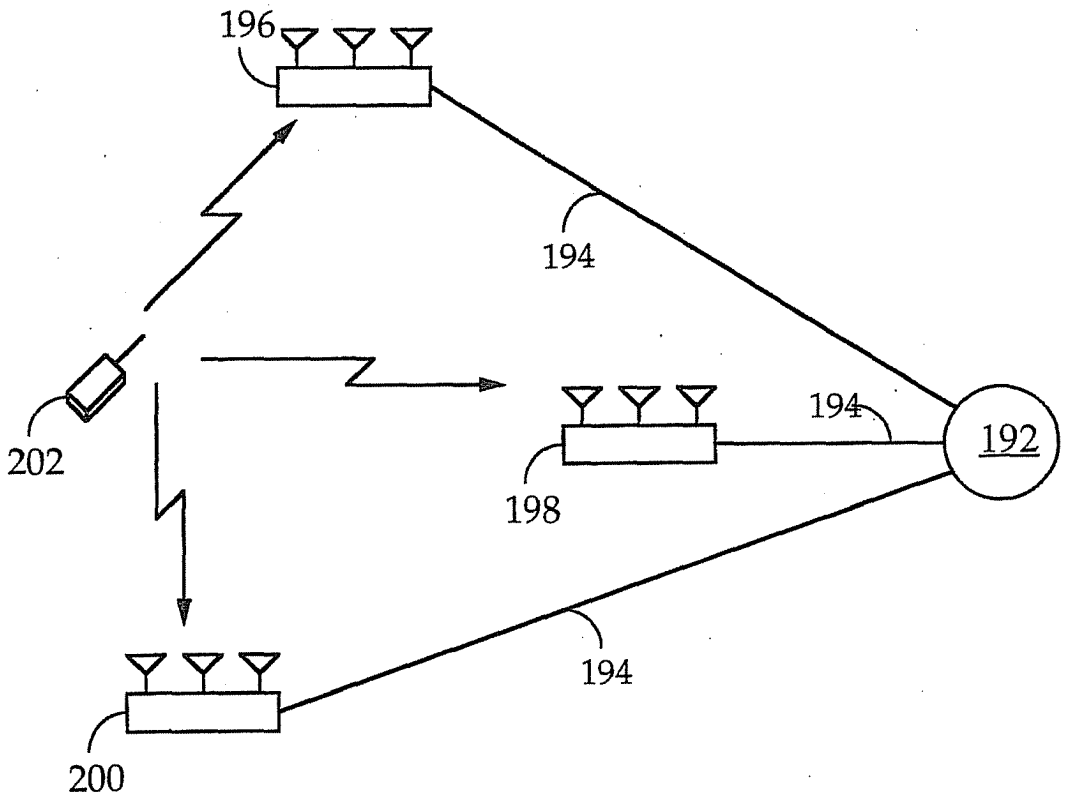


FIG. 13

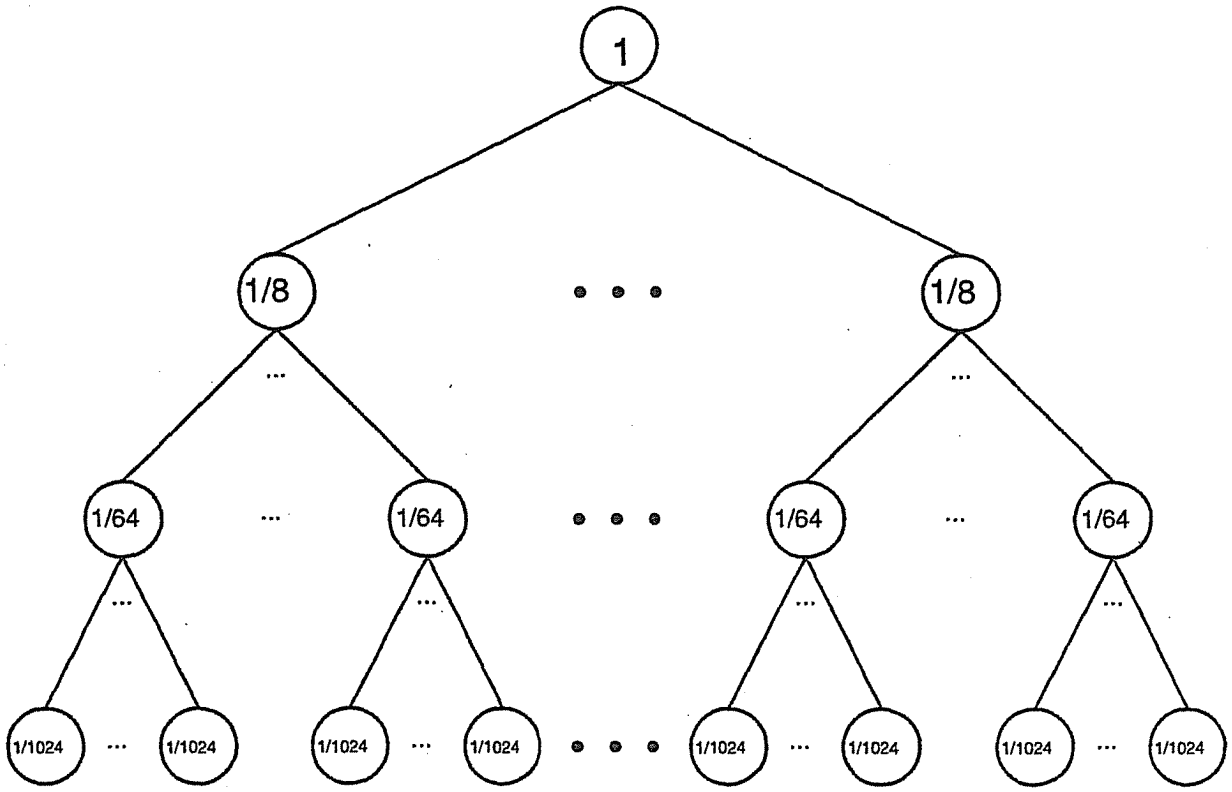

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FIG. 14

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
"A"	document defining the general state of the art which is not considered to be of particular relevance	"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
"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
"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)	"&"	document member of the same patent family
"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	Date of mailing of the international search report
08 MARCH 2000	10 MAY 2000
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer GREGORY C. ISSING

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

Electronic Acknowledgement Receipt

EFS ID:	4004013
Application Number:	12026333
International Application Number:	
Confirmation Number:	2910
Title of Invention:	METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT
First Named Inventor/Applicant Name:	Martin Alles
Customer Number:	79172
Filer:	Mark Charles Comtois/Jacquetta McBee
Filer Authorized By:	Mark Charles Comtois
Attorney Docket Number:	AND01 082
Receipt Date:	25-SEP-2008
Filing Date:	05-FEB-2008
Time Stamp:	13:23:46
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	Information Disclosure Statement (IDS) Filed (SB/08)	AND01_082_IDS.pdf	8837707 d97363d4ab3f555f8124ddb3d3162e8fc7a1321f	no	78

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National Stage of an International Application under 35 U.S.C. 371
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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
12/026,333	02/05/2008	Martin Alles	AND01 082

CONFIRMATION NO. 2910

PUBLICATION NOTICE

OC000000031433270

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

Title:METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT

Publication No.US-2008-0186234-A1
Publication Date:08/07/2008

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APPLICATION NUMBER	PATENT NUMBER	GROUP ART UNIT	FILE WRAPPER LOCATION
12/026,333		3662	

Correspondence Address / Fee Address Change

The following fields have been set to Customer Number 79172 on 06/11/2008

- Correspondence Address

The address of record for Customer Number 79172 is:
Duane Morris LLP
505 9th Street, N.W.
Suite 1000
Washington,DC 20004

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APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
12/026,333	02/05/2008	2617	4440	AND01 082	73	6

CONFIRMATION NO. 2910

UPDATED FILING RECEIPT

39290
DUANE MORRIS LLP
505 9th Street
Suite 1000
WASHINGTON, DC 20004-2166

OC000000029407716

Date Mailed: 04/16/2008

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 write to the Office of Initial Patent Examination's Filing Receipt Corrections. 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**

Applicant(s)

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

Assignment For Published Patent Application

CommScope, Inc. of North Carolina, Hickory, NC

Power of Attorney: The patent practitioners associated with Customer Number 39290

Domestic Priority data as claimed by applicant

This appln claims benefit of 60/899,379 02/05/2007

Foreign Applications

If Required, Foreign Filing License Granted: 02/19/2008

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 12/026,333**

Projected Publication Date: 08/07/2008

Non-Publication Request: No

Early Publication Request: No

Title

METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT

Preliminary Class

455

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set forth in 37 CFR 5.15. The scope and limitations of this license are set forth in 37 CFR 5.15(a) unless an earlier license has been issued under 37 CFR 5.15(b). The license is subject to revocation upon written notification. The date indicated is the effective date of the license, unless an earlier license of similar scope has been granted under 37 CFR 5.13 or 5.14.

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NOT GRANTED

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COMBINED DECLARATION AND POWER OF ATTORNEY FOR UTILITY PATENT APPLICATION

As a below named inventor, I hereby declare:

that my residence, post office address and citizenship are as stated below next to my name;

that I verily believe that I am the original, first and sole inventor (if only one name is listed below) or a joint inventor (if plural inventors are named below) of the invention which is the subject of an application entitled: METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT; said invention being described and claimed [ ] in the attached specification [X] in the specification of application Serial No. 12/026,333 filed 05 February 2008; that I have reviewed and understand the content of said specification including the claims; that I do not know and do not believe the said invention was ever known or used in the United States before my or our invention thereof, or patented or described in any printed publication in any country before my or our invention thereof or more than one year prior to said application; that said invention was not in public use or on sale in the United States more than one year prior to said application; that said invention has not been patented or made the subject of an inventor's certificate issued before the date of said application in any country foreign to the United States on an application filed by me or my legal representatives or assigns more than twelve months prior to said application; that I acknowledge my duty to disclose information of which I am aware which is material to patentability as defined in 37 CFR 1.56; and that no application for patent or inventor's certificate on this invention has been filed in any country foreign to the United States prior to said application by me or my legal representatives or assigns, except as follows:

COUNTRY/INTERNATIONAL	APPLICATION NUMBER	DATE OF FILING (day, month, year)	PRIORITY CLAIMED UNDER 35 U.S.C. 119/36
			YES___ NO__
			YES___ NO__

I hereby claim the benefit under 35 U.S.C. § 119(e) of any United States provisional application listed below:

60/899,379 filed February 5, 2007.

I hereby appoint Mark C. Comtois, Reg. No. 46,285; Joseph English, Reg. No. 42,514; Patrick D. McPherson, Reg. No. 46,255, associated with Customer No. 39290, to prosecute said application and to transact all business in the Patent and Trademark Office connected therewith and to file, prosecute and transact all business in connection with international applications directed to said invention:

Address all correspondence to: Duane Morris LLP
505 9th Street, N.W., Suite 1000
Washington, DC 20004

Direct all telephone calls to (202) 776-7800

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Martin ALLES
FULL NAME OF INVENTOR

x Martin Alles 04/01/08
SIGNATURE DATE

2421 Williams Avenue
US
CITIZENSHIP

Vienna, VA 22180
POST OFFICE ADDRESS

DM2/1397546.v1

John CARLSON	X	4/4/08
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George MAHER	X	3/31/2008
FULL NAME OF INVENTOR	SIGNATURE	DATE
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RESIDENCE	CITIZENSHIP	
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Selcuk MAZLUM	X	3/31/2008
FULL NAME OF INVENTOR	SIGNATURE	DATE
136 Clubhouse Drive SW, Apt. 201	Turkey	
RESIDENCE	CITIZENSHIP	
Leesburg, Virginia 20175		
POST OFFICE ADDRESS		

SUPPLEMENTAL APPLICATION DATA SHEET

Application Information

Application No.::	12/026,333
Filing Date::	02/05/2008
Application Type::	UTILITY
Title Line One::	METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT
Total Drawing Sheets::	10
Formal Drawings?::	YES
Docket Number::	AND01 082
Secrecy Order in Parent Appl?::	NO
Small Entity:	NO

Applicant Information

Inventor One Given Name::	Martin
Family Name::	ALLES
Name Suffix::	
Postal Address Line One::	~~16 Stonehaven Road~~ 2421 Williams Avenue
City::	~~Hamilton Parish~~ Vienna
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Country::	~~Bermuda~~ US
Postal or Zip Code	~~FL047~~ 22180
Citizenship Country::	US

Inventor Two Given Name::	John
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Country::	US
Postal or Zip Code	20166
Citizenship Country::	US

Inventor Three Given Name::	George
Family Name::	MAHER
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Country::	US
Postal or Zip Code	20170
Citizenship Country::	US

Inventor Four Given Name::	Selcuk
Family Name::	MAZLUM
Name Suffix::	
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City::	~~Frederick~~ Leesburg
State or Province::	~~Maryland~~ Virginia
Country::	US
Postal or Zip Code	~~21073~~ 20175
Citizenship Country::	~~US~~ TR

Correspondence Information

Customer Number::	39290 Mark C. Comtois DUANE MORRIS LLP 505 9th Street, N.W. Suite 1000 Washington, D.C. 20004 Tel: 202.778.7800 Fax: 202.778.7801

Representative Information

Customer Number:: 39290

ASSIGNEE INFORMATION

Assignee name:: ~~Andrew Corporation~~ CommScope, Inc. of North Carolina
Street of mailing address:: ~~1025 West NASA Boulevard~~ 1100 CommScope Place SE
City of mailing address:: ~~Melbourne~~ Hickory, North Carolina 28602

Electronic Patent Application Fee Transmittal

Application Number:	12026333
Filing Date:	05-Feb-2008
Title of Invention:	METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT
First Named Inventor/Applicant Name:	Martin Alles
Filer:	Mark Charles Comtois/Jacquetta McBee
Attorney Docket Number:	AND01 082

Filed as Large Entity

Utility Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Late filing fee for oath or declaration	1051	1	130	130
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Miscellaneous:				
			Total in USD ($)	**130**

Electronic Acknowledgement Receipt

EFS ID:	3134450
Application Number:	12026333
International Application Number:	
Confirmation Number:	2910
Title of Invention:	METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT
First Named Inventor/Applicant Name:	Martin Alles
Customer Number:	39290
Filer:	Mark Charles Comtois/Jacquetta McBee
Filer Authorized By:	Mark Charles Comtois
Attorney Docket Number:	AND01 082
Receipt Date:	10-APR-2008
Filing Date:	05-FEB-2008
Time Stamp:	15:53:21
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Deposit Account
Payment was successfully received in RAM	$130
RAM confirmation Number	1079
Deposit Account	041679
Authorized User	

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 1.21 (Miscellaneous fees and charges)

File Listing:

Document Number	Document Description	File Name	File Size(Bytes) /Message Digest	Multi Part /.zip	Pages (if appl.)
1	Oath or Declaration filed	AND01_082_DECLARATION.pdf	173986 6de9f600854d8ecda17c74ce770714c6e44dae67	no	2
Warnings:					
Information:					
2	Application Data Sheet	AND01_082_SUPPLEMENTAL_ADS.pdf	176754 dc866882b58503971a1c32efd75b5c23501bbc00	no	3
Warnings:					
Information:					
This is not an USPTO supplied ADS fillable form					
3	Fee Worksheet (PTO-06)	fee-info.pdf	8193 826c6c2fa594ad0a7bd3ff8f2920282deb3a20df	no	2
Warnings:					
Information:					
		Total Files Size (in bytes):	358933		

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<u>New Applications Under 35 U.S.C. 111</u>
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<u>National Stage of an International Application under 35 U.S.C. 371</u>
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.

<u>New International Application Filed with the USPTO as a Receiving Office</u>
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ATTORNEY DOCKET NO. AND01 082

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re the Patent Application of Martin ALLES, et al.

Confirmation No.: 2910

Serial No.: 12/026,333 Art Unit: 2617

Filed: February 5, 2008 Examiner: Unassigned

Title: **METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT**

TRANSMITTAL

Mail Stop Office of Initial Patent
Examination Filing Receipt Corrections
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

Sir:

Attached is a marked-up copy of an Official Filing Receipt issued by the U.S. Patent Trademark Office on February 21, 2008 for the above-referenced application for which issuance of a corrected filing receipt is respectfully requested, for the following reasons:

Please make the following changes to the "Applicants" section:

"Martin Alles, Hamilton Parish, MD" should read --**Vienna, VA--;**

"Selcuk Mazlum, Frederick, MD" should read --**Leesburg, VA**--.

Changes to the "Assignment for Published Patent Application" section:

"Andrew Corporation, Westchester, IL" should read--**CommScope, Inc. of North Carolina, Hickory, NC--**".

If a Petition for an Extension of Time is necessary for the paper transmitted herewith to be timely filed, this transmittal is to be considered as a petition to extend the response period by the amount of time needed for the paper to be timely filed.

The Commissioner is hereby authorized to charge payment of any additional fees associated with this communication or credit any overpayment to Deposit Account No. 04-1679.

Respectfully submitted,

/mcc/

Mark C. Comtois
Reg. No. 46,285

DUANE MORRIS LLP
505 9th Street, N.W., Suite 1000
Washington, D.C. 20004
Telephone: (202) 776-7800
Telecopier: (202) 776-7801
Dated: 10 April 2008

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

APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
12/026,333	02/05/2008	2617	4310	AND01 082	73	6

CONFIRMATION NO. 2910

FILING RECEIPT

39290
DUANE MORRIS LLP
505 9th Street
Suite 1000
WASHINGTON, DC 20004-2166

RECEIVED
DUANE MORRIS, LLP
FEB 25 2008

OC000000028380742

Date Mailed: 02/21/2008

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Applicant(s)

Martin Alles, ~~Hamilton Parish, MD;~~ Vienna, VA
John Carlson, Dulles, VA;
George Maher, Herndon, VA;
Selcuk Mazlum, ~~Frederick, MD;~~ LEESBURG, VA

Assignment For Published Patent Application

~~Andrew Corporation, Westchester, IL~~ CommScope, Inc. of North Carolina, Hickory NC

Power of Attorney: None

Domestic Priority data as claimed by applicant

This appln claims benefit of 60/899,379 02/05/2007

Foreign Applications

If Required, Foreign Filing License Granted: 02/19/2008

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 12/026,333**

Projected Publication Date: To Be Determined - pending completion of Missing Parts

Non-Publication Request: No

Early Publication Request: No

Title

METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT

Preliminary Class

455

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

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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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For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, http://www.stopfakes.gov. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4158).

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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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Electronic Acknowledgement Receipt

EFS ID:	3135083
Application Number:	12026333
International Application Number:	
Confirmation Number:	2910
Title of Invention:	METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT
First Named Inventor/Applicant Name:	Martin Alles
Customer Number:	39290
Filer:	Mark Charles Comtois/Jacquetta McBee
Filer Authorized By:	Mark Charles Comtois
Attorney Docket Number:	AND01 082
Receipt Date:	10-APR-2008
Filing Date:	05-FEB-2008
Time Stamp:	16:33:32
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	Request for Corrected Filing Receipt	AND01_082_CORRECTEDFILINGRECEIPT.pdf	487966 8d1494acf202c0c1a7f47bfe503f590bbb0af692	no	5

Warnings:

Information:

Total Files Size (in bytes):	487966

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New Applications Under 35 U.S.C. 111
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APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
12/026,333	02/05/2008	2617	4310	AND01 082	73	6

CONFIRMATION NO. 2910

39290
DUANE MORRIS LLP
505 9th Street
Suite 1000
WASHINGTON, DC 20004-2166

FILING RECEIPT

OC000000028380742

Date Mailed: 02/21/2008

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Applicant(s)

Martin Alles, Hamilton Parish, MD;
John Carlson, Dulles, VA;
George Maher, Herndon, VA;
Selcuk Mazlum, Frederick, MD;

Assignment For Published Patent Application

Andrew Corporation, Westchester, IL

Power of Attorney: None

Domestic Priority data as claimed by applicant

This appln claims benefit of 60/899,379 02/05/2007

Foreign Applications

If Required, Foreign Filing License Granted: 02/19/2008

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 12/026,333**

Projected Publication Date: To Be Determined - pending completion of Missing Parts

Non-Publication Request: No

Early Publication Request: No

Title

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Preliminary Class

455

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NOT GRANTED

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UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
12/026,333	02/05/2008	Martin Alles	AND01 082

CONFIRMATION NO. 2910

FORMALITIES LETTER

39290
DUANE MORRIS LLP
505 9th Street
Suite 1000
WASHINGTON, DC 20004-2166

OC000000028380743

Date Mailed: 02/21/2008

NOTICE TO FILE MISSING PARTS OF NONPROVISIONAL APPLICATION

FILED UNDER 37 CFR 1.53(b)

Filing Date Granted

Items Required To Avoid Abandonment:

An application number and filing date have been accorded to this application. The item(s) indicated below, however, are missing. Applicant is given **TWO MONTHS** from the date of this Notice within which to file all required items and pay any fees required below to avoid abandonment. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

- The oath or declaration is missing.
  A properly signed oath or declaration in compliance with 37 CFR 1.63, identifying the application by the above Application Number and Filing Date, is required.
  Note: If a petition under 37 CFR 1.47 is being filed, an oath or declaration in compliance with 37 CFR 1.63 signed by all available joint inventors, or if no inventor is available by a party with sufficient proprietary interest, is required.

The applicant needs to satisfy supplemental fees problems indicated below.

The required item(s) identified below must be timely submitted to avoid abandonment:

- To avoid abandonment, a surcharge (for late submission of filing fee, search fee, examination fee or oath or declaration) as set forth in 37 CFR 1.16(f) of $**130** for a non-small entity, must be submitted with the missing items identified in this notice.

SUMMARY OF FEES DUE:

Total additional fee(s) required for this application is $**130** for a non-small entity
- $**130** Surcharge.

Replies should be mailed to:

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria VA 22313-1450

Registered users of EFS-Web may alternatively submit their reply to this notice via EFS-Web.
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/masfaw/

Office of Initial Patent Examination (571) 272-4000 or 1-800-PTO-9199

PTO/SB/05 (07-07)
Approved for use through 06/30/2010. OMB 0651-0032
U.S. Patent and Trademark Office. U.S. DEPARTMENT OF COMMERCE
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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	AND01 082
First Inventor	Martin ALLES
Title	Method to Modify Calibration Data..
Express Mail Label No.	

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: **Commissioner for Patents**
P.O. Box 1450
Alexandria VA 22313-1450

1. [✓] **Fee Transmittal Form** (e.g., PTO/SB/17)
   (Submit an original and a duplicate for fee processing)
2. [ ] **Applicant claims small entity status.** See 37 CFR 1.27.
3. [✓] **Specification** [*Total Pages* 41]
   Both the claims and abstract must start on a new page
   (For information on the preferred arrangement, see MPEP 608.01(a))
4. [✓] **Drawing(s)** (*35 U.S.C. 113*) [*Total Sheets* 10]
5. **Oath or Declaration** [*Total Sheets* _____]
   a. [ ] Newly executed (original or copy)
   b. [ ] A copy from a prior application (37 CFR 1.63(d))
   (for continuation/divisional with Box 18 completed)
   i. [ ] DELETION OF INVENTOR(S)
   Signed statement attached deleting inventor(s) name in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).
6. [✓] **Application Data Sheet.** See 37 CFR 1.76
7. [ ] **CD-ROM or CD-R** in duplicate, large table or Computer Program *(Appendix)*
   [ ] Landscape Table on CD
8. **Nucleotide and/or Amino Acid Sequence Submission**
   (if applicable, items a. – c. are required)
   a. [ ] Computer Readable Form (CRF)
   b. Specification Sequence Listing on:
      i. [ ] CD-ROM or CD-R (2 copies); or
      ii. [ ] Paper
   c. [ ] Statements verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

9. [ ] **Assignment Papers** (cover sheet & document(s))
   Name of Assignee _____
10. [ ] **37 CFR 3.73(b) Statement** *(when there is an assignee)* [ ] **Power of Attorney**
11. [ ] **English Translation Document** *(if applicable)*
12. [ ] **Information Disclosure Statement** (PTO/SB/08 or PTO-1449)
    [ ] Copies of citations attached
13. [ ] **Preliminary Amendment**
14. [ ] **Return Receipt Postcard** (MPEP 503)
    (Should be specifically itemized)
15. [ ] **Certified Copy of Priority Document(s)**
    (if foreign priority is claimed)
16. [ ] **Nonpublication Request** under 35 U.S.C. 122(b)(2)(B)(i). Applicant must attach form PTO/SB/35 or equivalent.
17. [ ] Other: _____

18. If a CONTINUING APPLICATION, *check appropriate box, and supply the requisite information below and in the first sentence of the specification following the title, or in an Application Data Sheet under 37 CFR 1.76:*

[ ] Continuation [ ] Divisional [ ] Continuation-in-part (CIP) of prior application No.: .....

Prior application information: *Examiner* _____ *Art Unit:* _____

19. CORRESPONDENCE ADDRESS

[✓] The address associated with Customer Number: 39290 *OR* [ ] Correspondence address below

Name	Duane Morris LLP				
Address	505 9th Street, N.W., Suite 1000				
City	Washington	State	D.C.	Zip Code	20004-2166
Country	USA	Telephone	202.776-7800	Email	

Signature	/mcc/	Date	05 February 2008
Name (Print/Type)	Mark C. Comtois	Registration No. (Attorney/Agent)	46,285

This collection of information is required by 37 CFR 1.53(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.

PTO/SB/17 (10-07)
Approved for use through 06/30/2010. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
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Effective on 12/08/2004.
Fees pursuant to the Consolidated Appropriations Act, 2005 (H.R. 4818).

FEE TRANSMITTAL
For FY 2008

☐ Applicant claims small entity status. See 37 CFR 1.27

TOTAL AMOUNT OF PAYMENT ($) 4,310.00

Complete if Known	
Application Number	New Application
Filing Date	05 February 2008
First Named Inventor	Martin ALLES
Examiner Name	Unassigned
Art Unit	Unassigned
Attorney Docket No.	AND01 082

METHOD OF PAYMENT (check all that apply)

☐ Check ☐ Credit Card ☐ Money Order ☐ None ☐ Other (please identify): _____

☑ Deposit Account Deposit Account Number: 04-1679 Deposit Account Name: Duane Morris LLP

For the above-identified deposit account, the Director is hereby authorized to: (check all that apply)

☑ Charge fee(s) indicated below ☐ Charge fee(s) indicated below, **except for the filing fee**

☑ Charge any additional fee(s) or underpayments of fee(s) under 37 CFR 1.16 and 1.17 ☑ Credit any overpayments

WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

FEE CALCULATION

1. BASIC FILING, SEARCH, AND EXAMINATION FEES

	FILING FEES		SEARCH FEES		EXAMINATION FEES		
Application Type	**Fee ($)**	**Small Entity Fee ($)**	**Fee ($)**	**Small Entity Fee ($)**	**Fee ($)**	**Small Entity Fee ($)**	**Fees Paid ($)**
Utility	310	155	510	255	210	105	1,030.00
Design	210	105	100	50	130	65	
Plant	210	105	310	155	160	80	
Reissue	310	155	510	255	620	310	
Provisional	210	105	0	0	0	0	

2. EXCESS CLAIM FEES

Fee Description	**Fee ($)**	**Small Entity Fee ($)**
Each claim over 20 (including Reissues)	50	25
Each independent claim over 3 (including Reissues)	210	105
Multiple dependent claims	370	185

Multiple Dependent Claims **Fee ($)** _____ **Fee Paid ($)** _____

Total Claims		**Extra Claims**		**Fee ($)**		**Fee Paid ($)**
73	- 20 or HP =	53	x	50.00	=	2,650.00

HP = highest number of total claims paid for, if greater than 20.

Indep. Claims		**Extra Claims**		**Fee ($)**		**Fee Paid ($)**
6	- 3 or HP =	3	x	210.00	=	630.00

HP = highest number of independent claims paid for, if greater than 3.

3. APPLICATION SIZE FEE

If the specification and drawings exceed 100 sheets of paper (excluding electronically filed sequence or computer listings under 37 CFR 1.52(e)), the application size fee due is $260 ($130 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).

Total Sheets		**Extra Sheets**		**Number of each additional 50 or fraction thereof**		**Fee ($)**		**Fee Paid ($)**
51	- 100 =	0	/ 50 =	0 (round **up** to a whole number)	x	0.00	=	0.00

4. OTHER FEE(S) **Fees Paid ($)**

Non-English Specification, $130 fee (no small entity discount) _____

Other (e.g., late filing surcharge): _____ _____

SUBMITTED BY

Signature	/mcc/	Registration No. (Attorney/Agent) 46,285	Telephone 202-776-7800
Name (Print/Type)	Mark C. Comtois		Date 05 February 2008

This collection of information is required by 37 CFR 1.136. 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 30 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.**

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	AND01 082
	Application Number	
Title of Invention	METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT	

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.)

Applicant Information:

Applicant 1

Applicant Authority ◉ Inventor ◯ Legal Representative under 35 U.S.C. 117 ◯ Party of Interest under 35 U.S.C. 118

Prefix	Given Name	Middle Name	Family Name	Suffix
	Martin		ALLES	

Residence Information (Select One) ◉ US Residency ◯ Non US Residency ◯ Active US Military Service

City	Hamilton Parish	State/Province	MD	Country of Residence	BM

Citizenship under 37 CFR 1.41(b) BM

Mailing Address of Applicant:

Address 1	16 Stonehaven Road		
Address 2			
City	Hamilton Parish	State/Province	
Postal Code		Country	BM

Applicant 2

Applicant Authority ◉ Inventor ◯ Legal Representative under 35 U.S.C. 117 ◯ Party of Interest under 35 U.S.C. 118

Prefix	Given Name	Middle Name	Family Name	Suffix
	John		CARLSON	

Residence Information (Select One) ◉ US Residency ◯ Non US Residency ◯ Active US Military Service

City	Dulles	State/Province	VA	Country of Residence	US

Citizenship under 37 CFR 1.41(b) US

Mailing Address of Applicant:

Address 1	43479 Ogden Place		
Address 2			
City	Dulles	State/Province	VA
Postal Code	20166	Country	US

Applicant 3

Applicant Authority ◉ Inventor ◯ Legal Representative under 35 U.S.C. 117 ◯ Party of Interest under 35 U.S.C. 118

Prefix	Given Name	Middle Name	Family Name	Suffix
	George		MAHER	

Residence Information (Select One) ◉ US Residency ◯ Non US Residency ◯ Active US Military Service

City	Herndon	State/Province	VA	Country of Residence	US

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 082
	Application Number	
Title of Invention	METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT	

Citizenship under 37 CFR 1.41(b)	US		
Mailing Address of Applicant:			
Address 1	100 Adele Garden Way		
Address 2			
City	Herndon	**State/Province**	VA
Postal Code	20170	**Country**	US

Applicant 4

Applicant Authority ◉ Inventor ◯ Legal Representative under 35 U.S.C. 117 ◯ Party of Interest under 35 U.S.C. 118

Prefix	Given Name	Middle Name	Family Name	Suffix
	Selcuk		MAZLUM	

Residence Information (Select One) ◉ US Residency ◯ Non US Residency ◯ Active US Military Service

City	Frederick	**State/Province**	MD	**Country of Residence**	US
Citizenship under 37 CFR 1.41(b)	US				
Mailing Address of Applicant:					
Address 1	7144 Canterbury Court				
Address 2					
City	Frederick	**State/Province**	MD		
Postal Code	21073	**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	39290		
Email Address		Add Email	Remove Email

Application Information:

Title of the Invention	METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT		
Attorney Docket Number	AND01 082	**Small Entity Status Claimed**	☐
Application Type	Nonprovisional		
Subject Matter	Utility		
Suggested Class (if any)		**Sub Class (if any)**	
Suggested Technology Center (if any)			
Total Number of Drawing Sheets (if any)	10	**Suggested Figure for Publication (if any)**	

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 082
	Application Number	
Title of Invention	METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT	

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).
Enter either 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	39290		

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(a)(2) or CFR 1.78(a)(4), and need not otherwise be made part of the specification.

Prior Application Status	Expired		Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
	non provisional of	60899379	2007-02-05

Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the **Add** button.

Foreign Priority Information:

This section allows for the applicant to claim benefit of foreign priority and to identify any prior foreign application for which priority is not claimed. 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(a).

			Remove
Application Number	Country[i]	Parent Filing Date (YYYY-MM-DD)	Priority Claimed
			◉ Yes ○ No

Additional Foreign Priority Data may be generated within this form by selecting the **Add** button.

Assignee Information:

Providing this information in the application data sheet does not substitute for compliance with any requirement of part 3 of Title 37 of the CFR to have an assignment recorded in the Office.

Assignee 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 082
	Application Number	
Title of Invention	METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT	

If the Assignee is an Organization check here. ☒			
Organization Name	Andrew Corporation		
Mailing Address Information:			
Address 1	3 Westbrook Corporate Center		
Address 2	Suite 900		
City	Westchester	**State/Province**	IL
Country	US	Postal Code	60154
Phone Number		Fax Number	
Email Address			
Additional Assignee Data may be generated within this form by selecting the **Add** button.			

Signature:

A signature of the applicant or representative is required in accordance with 37 CFR 1.33 and 10.18. Please see 37 CFR 1.4(d) for the form of the signature.					
Signature	/mcc/			Date (YYYY-MM-DD)	2008-02-05
First Name	Mark	Last Name	Comtois	Registration Number	46285

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.**

UNITED STATES PATENT APPLICATION

of

MARTIN ALLES

JOHN CARLSON

GEORGE MAHER

and

SELCUK MAZLUM

for

METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT

CROSS REFERENCES

[0001] The present application is related to provisional application No. 60/899,379 entitled "Mobile Location Using Network Measurement Reports" filed on February 5, 2007, which is hereby incorporated by reference in its 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 or "geo-locating" 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), etc.). Calibration data is typically collected in an outdoor environment. The primary reason for collecting calibration data outdoors is the greater ease of performing automated calibration collection procedures or, in some instances, manual collection procedures along roads. It is more time-consuming to perform calibration procedures indoors due to the required access to buildings and the inability to utilize automated collection procedures designed for outdoor environments.

[0004] When a wireless device is located indoors, the signal strengths of signals received from the serving and/or neighboring base stations tend to be lower than the

strength of the signals received by a wireless device located outdoors. As a result of these lower signal strengths, performing comparisons between the received signal strengths of the indoor wireless device and signal strength data stored in a calibration database may result in a poor estimated location accuracy. Modifying the calibration data obtained outdoors may provide a way to simulate indoor calibration data characteristics. Calibration data collected in areas located adjacent to indoor facilities may be altered to increase the accuracy of location estimates of a mobile station located indoors.

[0005] One embodiment of the present subject matter is a method for determining a location of a mobile station. The method includes providing a database of previously-gathered calibration data for a predetermined region in a wireless network and collecting observed network measurement data. The method also includes modifying the observed network measurements and then comparing the modified data with the database of calibration data to determine the location of the mobile station.

[0006] Another embodiment of the present subject matter is a system for determining a location of a mobile station. The system includes a database of previously-gathered calibration data for a region in a wireless network and circuitry such as a wireless receiver for collecting observed network measurement data. The system includes circuitry, such as a processor, for modifying the observed network measurement data; and circuitry, such as a processor, for comparing the modified data with the calibration data in the database to determine the location of the mobile station.

[0007] Yet another embodiment of the present subject matter is a method for determining a location of a mobile station. The method includes providing a database of

previously-gathered calibration data for a region in a wireless network which includes a serving transmitter. The method collects observed network measurement data including a first network characteristic from said serving transmitter and modifies the observed network measurement data using said first characteristic. The method compares the modified network measurement data with the database of calibration data to thereby determine the location of the mobile station.

[0008] Still yet another embodiment of the present subject matter is a method for determining a location of a mobile station. The method includes providing a database of previously-gathered calibration data for a region in a wireless network including a first transmitter and a second transmitter. The method also includes collecting observed network measurement data including a first and second signal characteristic from the first and second transmitters respectively and determining which of the first and second signal characteristics has a greater magnitude. The observed network measurement data may be modified using the greater magnitude signal characteristic, and the modified network measurement data may be compared with the database of calibration data to determine the location of the mobile station.

[0009] A further embodiment of the present subject matter is a method for determining a location of a mobile station. The method includes providing a database of previously-gathered calibration data for a region in a wireless network and collecting observed network measurement data from a plurality of transmitters which includes a signal characteristic from each one of said plural transmitters. The method also includes determining an average value for the signal characteristics and modifying the observed

network measurement data using the average value. The method may then compare the modified network measurement data with the database of calibration data to determine the location of the mobile station.

[0010] Still a further embodiment of the present subject matter recognizes that it may be desirable to locate a mobile station by obtaining at least one network measurement report representing at least one first signal characteristic of the mobile station's serving base station, and at least one second and third signal characteristics of neighboring base stations. The method may also compute the difference between the at least one first signal characteristic of the mobile station's serving base station and the at least one second signal characteristic of at least one of the neighboring base stations to determine a first solution and determine which neighboring base station has the highest signal power level at a particular location. The difference between the highest signal power and the power levels of the serving base station and the remaining neighboring base stations may be computed to determine a second solution. It may also be determined which neighboring base station has the lowest signal power level at the particular location. The method may also comprise computing an average signal power level intermediary to the difference between the highest signal power level and the lowest signal power level to determine a third solution and determining which of the three solutions is a most optimal solution based on at least one comparison of the three solutions. At least one signal characteristic of the network measurement report may be adjusted based on the most optimal solution and the modified network measurement report may be utilized to locate a mobile station.

[0011] Another embodiment of the present subject matter is a method for determining a location of a mobile station. The method includes providing a database of previously-gathered outdoor calibration data for a region in a wireless network, collecting network measurement data, and comparing the network measurement data with the database of calibration data to thereby determine several location estimates of the mobile station. The method may also include determining a confidence measure for each of the plurality of location estimates and determining the location of the mobile station based on the plurality of location estimates and their respective confidence measures.

[0012] 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

[0013] FIG. 1 illustrates a wireless communications networking environment.

[0014] FIG. 2 illustrates a flow diagram of an exemplary inventive concept.

[0015] FIG. 3 illustrates a flow diagram of another exemplary inventive concept.

[0016] FIG. 4 illustrates a flow diagram of yet another exemplary inventive concept.

[0017] FIG. 5 illustrates a flow diagram of still another exemplary inventive concept.

[0018] FIG. 6 illustrates a flow diagram of still yet another exemplary inventive concept.

[0019] FIG. 7 illustrates a flow diagram of an embodiment of the subject matter.

[0020] FIG. 8 illustrates a flow diagram of another embodiment of the subject matter.

[0021] FIG. 9 illustrates a flow diagram of another embodiment of the subject matter.

[0022] FIG. 10 illustrates a flow diagram of another embodiment of the subject matter.

DETAILED DESCRIPTION

[0023] Calibration data samples obtained outdoors may be used to simulate indoor calibration data to locate a mobile station (MS) in an indoor facility. A method of utilizing calibration data samples to represent indoor and/or outdoor wireless networking environments is described herein.

[0024] Reliably locating a mobile station located indoors, even when the calibration data has been obtained in an outdoor environment, may simplify a calibration collection procedure. Calibration data obtained outdoors may be modified and substituted for indoor calibration data. In addition network measurement data may be modified for comparison with the outdoor calibration data.

[0025] In general, a non-uniform grid point (NUG) may represent the signal characteristics and/or calibration data over a given region. As illustrated in FIG. 1, a set

of NUGs (NUG1, NUG2 and NUG3) are shown as being a part of a larger geographical region (R), which includes various wireless networking components (*e.g.,* (MS 11 and BS 20 - NUG1), (MSs 12-15 - NUG2) and (MSs 16-18 and BS 30 - NUG3)). The NUGs represent an area of collected calibration data, which may be stored in a database for easy retrieval during a calibration data comparison operation between the NUG and a received network measurement report (NMR).

[0026] Calibration data may be obtained from data collection devices during field test operations, and/or from MSs or other communication devices within the general area of the NUG. Cross-NUG communications may occur between MSs and/or BSs located within communication range of one or more of the NUGs. For example, BS 10 may be located outside the region (R) and may communicate with one or more devices located in the various NUGs 1-3. The different NUGs 1-3 may be separately defined by a variety of parameters. For example, geographical areas (*e.g.,* mountains, buildings, roads) may be a factor in deciding the boundaries of a NUG. Additionally, varying concentrations of MSs may be another factor that separates one NUG from another.

[0027] Network measurement reports (NMRs) may be used to represent network characteristics at particular locations within a given region (R). Any point located within a NUG may have corresponding signal strength levels that represent the signal power of the serving and/or neighboring cell (NC) BSs. An exemplary NMR may be represented by example_data_vector = [P1, P2, P3, TA1]. Referring to FIG. 1, the power level signals (P1-P3) may represent the power levels of the three BSs 10, 20 and 30, as measured at a particular location. The timing advance parameter TA1 (or equivalent

parameter) may be used to represent timing information of signals transmitted between the MS and one or more BSs.

[0028] 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 be periodically adjusted as the distance from the MS to the BS changes. Of course, a NMR may contain any number and type of parameters, and may be used to estimate the location of a MS.

[0029] For example, NMR(s) may be transmitted from the MS or from other wireless communication components to position determining equipment (PDE) 50, which processes the received NMR information and may attempt to locate the position of the MS. NMR(s) may be periodically generated by MSs or other communication devices to calibrate the NUG. The NUG may also be based entirely on information received from NMR(s) generated by MSs located in the NUG.

[0030] The received Network Measurement data (NM data) may be compared to predetermined calibration data representing one or more NUGs to estimate the location of a MS. In a case where NM data is compared against a NUG, like parameters may be compared to estimate if the target MS 18 is within the NUG. Similarly, NUG parameters may be computed in response to a comparison operation, and then compared to the NM

data. Each NUG may have a series of parameters and/or functions characterizing one or more particular locations in the NUG. Given a received set of one or more NMR(s) obtained from some unknown location, an estimate of that unknown location may be calculated using the characterization of the NUG or uniform grid (UG) over that region.

[0031] It may be desirable to use the original unmodified NM data directly without modification when locating a mobile station. Assuming the MS is located in an indoor facility, the data contained in the NMR(s) may be a function of calibration data collected outdoors. In some cases, the unmodified outdoor calibration data used to represent the indoor facility may provide an accurate representation of the location of the target MS 18 (*e.g.,* low distortion structures, open-faced facilities, etc.).

[0032] Referring to FIG. 1, the NM data may be sent from the target MS 18 to the BS 10, where the PDE 50 processes the NMR and performs one or more comparison operations between the NM data and the calibration data of the NUG(s). Once the comparison operation is complete, the location of the target MS 18 may be estimated. A direct comparison of the original NM data may be made against the corresponding NUG(s) characteristics. Alternatively, the NM data may not be modified even if NUG(s) are utilized to estimate the location of the mobile station.

[0033] NM data may also be modified to adjust the power levels received from the serving and/or neighboring cell (NC) base stations. For example, differences in parameters between the serving cell and the NC may be calculated and the quantities used to modify the original NM data.

[0034] If an original NMR received at the PDE 50 had the form NMR1 = [P1, P2, P3, TA1], where P1 is the serving BS power at a particular location, P2 is a first NC power, P3 is a second NC power, and TA1 is the timing advance parameter, the modified NMR may be represented by: NMR_modified = [0, P1-P2, P1-P3, TA1]. The resulting data vector may be used to calculate new relative power levels of the NC BSs by subtracting or adding the NMR_modified parameters from the original NMR1 parameters. In this example, the power of the serving BS may be used as a basis to obtain relative power level modification parameters to modify the NC power level parameters of NMR(s).

[0035] The calculated modified parameters (NMR_modified = [0, P1-P2, P1-P3, TA1]) may also be used to simulate an indoor facility by modifying NMR(s) received from an indoor location. Alternatively, the modified parameters may be used to conduct other calculations to obtain a desired set of modified results. For example, the modified NMR may be compared to one or more of the NUG(s) to provide an estimated location of a MS. Of course, the serving BS power level is not a required parameter to be used as a basis to obtain relative power level modification parameters, and many other parameters may be used to modify the NM data to simulate an indoor facility.

[0036] To further illustrate modification of the NMR, consider a particular implementation where the variable RxLevServing_WD represents the received signal strength of the serving base station's control channel measured by the wireless device at an unknown location. Let RxLevNeigh_i_WD represent the received signal strength of the ith neighbor's control channel, RxLevServing_DB represent the average received

signal strength of the serving station's control channel, stored in a database of the PDE 50 during the calibration process, and RxLevNeigh_i_DB represent the average received signal strength of the ith neighbor's control channel stored in the database during a calibration process (i = 1 to N, where N is the number of neighbor cells reported).

[0037] A comparison operation may be conducted between the received signal strengths of the NC-BSs relative to the serving BS's received signal strength. For example, a comparison may include computing the difference between the parameters of the serving base station and the ith neighbor's parameters (*i.e.*, (RxLevServing_WD - RxLevNeigh_i_WD) and (RxLevServing_DB - RxLevNeigh_i_DB)). Once the differences are calculated, the magnitudes of the differences may be compared to a predetermined threshold value used to distinguish between an acceptable difference value requiring no modification to the NM data and a non-acceptable difference value invoking further modification efforts.

[0038] NM data may be modified by an amount relative to the signal strength of a NC-BS. In this example, the NC-BS having the highest signal power may be used as a basis to modify the values of the NM data. The differences between the NC having the highest cell power and the cell powers of the remaining NC-BSs may be calculated and the quantities thereof used to modify the original NM data.

[0039] An exemplary NMR may have the form NMR = [P1, P2, P3, P4, TA1], where P1 is the serving BS signal power, P2 is a NC having the highest signal power at the intended location of the NMR, P3 and P4 are different NC signal powers, and TAl is a timing advance parameter. In this example, P2 has the highest signal power level and

may be used as the basis for modifying the parameters of the NMR. The modified NMR may then be represented by NMR_modified2 = [P2-P1, 0, P2-P3, P2-P4, TA1]. The resulting data vector NMR_modified2 may be used to calculate new power levels of the NC base stations by subtracting or adding the NMR_modified2 parameters to the original NMR parameters.

[0040] The modified NMR may be compared to one or more of the NUG(s). In the previous examples, the power of the serving BS and the NC with the highest signal power level were used to obtain the relative power modification quantities. The signal power level of the serving BS and/or the NC having the highest signal power may be used solely to modify the NMR, and may not be included in comparison operations against the NUG(s). If the serving BS power level parameter and/or the NC having the highest signal power level parameter are excluded from the comparison to the NUG(s), the first and/or additional terms of the NMR may be ignored during the comparison operation. Of course, any other parameter may be utilized and the example above including power level should not limit the scope of the claims appended herewith.

[0041] To further illustrate modification of the NMR, consider a particular implementation where the variable RxLevNeigh_h_WD represents the received signal strength of a neighboring BS's control channel (neighbor A) having the highest signal level, as measured by the wireless device. RxLevNeigh_h_WD may be listed first in a measurement report list containing signal strengths sorted in descending order (h = 1). Let RxLevNeigh_i_WD represent the received signal strength of the ith neighbor's control channel measured (neighbor i, where $i \neq h$), as by the wireless device, and

RxLevNeigh_h_DB represent the received signal strength of the neighbor (neighbor A) with the highest received signal strength, as measured by the wireless device, and which may be stored in the PDE 50 database during a calibration process. RxLevNeigh_i_DB may be used to represent the received signal strength of the ith neighboring BS's control channel (neighbor i, where $i \neq h$, and $i = 1$ to N, and where N is the number of neighbors reported). RxLevNeigh_i_DB may be stored in the PDE 50 database during a calibration process.

[0042] In this example, correlation may be conducted over the received signal strengths of the NC-BSs relative to the NC-BS having the highest received signal strength, as observed by the wireless device. A comparison may include computing the difference between the parameters of the serving BS and the ith neighbor's parameters (i.e. (RxLevNeigh_h_WD - RxLevNeigh_i_WD) and (RxLevNeigh_h_DB - RxLevNeigh_i_DB)). Comparisons may also be conducted for any one, combination of or all of the measured parameters of the NC-BSs.

[0043] NM data may be modified to adjust the power levels received from the serving and/or neighboring cell (NC) base stations by an amount relative to the average signal strength of one or more NC base stations. Each signal power or parameter component of the NMR may also be modified by an average signal power or parameter level based on one or more of the measured NC signal power levels. The average received signal power level may be calculated a number of different ways, for example, the average of the two highest signal powers, the three highest powers, the average of all (N) signal powers, or an intermediary number between one or more of the measured NC

signal power components. Modifying the original NMR components may include subtracting or adding to the existing NMR power components by an amount based on the calculated average, or other various known functions.

[0044] To further illustrate modification of the NMR, consider a particular implementation where RxLevNeigh_avg_WD represents the average received signal strength based upon a number of control channel signal powers of neighboring BSs, as measured by the wireless device at an unknown location to be estimated. Let RxLevNeigh_i_WD represent the received signal strength of the ith neighbor's control channel signal power, and RxLevNeigh_avg_DB represent the average received signal strength of data stored during calibration, and computed based on the neighboring BSs, as measured by the wireless device and used in computing the average received signal strength. The same neighboring BSs may be used to represent the average received signal strength of the signal power levels received by the wireless device and for the average received signal strength of calibration data stored in the PDE 50 database. Let RxLevNeigh_i_DB represent the received signal strength of the ith neighbor's control channel stored in the PDE 50 database during the calibration process (i = 1 to N, where N is the number of neighbors reported).

[0045] In this example, a comparison may be conducted over the received signal strengths of the neighboring BSs relative to the average received signal strength computed for all neighboring BSs observed by the wireless device (*i.e.*, compare between (RxLevNeigh_avg_WD - RxLevNeigh_i_WD)) and for all neighbors previously measured by the wireless device (*i.e.*, compare between (RxLevNeigh_avg_DB -

RxLevNeigh_i_DB)). The average signal power level observed over all the neighbor signal power levels may be realized in absolute powers (mW) or in relative powers (dBm).

[0046] Any combination of the above NMR modification procedures may be performed to increase the accuracy of mobile station location estimates. Further, any number of or type of parameters may be utilized in any of the aforementioned procedures and the exemplary parameters of power level, signal strength, etc. should not limit the scope of the claims appended wherewith. Certain factors impacting the modification procedure selection process may include the specific type of cellular technology, the geographical terrain and/or environmental conditions, etc. Further, the present subject matter acknowledges that some NMR modification procedures may be best suited for outdoor location estimation, while others are better suited for indoor location estimation, and some even may be best for mixed (indoor & outdoor) location estimation.

[0047] For example, if the serving BS for a mobile station is known to be in an area where there are no buildings or obstructions then it may be prudent to leave the NM data unmodified or select the NMR modification procedure where the serving base station is used as the basis to calculate NMR modifications. Further, if the serving cell is in a geographical area with known large obstructions (*e.g.,* buildings, mountains etc.) then it may be prudent to use the NMR modification procedure that selects the NC base station having the highest signal power as the basis to calculate NMR modifications. Additionally, if the serving cell is in an area containing both outdoor and indoor facilities,

then it may be best to use the average of more than one NC signal power value as the basis to modify the NMR(s).

[0048] Regardless of the type of modification algorithm selected to modify the NM data, a margin of error may still be present when attempting to determine the precise location of a mobile station. Determining the amount of location error may be useful when estimating the likelihood of accurately locating a mobile station. A confidence measure may also be used to represent the accuracy of a mobile station's estimated location.

[0049] The value of a confidence measure may vary depending on the estimated accuracy of the location estimated. If estimated locations derived from mapping NM data to a given location, whether using a NUG or other form of a data source for comparison purposes, agree under any or all combinations, the respective confidence measure "C" may be considered high. A confidence measure may also be represented as a function that increases as the quantity of measured data correctly matches data associated with a final estimated location. An exemplary confidence measure or function may be represented as a fraction of all locations that are similar to the final estimated location, however, such an example should not limit the scope of the claims appended herewith.

[0050] After one or more of the data modification procedures have been calculated, respective confidence measures may be calculated to represent the likely accuracy of the modification procedures. Confidence measures may then be compared and the best one selected to represent the appropriate modification procedure to implement.

[0051] Certain estimated locations may be assigned weights by using a confidence measure as a weight to represent the probability of locating a mobile station at a given location. For example, confidence measures may be based on one or more calculated parameters, including, but not limited to: a probability density function (PDF), a joint PDF, Mahalanobis distance, distortion measure, ordered number parameter, timing advance (TA) parameter, mobile orientation etc. The calculated parameters may be derived from the NUG calibration data stored in the PDE 50 database. The parameters may be pre-stored in memory or may be calculated during a NMR to NUG comparison operation.

[0052] Probability density functions may be calculated based on an individual NC base station power level, or a set of multiple NC base station power levels. The calculated probability density function may be compared to the set of available NUGs (*i.e.,* NUGS 1-3 of FIG. 1) to determine a probability that the NM data matches a particular NUG location. A joint probability may also be calculated over a set of probabilities to further estimate the location of the mobile station. The results of the calculated PDF may be used in a number of estimation techniques to locate the mobile station.

[0053] Distortion measures may be determined at a particular location may be included in a NMR and used in a comparison operation to measure the difference in distortion between NUG data and NM data. The distortion measures may be used to estimate a location of a mobile station based on the results of the comparison.

[0054] A Mahalanobis distance may be an exemplary distortion measure and may utilized to assist in identifying and analyzing different patterns in a wireless communications environment. The Mahalanobis distance may also be useful in determining similarities between an unknown sample data set and a known data set.

[0055] Ordering number lists may also be used to organize parameters for comparison purposes. An ordering number list may be a list or table of data parameters organized in a particular order. The power levels may be listed in descending order and compared to similar parameters associated with a NUG(s). A threshold power level may be used to represent an acceptable amount of deviation between a comparison of power levels obtained from a NMR(s) and/or a NUG(s). If one or more power levels in the NMR(s) and the NUG(s) fall within an acceptable range of one another, the location of a mobile station may be measured with a corresponding degree of accuracy.

[0056] Each generated NMR may be used to provide an individual estimate of the mobile station's location. The PDE 50 may receive a number of NMRs over a period of time, a corresponding number of location estimates may be generated based on the number of NMRs received. These estimates may be combined in a statistical algorithm and may provide a more accurate location estimate than the individual NMRs.

[0057] Given a particular NMR or set of NMR(s) containing data collected outdoors, a selection procedure may be conducted to select the most appropriate modification procedure to use when modifying the NM data. Once one or more of the above described NMR modification procedures have been calculated, (*e.g.,* non-modification, serving cell power level, highest NC power level, average(s) of the NC

power levels, etc.) one or more of these calculations may be selected as an optimal solution to be used to modify the NMR.

[0058] One way to determine the optimal solution that should be used to modify the NMR is to calculate a confidence measure for each of the calculated modification procedures. Once the confidence measures have been calculated, the optimal solution may be selected as the modification procedure with the highest confidence measure. Alternatively, a location estimate may be made by weighting the individual solutions by the applicable confidence measure and combining the results into a single NMR solution.

[0059] Combining multiple NMR(s) may generate a location estimate with increased accuracy. When comparing NM data to a NUG, the grid point data that most closely matches the NM data may become the estimated location of the mobile station. In an alternative arrangement, interpolation may be used for determining a location that falls between two grid points to provide an even more accurate location estimate. Applying probabilistic weights, hypotheses and deriving confidence measures may increase the accuracy of the location estimates. Utilizing exemplary probabilistic measures, the estimated location of a mobile station may be determined within a particular degree of certainty. A similar approach may also be applied to select the appropriate NMR modification procedure to accommodate for varying conditions and other operational variables (*e.g.,* different air standards, varying environmental circumstances, etc.).

[0060] FIG. 2 illustrates a flow diagram 200 of a method to locate a mobile station. Observed network measurement data may be collected (operation 201). The observed

data would typically be the same or similar to the data in a network measurement report (NMR). The network measurement data represents at least one network characteristic observed by the mobile station operating at a particular location within a region. The NM data may be compared to calibration database data, where the calibration database data represents calibration data measured within the geographical area of the region (operation 202). The location of the mobile station may be estimated based on the comparison of the modified network measurement data and the calibration database data (operation 203).

[0061] FIG. 3 illustrates a flow diagram 300 of a method to locate a mobile station in an indoor environment. Calibration data samples are collected in an outdoor environment (operation 301). At least one attenuation variable may be applied to the calibration data sample to simulate an indoor environment (operation 302). The modified network measurement data sample may be applied to a mobile station location algorithm (operation 303). The mobile station may be then located in the indoor environment based on the mobile station location algorithm implementing the at least one modified calibration sample (operation 304).

[0062] FIG. 4 illustrates a flow diagram 400 of a method to locate a mobile station. NM data may be obtained to represent at least one network characteristic of the mobile station's serving base station and at least one second network characteristic of at least one of the mobile station's neighboring base stations (operation 401). The difference between the at least one first signal characteristic and the at least one second signal characteristic may be computed (operation 402). At least one signal characteristic of the

NM data may be adjusted based on the computed difference (operation 403). The mobile station may be then located based on the modified network measurement data (operation 404).

[0063] FIG. 5 illustrates a flow diagram 500 of a method to locate a mobile station. NM data may be obtained (operation 501), which represents at least one first network characteristic of the mobile station's serving base station, and at least one second and third network characteristic of the mobile station's at least two neighboring base stations. It may be then determined which base station has the highest signal power at a particular location (operation 502). The difference between the highest signal power at the particular location and the power levels at the particular location of the serving base station and the remaining neighboring base stations may be determined (operation 503). At least one signal characteristic of the NM data may be adjusted based on the computed differences (operation 504). The mobile station may then be located based on the modified NMR (operation 505).

[0064] FIG. 6 illustrates a flow diagram 600 of a method to locate a mobile station. A NMR may be obtained (operation 601), which represents at least one first signal characteristic of the mobile station's serving base station, and at least one second and third signal characteristics of the mobile station's at least two respective neighboring base stations. A difference may be computed between the at least one first signal characteristic of the mobile station's serving base station and the at least one second signal characteristic of at least one of the mobile station's neighboring base stations to determine a first solution (operation 602). It may then be determined which base station

has the highest signal power level at a particular location (operation 603). The difference between the highest signal power and the power levels of the serving base station and the remaining neighboring base stations may be determined as a second solution (operation 604). The neighboring base station having the lowest signal power level at the particular location may be determined (operation 605). An average signal power level intermediary to the difference between the highest signal power level and the lowest signal power level may be determined as a third solution (operation 606). It may then be determined which solution is a most optimal solution by comparing the three solutions (operation 607). The signal characteristic of the NM data may then be adjusted based on the most optimal solution (operation 608). The mobile station may then be located based on the adjusted NM data (operation 609).

[0065] FIG 7 illustrates an embodiment of the present subject matter. The method includes providing a database of previously-gathered calibration data for a predetermined region in a wireless network (operation 701). The database may be a collection of data from uniform or non-uniform grids that contain network measurements with associated location estimates. Network measurement data may be then observed and measured typically by a mobile station or any other wireless device (operation 703). The network measurement data may include received base station power and timing advance, as well as other network characteristics observable by a mobile station. The observed network measurement data may then be modified (operation 705). This modification may include applying an attenuation function to some or all of the network measurement data or converting absolute values into relative values. The modification may be performed by a

processor, microprocessor or ASICS. The modified network measurement data may then be compared to the calibration database in order to determine the location of the mobile station (operation 707). The comparison may be performed by a processor, microprocessor or ASICS.

[0066] FIG 8 is another illustration of an embodiment of the present subject matter. A database of previously-gathered calibration data for a predetermined region in a wireless network may be provided (operation 801). Observed network measurement data may be collected which includes a first signal characteristic from the mobile's serving transmitter (operation 803). The observed network measurement data may be modified as a function of the first signal characteristic (operation 805), for example the first signal characteristic may be received power and the modification may be a function of the relative value with respect to the received power. The modified network measurement data may be compared with the database of calibration data to determine the location of the mobile station (operation 807)

[0067] FIG 9 is an illustration of an embodiment of the present subject matter for determining a location of a mobile station. A database of calibration data for a region may be provided (901). Network measurement data from transmitters may be observed and collected including a signal characteristic from each of the transmitters (operation 903). An average value for the signal characteristic among the transmitters may be determined (operation 905). The average for the signal characteristic may be a weighted average. The observed network measurement data may be modified using the determined average value (operation 907) and the modified network measurement data may be

compared with the database of calibration data to determine the location of the mobile station (operation 909)

[0068] FIG 10 is an illustration of an embodiment of the present subject matter for determining a location of a mobile station. A database of previously-gathered outdoor calibration data for a predetermined region in a wireless network may be provided (operation 1001). Network measurement data may be observed and collected (operation 1003). The network measurement data may be compared with the database of calibration data to thereby determine a plurality of location estimates for the mobile station (operation 1005). The location estimates may be derived using modified, unmodified, limited signal characteristics, several signal characteristics, etc. For each location estimate, a confidence measure may be determined (operation 1007). A location may be determined based on the plurality of location estimates and their respective confidence measures (1009). For example, the location may be determined based on a weighted average, where the weights are directly proportional to the confidence measures.

[0069] The embodiments described above may be used in communication devices, such as, a base station, having varying configurations that include, but are not limited to: predetermined calibration data collected over varying terrain, different base station configurations, varying cellular communication protocols, etc.

[0070] 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 determining a location of a mobile station, comprising:

providing a database of previously-gathered calibration data for a predetermined region in a wireless network;

collecting observed network measurement data;

modifying said observed network measurement data; and

comparing said modified network measurement data with said database of calibration data to thereby determine the location of the mobile station.

2. The method of Claim 1 wherein said database comprises previously-gathered calibration data at one or more predetermined calibration points within said region.

3. The method of Claim 2 wherein said previously-gathered calibration data at one or more predetermined calibration points is combined to form previously-gathered calibration data for one or more non-uniform grid points within said region.

4. The method of Claim 1 wherein said database comprises previously-gathered calibration data for one or more non-uniform grid points within said region.

5. The method of Claim 1 wherein said observed network measurement data includes data collected at the mobile station.

6. The method of Claim 1 wherein said previously-gathered calibration data includes signal strength information measured at a predetermined calibration point within said region for a signal transmitted from a known location within or in proximity to said region.

7. The method of Claim 1 wherein said previously-gathered calibration data includes signal strength information measured by a receiver at a known location within or in proximity to said region for a signal transmitted from a predetermined calibration point within said region.

8. The method of Claim 1 wherein said previously-gathered calibration data includes round trip time information for signals traveling between a predetermined calibration point within said region and a known location within or in proximity to said region.

9. The method of Claim 1 wherein said previously-gathered calibration data includes time difference of arrival information for a first signal traveling between a first known location and a predetermined calibration point within said region and a second signal traveling between a second known location and said calibration point.

10. The method of Claim 1 wherein said previously-gathered calibration data includes information identifying a serving cell of a transmitter transmitting a signal received at a predetermined calibration point within said region.

11. The method of Claim 1 wherein said previously-gathered calibration data includes information identifying a serving sector of a transmitter transmitting a signal received at a predetermined calibration point within said region.

12. The method of Claim 1 wherein said previously-gathered calibration data includes information regarding a state of said wireless network.

13. The method of Claim 1 wherein said previously-gathered calibration data includes calibration data gathered at a predetermined calibration point within said region wherein said predetermined calibration point is not located within a structure.

14. The method of Claim 13 wherein said observed network measurement data is collected at a mobile station located within a structure.

15. A system for determining a location of a mobile station, comprising:

a database of previously-gathered calibration data for a predetermined region in a wireless network;

circuitry for collecting observed network measurement data;

circuitry for modifying said observed network measurement data; and

circuitry for comparing said modified network measurement data with said database of calibration data to thereby determine the location of the mobile station.

16. The system of Claim 15 wherein said database comprises previously-gathered calibration data at one or more predetermined calibration points within said region.

17. The system of Claim 16 further comprising circuitry for combining said previously-gathered calibration data at one or more predetermined calibration points to thereby form previously-gathered calibration data for one or more non-uniform grid points within said region.

18. The system of Claim 15 wherein said database comprises previously-gathered calibration data for one or more non-uniform grid points within said region.

19. The system of Claim 15 wherein said mobile station includes said circuitry for collecting observed network measurement data.

20. The system of Claim 15 further comprising circuitry for measuring signal strength at a predetermined calibration point within said region for a signal transmitted from a known location within or in proximity to said region.

21. The system of Claim 15 further comprising circuitry for measuring signal strength at a receiver at a known location within or in proximity to said region for a signal transmitted from a predetermined calibration point within said region.

22. The system of Claim 15 further comprising circuitry for determining round trip time for signals traveling between a predetermined calibration point within said region and a known location within or in proximity to said region.

23. The system of Claim 15 further comprising circuitry for determining time difference of arrival for a first signal traveling between a first known location and a predetermined calibration point within said region and a second signal traveling between a second known location and said calibration point.

24. The system of Claim 15 further comprising circuitry for identifying a serving cell of a transmitter transmitting a signal received at a predetermined calibration point within said region.

25. The system of Claim 15 further comprising circuitry for identifying a serving sector of a transmitter transmitting a signal received at a predetermined calibration point within said region.

26. The system of Claim 15 wherein said previously-gathered calibration data includes information regarding a state of said wireless network.

27. The system of Claim 15 wherein said previously-gathered calibration data includes calibration data gathered at a predetermined calibration point within said region wherein said predetermined calibration point is not located within a structure.

28. The system of Claim 27 wherein said observed network measurement data is collected at a mobile station located within a structure.

29. A method for determining a location of a mobile station, comprising:

providing a database of previously-gathered calibration data for a predetermined region in a wireless network, wherein said network includes a serving transmitter;

collecting observed network measurement data including a first signal characteristic from said serving transmitter;

modifying said observed network measurement data using said first signal characteristic; and

comparing said modified network measurement data with said database of calibration data to thereby determine the location of the mobile station.

30. The method of Claim 29 wherein said database comprises previously-gathered calibration data for one or more non-uniform grid points within said region.

31. The method of Claim 29 wherein said observed network measurement data includes data collected at the mobile station.

32. The method of Claim 29 wherein said previously-gathered calibration data includes calibration data gathered at a predetermined calibration point within said region wherein said predetermined calibration point is not located within a structure.

33. The method of Claim 32 wherein said observed network measurement data is collected at a mobile station located within a structure.

34. The method of Claim 29 wherein said first signal characteristic is signal strength.

35. The method of Claim 34 wherein said collecting observed network measurement data further includes collecting a second signal characteristic from a neighboring transmitter wherein said second signal characteristic is signal strength.

36. The method of Claim 35 wherein the modifying of said calibration data uses a difference between said first and second signal characteristics.

37. The method of Claim 29 wherein said first signal characteristic is signal strength of a control channel transmitted by said serving transmitter and received by said mobile station.

38. The method of Claim 37 wherein said collecting observed network measurement data further includes collecting a second signal characteristic from a neighboring transmitter wherein said second signal characteristic is signal strength of a control channel transmitted by said neighboring transmitter and received by said mobile station.

39. The method of Claim 29 wherein said observed network measurement data includes a data set comprising:

$[P_1,... P_n, TA]$

where:

P_1 represents the signal strength of said serving transmitter as measured at said mobile station,

P_n represents a signal strength of at a nth neighboring transmitter as measured at said mobile station, and

TA represents a timing advance parameter;

and wherein said modified network measurement data includes a data set comprising:

$[0,...P_1-P_{n-1}, P_1-P_n, TA]$

where:

0 represents a difference between P_1 and P_1,

P_1-P_{n-1} represents a difference between P_1 and P_{n-1}, and

P_1-P_n represents a difference between P_1 and P_n.

40. The method of Claim 39 wherein said first neighboring transmitter is not a member of said wireless network.

41. A method for determining a location of a mobile station, comprising:

providing a database of previously-gathered calibration data for a predetermined region in a wireless network, wherein said network includes a first transmitter and a second transmitter;

collecting observed network measurement data including a first signal characteristic from said first transmitter and a second signal characteristic from said second transmitter;

determining which of said first and second signal characteristics has a greater magnitude;

modifying said observed network measurement data using the greater magnitude signal characteristic; and

comparing said modified network measurement data with said database of calibration data to thereby determine the location of the mobile station.

42. The method of Claim 41 wherein said database comprises previously-gathered calibration data for one or more non-uniform grid points within said region.

43. The method of Claim 41 wherein said observed network measurement data includes data collected at the mobile station.

44. The method of Claim 41 wherein said previously-gathered calibration data includes calibration data gathered at a predetermined calibration point within said region wherein said predetermined calibration point is not located within a structure.

45. The method of Claim 44 wherein said observed network measurement data is collected at a mobile station located within a structure.

46. The method of Claim 44 wherein said first signal characteristic is signal strength.

47. The method of Claim 46 wherein said second signal characteristic is signal strength.

48. The method of Claim 47 wherein the modifying of said calibration data uses a difference between said first or second signal characteristics.

49. The method of Claim 47 wherein said first signal characteristic is signal strength of a control channel transmitted by said first transmitter and received by said mobile station.

50. The method of Claim 49 wherein said second signal characteristic is signal strength of a control channel transmitted by said second transmitter and received by said mobile station.

51. The method of Claim 41, wherein the observed network measurement data includes received signal strength of said transmitters as said mobile station.

52. The method of Claim 41 wherein said observed network measurement data includes a data set comprising:

$[P_1, P_2..., P_n, TA]$

where:

P_1 represents the signal strength of said first transmitter as measured at said mobile station,

P_2 represents a signal strength of said second transmitter as measured at said mobile station wherein $P_2 > P_1$,

P_n represents a signal strength of a nth transmitter as measured at said mobile station wherein $P_2 > P_n$, and

TA represents a timing advance parameter;

and wherein said modified network measurement data includes a data set comprising:

$[P_2\text{-}P_1, 0, P_2\text{-}P_n, TA]$

where:

$P_2\text{-}P_1$ represents a difference between P_2 and P_1,

0 represents a difference between P_2 and P_2, and

$P_2\text{-}P_n$ represents a difference between P_2 and P_n.

53. The method of Claim 52 wherein said first transmitter is a serving transmitter for said mobile station and said second and third transmitters are neighboring transmitters.

54. The method of Claim 52 wherein said third transmitter is not a member of said wireless network.

55. A method for determining a location of a mobile station, comprising:

providing a database of previously-gathered calibration data for a predetermined region in a wireless network;

collecting observed network measurement data from each of a plurality of transmitters including a signal characteristic from each one of said plural transmitters;

determining an average value for select ones of said signal characteristics;

modifying said observed network measurement data using said average value; and

comparing said modified network measurement data with said database of calibration data to thereby determine the location of the mobile station.

56. The method of Claim 55 wherein said database comprises previously-gathered calibration data for one or more non-uniform grid points within said region.

57. The method of Claim 55 wherein said observed network measurement data includes data collected at the mobile station.

58. The method of Claim 55 wherein said previously-gathered calibration data includes calibration data gathered at a predetermined calibration point within said region wherein said predetermined calibration point is not located within a structure.

59. The method of Claim 55 wherein said observed network measurement data is collected at a mobile station located within a structure.

60. The method of Claim 55 wherein said signal characteristic is signal strength.

61. The method of Claim 60 wherein the modifying of said calibration data uses a difference between said average value and said signal characteristic for a first one of said plural transmitters.

62. The method of Claim 55 wherein said signal characteristic is signal strength of a control channel.

63. A The method of Claim 55, wherein the observed network measurement data includes received signal strength of said transmitters as said mobile station.

64. The method of Claim 55 wherein said observed network measurement data includes a data set comprising:

$[P_1, P_2, P_3, TA]$

where:

P_1 represents the signal strength of a first one of said plural transmitters as measured at said mobile station,

P_2 represents a signal strength of a second one of said plural transmitters as measured at said mobile station wherein $P_2 > P_1$,

P_3 represents a signal strength of a third one of said plural transmitters as measured at said mobile station wherein $P_2 > P_3$, and

TA represents a timing advance parameter;

and wherein said modified network measurement data includes a data set comprising:

$[P_1\text{-}P_{AVG}, P_2\text{-}P_{AVG}, P_3\text{-}P_{AVG}, TA]$

where:

P_{AVG} represents an average value of P_1, P_2, and P_3,

$P_1\text{-}P_{AVG}$ represents a difference between P_1 and P_{AVG},

$P_2\text{-}P_{AVG}$ represents a difference between P_2 and P_{AVG},

$P_3\text{-}P_{AVG}$ represents a difference between P_3 and P_{AVG},

65. The method of Claim 64 wherein said first transmitter is a serving transmitter for said mobile station and said second and third transmitters are neighboring transmitters.

66. The method of Claim 55 wherein at least one of said plurality of transmitters is not a member of said wireless network.

67. A method for determining a location of a mobile station, comprising:

providing a database of previously-gathered outdoor calibration data for a predetermined region in a wireless network;

collecting network measurement data;

comparing said network measurement data with said database of calibration data to thereby determine a plurality of location estimate of the mobile station

determining a confidence measure for each of the plurality of location estimates;

determining the location of the mobile station based on the plurality of location estimates and the respective confidence measures.

68. The method of Claim 67, wherein the step of determining the location based on the plurality of location estimates and the respective confidence measures comprises selecting the location estimate having the highest respective confidence measure as the location of the mobile station.

69. The method of Claim 67, wherein the step of determining the location based on the plurality of location estimates and their respective confidence measures comprises weighing the plurality location estimates based on their respective confidence measures and obtaining a weighted average as the location of the mobile.

70. The method of 67, wherein the confidence measures comprises one or more of the group consisting of a pdf, the Mahalanobis distance, and a distortion measure.

71. The method of Claim 67, wherein the step of collecting network propagation data further comprises modifying the network propagation data.

72. The method of Claim 67, wherein the step of comparing said network propagation data with said database of calibration data to thereby determine a plurality of

location estimate of the mobile station, further comprises modifying said calibration data prior to the comparison.

73. The method of Claim 72, wherein the step of comparing said network propagation data with said database of calibration data to thereby determine a plurality of location estimate of the mobile station, further comprises modifying said calibration data prior to the comparison.

ABSTRACT

A method of modifying calibration data used to geo-locate a mobile station located in an indoor environment is disclosed. When a mobile station is located indoors, the signal strength of signals received and/or transmitted by the mobile station have the tendency to be lower than the strength of the signals received by a mobile station located outdoors. As a result of these lower signal strengths, geo-location efforts which rely on signal strengths may result in unsatisfactory location accuracy. Modifying pre-existing calibration data obtained outdoors may provide a way to simulate indoor calibration data characteristics.

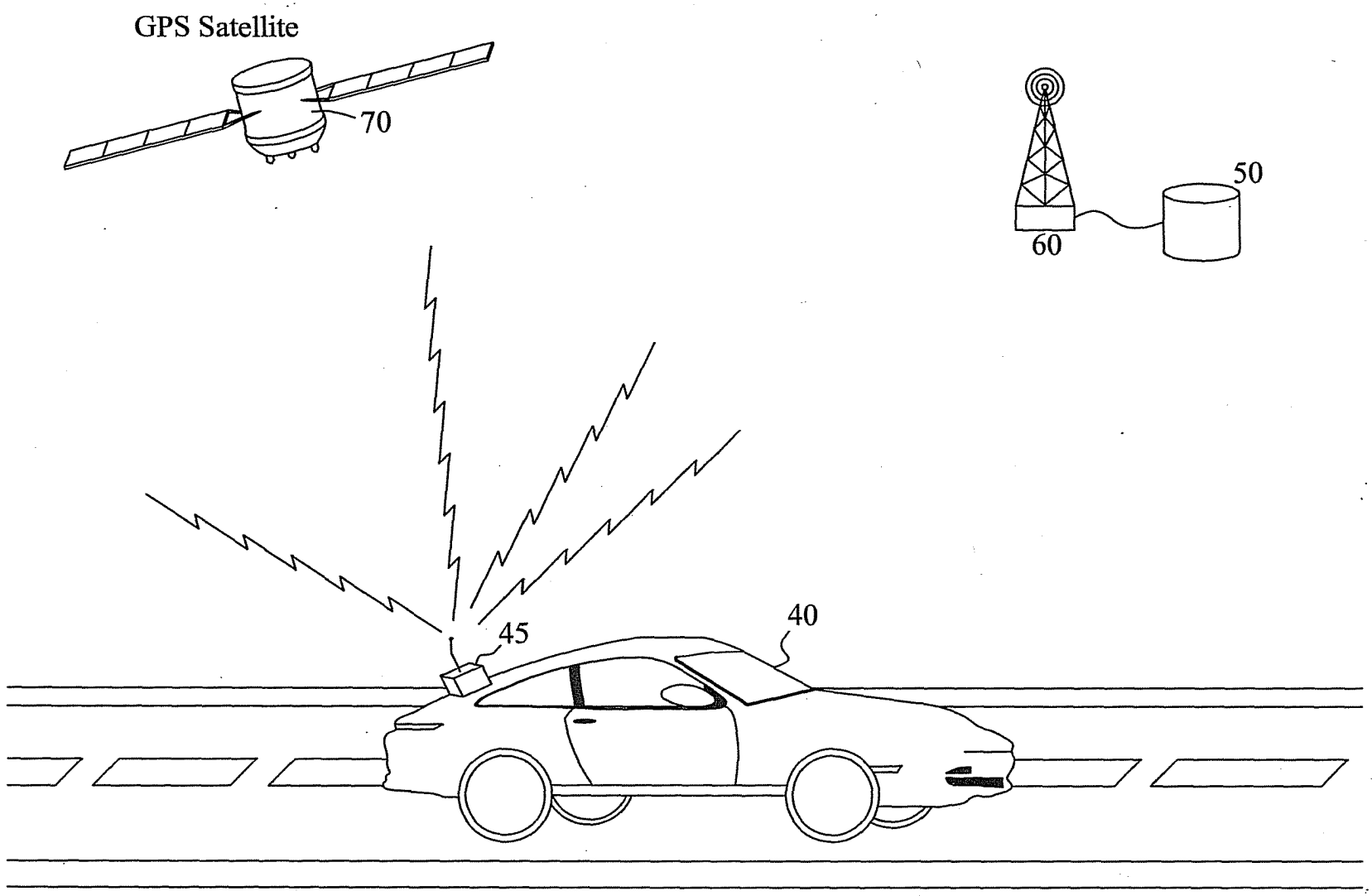

Figure 1

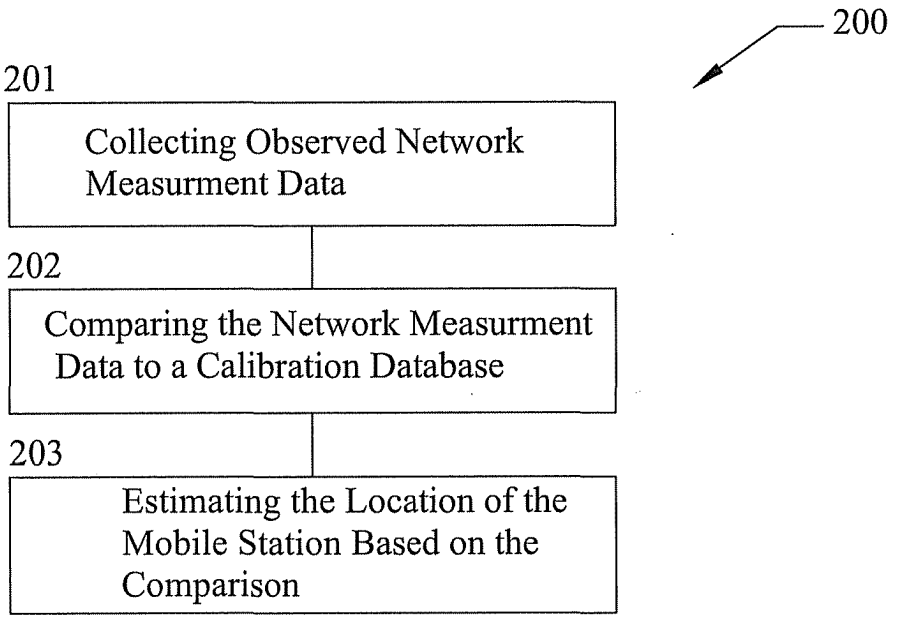
200
201
Collecting Observed Network Measurment Data
202
Comparing the Network Measurment Data to a Calibration Database
203
Estimating the Location of the Mobile Station Based on the Comparison

Figure 2

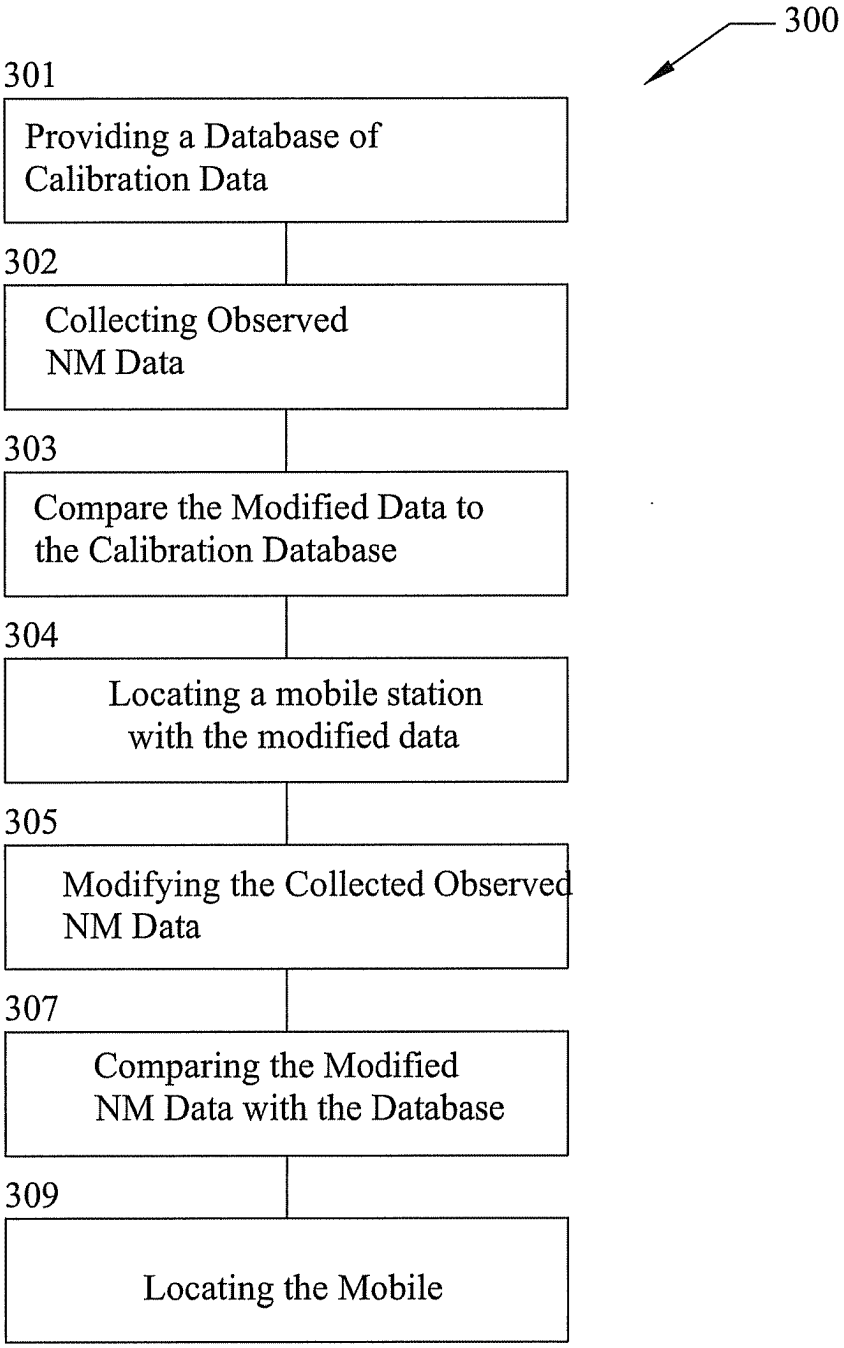
300
301
Providing a Database of Calibration Data
302
Collecting Observed NM Data
303
Compare the Modified Data to the Calibration Database
304
Locating a mobile station with the modified data
305
Modifying the Collected Observed NM Data
307
Comparing the Modified NM Data with the Database
309
Locating the Mobile

Figure 3

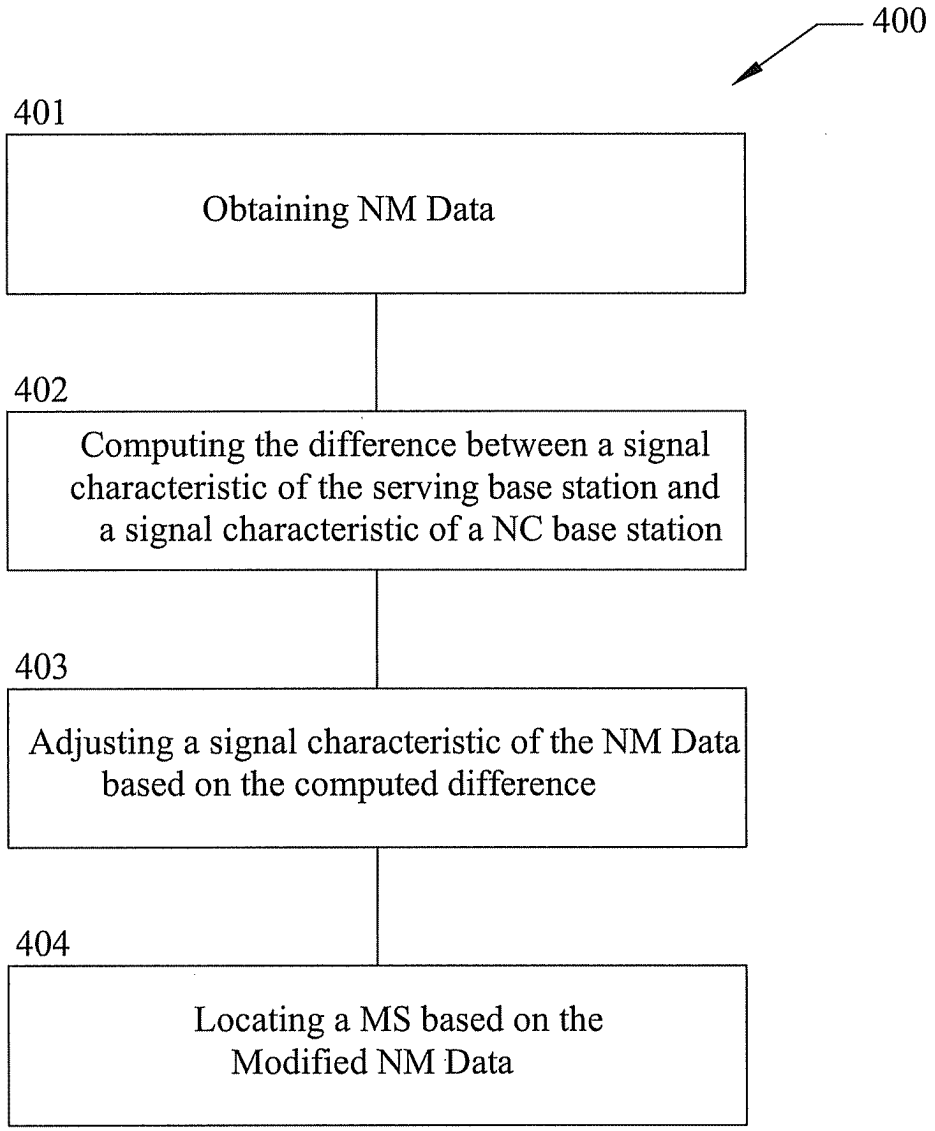
400
401
Obtaining NM Data
402
Computing the difference between a signal characteristic of the serving base station and a signal characteristic of a NC base station
403
Adjusting a signal characteristic of the NM Data based on the computed difference
404
Locating a MS based on the Modified NM Data

Figure 4

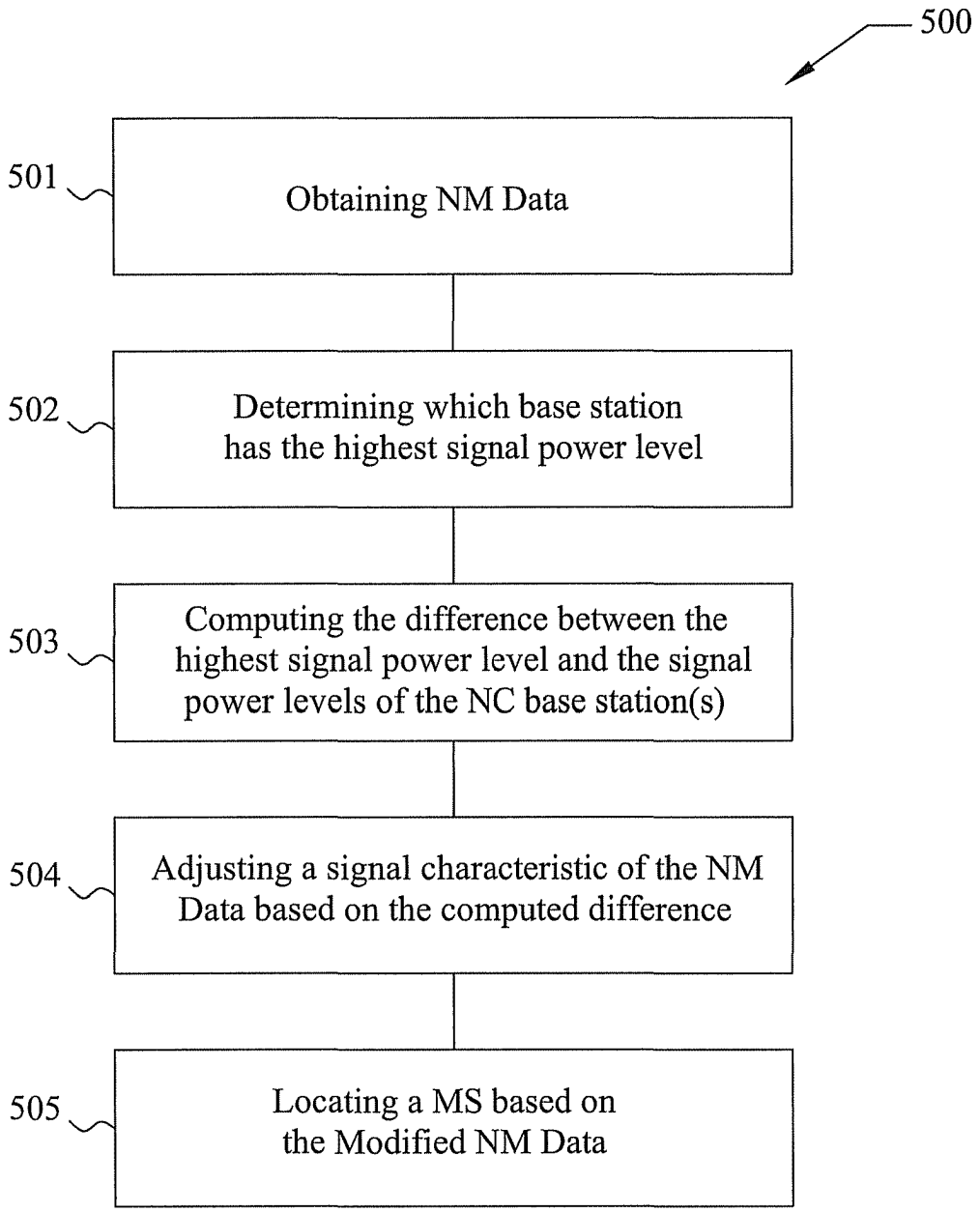
500
501
Obtaining NM Data
502
Determining which base station has the highest signal power level
503
Computing the difference between the highest signal power level and the signal power levels of the NC base station(s)
504
Adjusting a signal characteristic of the NM Data based on the computed difference
505
Locating a MS based on the Modified NM Data

Figure 5

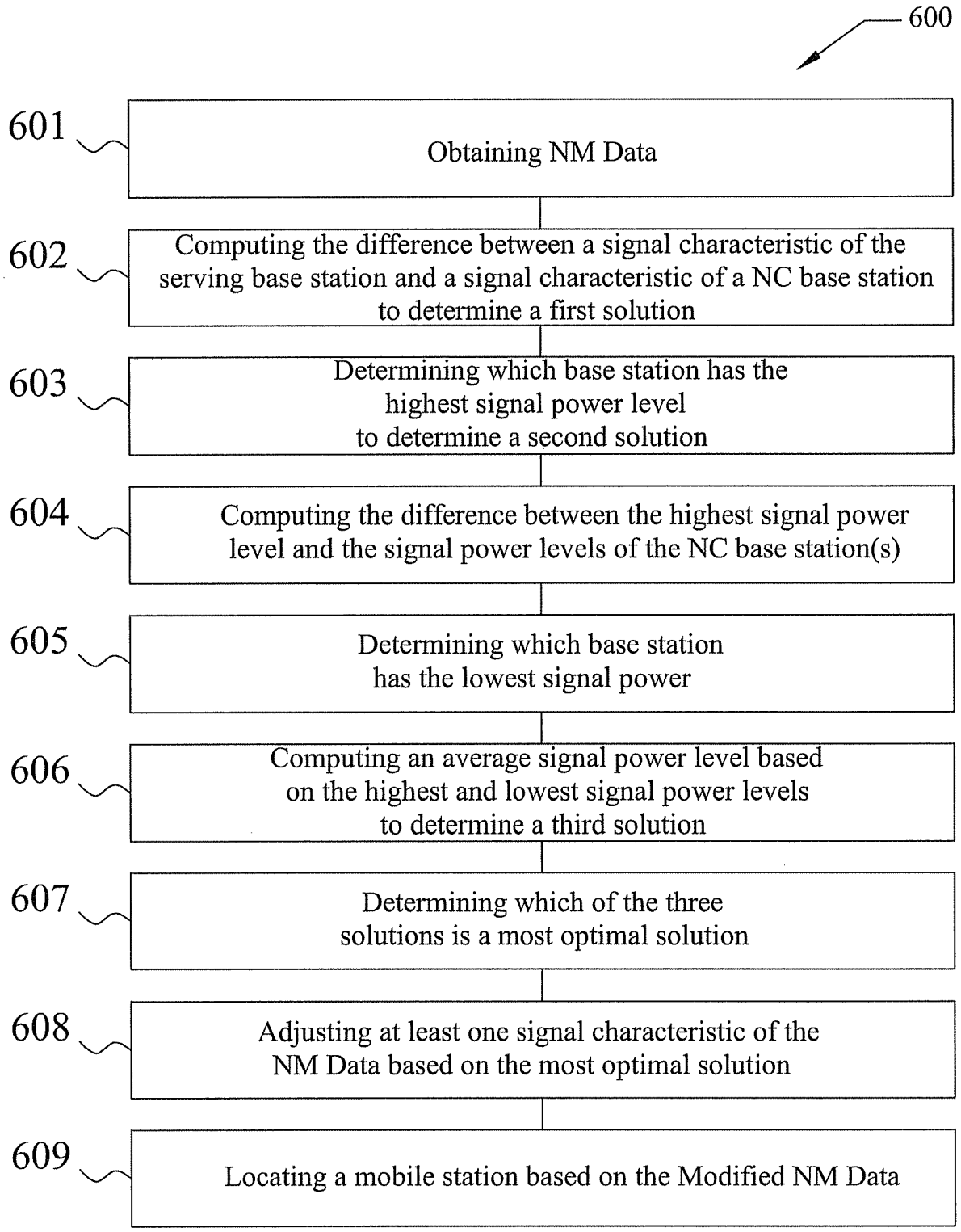
600
601
Obtaining NM Data
602
Computing the difference between a signal characteristic of the serving base station and a signal characteristic of a NC base station to determine a first solution
603
Determining which base station has the highest signal power level to determine a second solution
604
Computing the difference between the highest signal power level and the signal power levels of the NC base station(s)
605
Determining which base station has the lowest signal power
606
Computing an average signal power level based on the highest and lowest signal power levels to determine a third solution
607
Determining which of the three solutions is a most optimal solution
608
Adjusting at least one signal characteristic of the NM Data based on the most optimal solution
609
Locating a mobile station based on the Modified NM Data

Figure 6

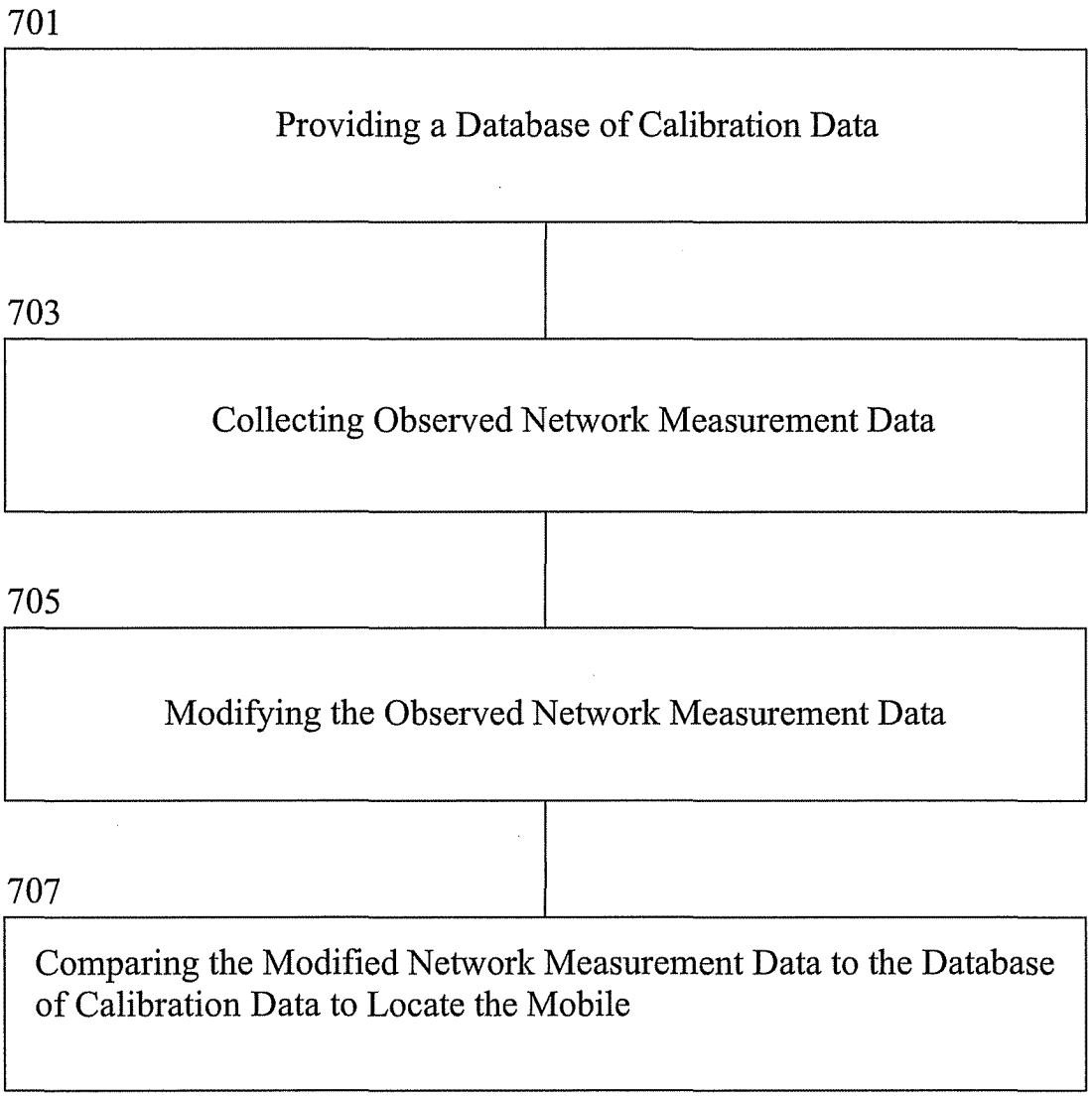
701
Providing a Database of Calibration Data
703
Collecting Observed Network Measurement Data
705
Modifying the Observed Network Measurement Data
707
Comparing the Modified Network Measurement Data to the Database of Calibration Data to Locate the Mobile

Figure 7

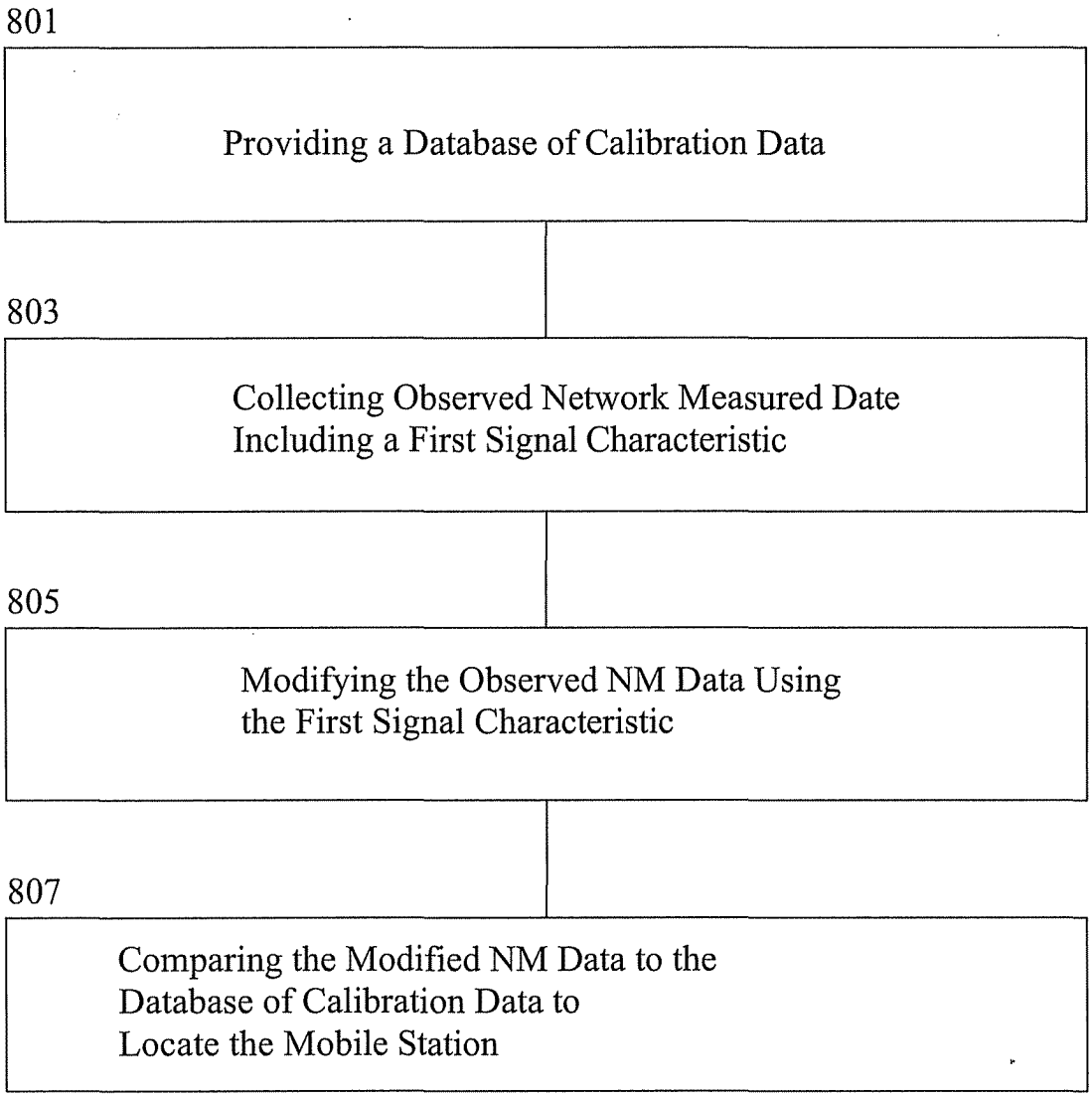
801
Providing a Database of Calibration Data
803
Collecting Observed Network Measured Date Including a First Signal Characteristic
805
Modifying the Observed NM Data Using the First Signal Characteristic
807
Comparing the Modified NM Data to the Database of Calibration Data to Locate the Mobile Station

Figure 8

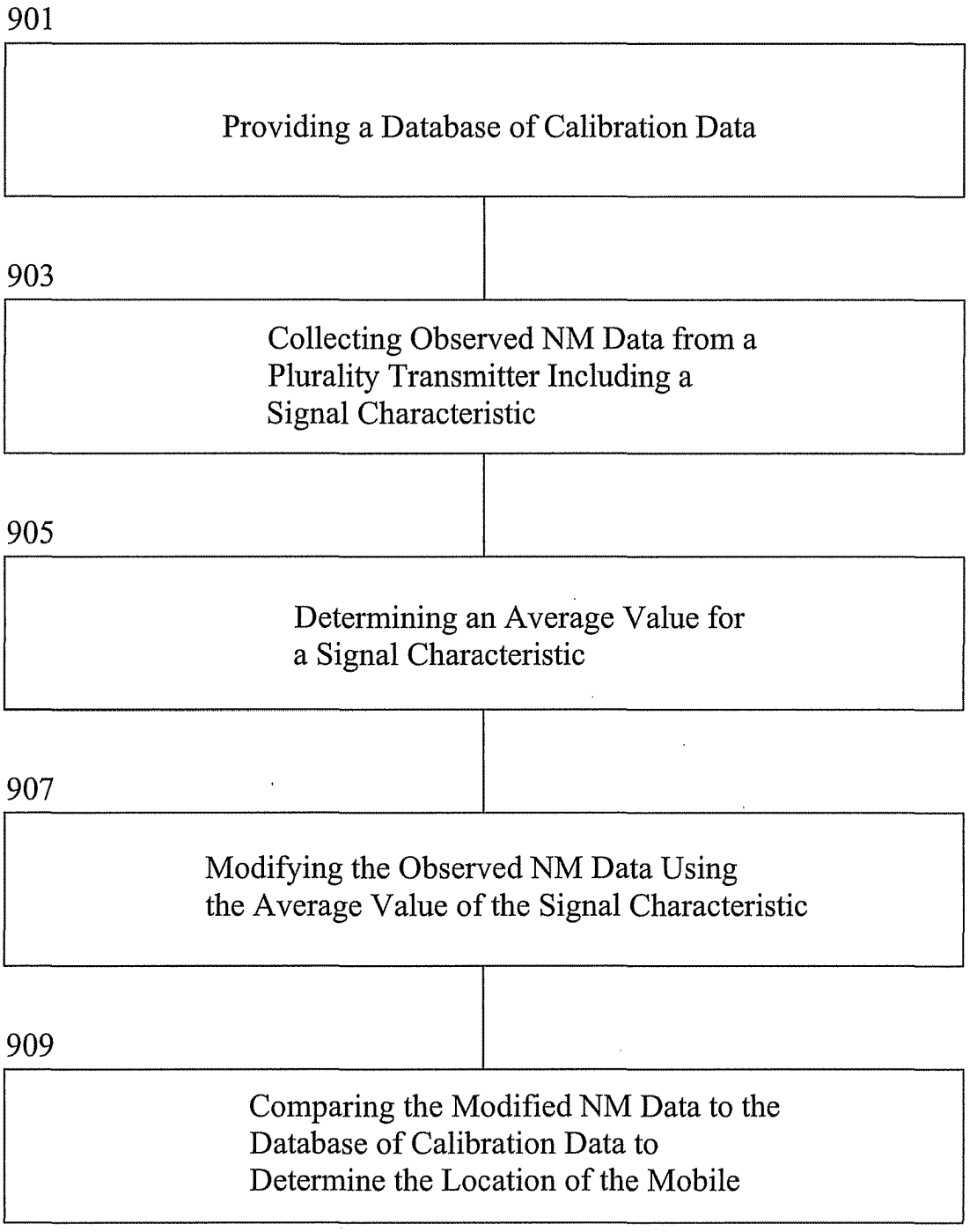
901
Providing a Database of Calibration Data
903
Collecting Observed NM Data from a Plurality Transmitter Including a Signal Characteristic
905
Determining an Average Value for a Signal Characteristic
907
Modifying the Observed NM Data Using the Average Value of the Signal Characteristic
909
Comparing the Modified NM Data to the Database of Calibration Data to Determine the Location of the Mobile

Figure 9

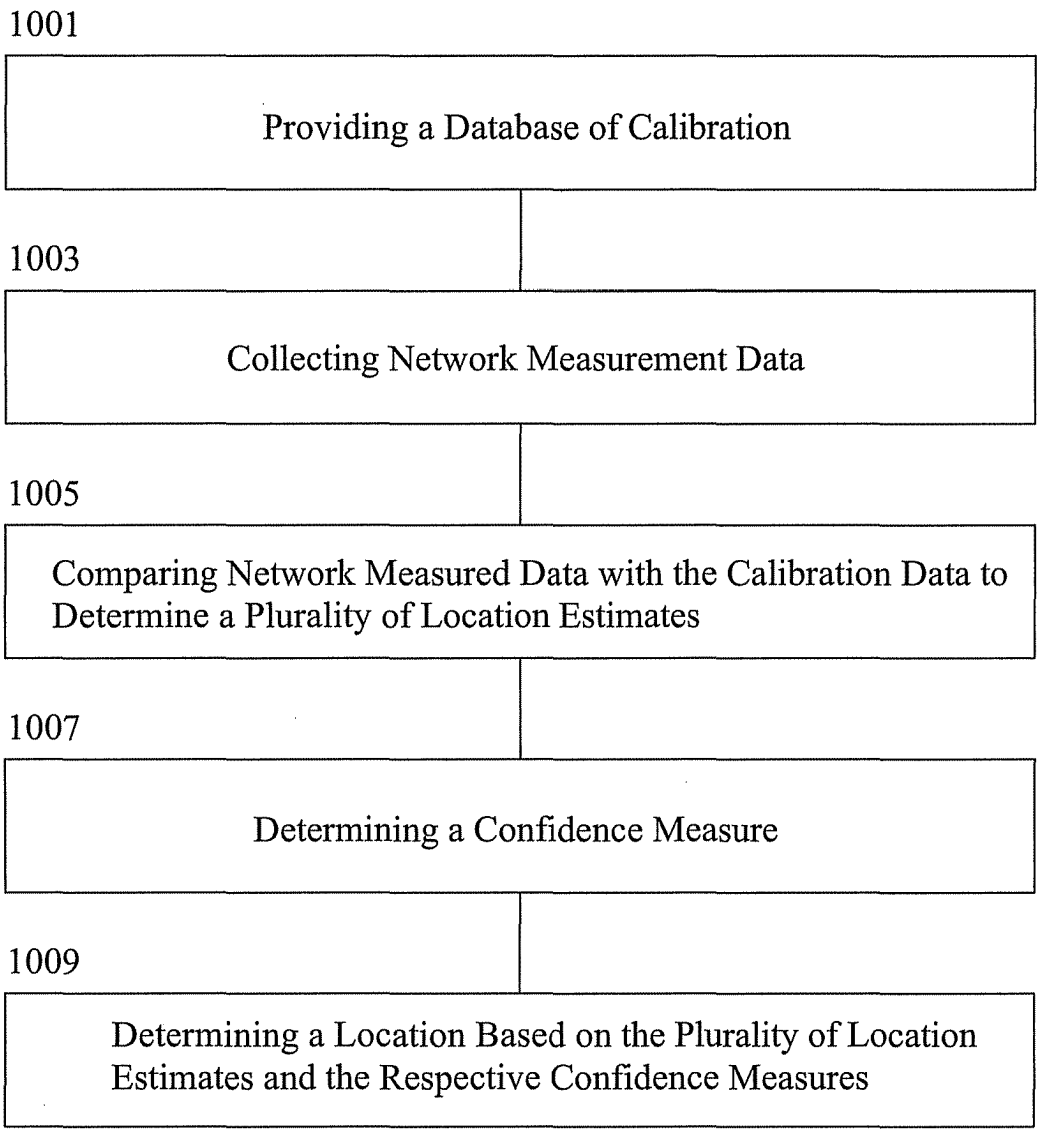
1001
Providing a Database of Calibration
1003
Collecting Network Measurement Data
1005
Comparing Network Measured Data with the Calibration Data to Determine a Plurality of Location Estimates
1007
Determining a Confidence Measure
1009
Determining a Location Based on the Plurality of Location Estimates and the Respective Confidence Measures

Figure 10

Electronic Patent Application Fee Transmittal

Application Number:	
Filing Date:	
Title of Invention:	METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT
First Named Inventor/Applicant Name:	Martin ALLES
Filer:	Mark Charles Comtois/Jacquetta McBee
Attorney Docket Number:	AND01 082

Filed as Large Entity

Utility Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Utility application filing	1011	1	310	310
Utility Search Fee	1111	1	510	510
Utility Examination Fee	1311	1	210	210
Pages:				
Claims:				
Claims in excess of 20	1202	53	50	2650
Independent claims in excess of 3	1201	3	210	630
Miscellaneous-Filing:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Miscellaneous:				
			Total in USD ($)	**4310**

Electronic Acknowledgement Receipt

EFS ID:	2818261
Application Number:	12026333
International Application Number:	
Confirmation Number:	2910
Title of Invention:	METHOD TO MODIFY CALIBRATION DATA USED TO LOCATE A MOBILE UNIT
First Named Inventor/Applicant Name:	Martin ALLES
Customer Number:	39290
Filer:	Mark Charles Comtois/Jacquetta McBee
Filer Authorized By:	Mark Charles Comtois
Attorney Docket Number:	AND01 082
Receipt Date:	05-FEB-2008
Filing Date:	
Time Stamp:	17:45:01
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Deposit Account
Payment was successfully received in RAM	$4310
RAM confirmation Number	2868
Deposit Account	041679
Authorized User	

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 1.21 (Miscellaneous fees and charges)

File Listing:

Document Number	Document Description	File Name	File Size(Bytes) /Message Digest	Multi Part /.zip	Pages (if appl.)
1		AND01_082_NEWAPPLICATION.pdf	5216321 c76696c000d1a1db6c0773156e2bc9299078da3b	yes	57

Multipart Description/PDF files in .zip description

Document Description	Start	End
Transmittal of New Application	1	1
Fee Worksheet (PTO-06)	2	2
Application Data Sheet	3	6
Specification	7	32
Claims	33	46
Abstract	47	47
Drawings-only black and white line drawings	48	57

Warnings:

Information:

2	Fee Worksheet (PTO-06)	fee-info.pdf	8582 a591e7c7d18fdbe4c5a352e98c1a425107031168	no	2

Warnings:

Information:

Total Files Size (in bytes):	5224903

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.

PTO/SB/05 (07-07)
Approved for use through 06/30/2010. OMB 0651-0032
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.

UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	AND01 082
First Inventor	Martin ALLES
Title	Method to Modify Calibration Data..
Express Mail Label No.	

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: **Commissioner for Patents**
P.O. Box 1450
Alexandria VA 22313-1450

1. [✓] **Fee Transmittal Form** (e.g., PTO/SB/17)
   (Submit an original and a duplicate for fee processing)
2. [ ] **Applicant claims small entity status.** See 37 CFR 1.27.
3. [✓] **Specification** [*Total Pages* 41]
   Both the claims and abstract must start on a new page
   (For information on the preferred arrangement, see MPEP 608.01(a))
4. [✓] **Drawing(s)** (*35 U.S.C. 113*) [*Total Sheets* 10]
5. **Oath or Declaration** [*Total Sheets* _____]
   a. [ ] Newly executed (original or copy)
   b. [ ] A copy from a prior application (37 CFR 1.63(d))
   (for continuation/divisional with Box 18 completed)
   i. [ ] DELETION OF INVENTOR(S)
   Signed statement attached deleting inventor(s) name in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).
6. [✓] **Application Data Sheet.** See 37 CFR 1.76
7. [ ] **CD-ROM or CD-R** in duplicate, large table or Computer Program *(Appendix)*
   [ ] Landscape Table on CD
8. **Nucleotide and/or Amino Acid Sequence Submission**
   (if applicable, items a. – c. are required)
   a. [ ] Computer Readable Form (CRF)
   b. Specification Sequence Listing on:
      i. [ ] CD-ROM or CD-R (2 copies); or
      ii. [ ] Paper
   c. [ ] Statements verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

9. [ ] **Assignment Papers** (cover sheet & document(s))
   Name of Assignee _____
10. [ ] **37 CFR 3.73(b) Statement** *(when there is an assignee)* [ ] **Power of Attorney**
11. [ ] **English Translation Document** *(if applicable)*
12. [ ] **Information Disclosure Statement** (PTO/SB/08 or PTO-1449)
    [ ] Copies of citations attached
13. [ ] **Preliminary Amendment**
14. [ ] **Return Receipt Postcard** (MPEP 503)
    (Should be specifically itemized)
15. [ ] **Certified Copy of Priority Document(s)**
    (if foreign priority is claimed)
16. [ ] **Nonpublication Request** under 35 U.S.C. 122(b)(2)(B)(i). Applicant must attach form PTO/SB/35 or equivalent.
17. [ ] Other: _____

18. If a CONTINUING APPLICATION, *check appropriate box, and supply the requisite information below and in the first sentence of the specification following the title, or in an Application Data Sheet under 37 CFR 1.76:*

[ ] Continuation [ ] Divisional [ ] Continuation-in-part (CIP) of prior application No.: .....

Prior application information: *Examiner* _____ *Art Unit:* _____

19. CORRESPONDENCE ADDRESS

[✓] The address associated with Customer Number: 39290 *OR* [ ] Correspondence address below

Name	Duane Morris LLP				
Address	505 9th Street, N.W., Suite 1000				
City	Washington	State	D.C.	Zip Code	20004-2166
Country	USA	Telephone	202.776-7800	Email	

Signature	/mcc/	Date	05 February 2008
Name (Print/Type)	Mark C. Comtois	Registration No. (Attorney/Agent)	46,285

This collection of information is required by 37 CFR 1.53(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.

PTO/SB/17 (10-07)
Approved for use through 06/30/2010. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
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Effective on 12/08/2004.
Fees pursuant to the Consolidated Appropriations Act, 2005 (H.R. 4818).

FEE TRANSMITTAL
For FY 2008

☐ Applicant claims small entity status. See 37 CFR 1.27

TOTAL AMOUNT OF PAYMENT ($) 4,310.00

Complete if Known	
Application Number	New Application
Filing Date	05 February 2008
First Named Inventor	Martin ALLES
Examiner Name	Unassigned
Art Unit	Unassigned
Attorney Docket No.	AND01 082

METHOD OF PAYMENT (check all that apply)

☐ Check ☐ Credit Card ☐ Money Order ☐ None ☐ Other (please identify): _____

☑ Deposit Account Deposit Account Number: 04-1679 Deposit Account Name: Duane Morris LLP

For the above-identified deposit account, the Director is hereby authorized to: (check all that apply)

☑ Charge fee(s) indicated below ☐ Charge fee(s) indicated below, **except for the filing fee**

☑ Charge any additional fee(s) or underpayments of fee(s) under 37 CFR 1.16 and 1.17 ☑ Credit any overpayments

WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

FEE CALCULATION

1. BASIC FILING, SEARCH, AND EXAMINATION FEES

	FILING FEES		SEARCH FEES		EXAMINATION FEES		
Application Type	**Fee ($)**	**Small Entity Fee ($)**	**Fee ($)**	**Small Entity Fee ($)**	**Fee ($)**	**Small Entity Fee ($)**	**Fees Paid ($)**
Utility	310	155	510	255	210	105	1,030.00
Design	210	105	100	50	130	65	
Plant	210	105	310	155	160	80	
Reissue	310	155	510	255	620	310	
Provisional	210	105	0	0	0	0	

2. EXCESS CLAIM FEES

Fee Description	**Fee ($)**	**Small Entity Fee ($)**
Each claim over 20 (including Reissues)	50	25
Each independent claim over 3 (including Reissues)	210	105
Multiple dependent claims	370	185

Multiple Dependent Claims **Fee ($)** _____ **Fee Paid ($)** _____

Total Claims		**Extra Claims**		**Fee ($)**		**Fee Paid ($)**
73	- 20 or HP =	53	x	50.00	=	2,650.00

HP = highest number of total claims paid for, if greater than 20.

Indep. Claims		**Extra Claims**		**Fee ($)**		**Fee Paid ($)**
6	- 3 or HP =	3	x	210.00	=	630.00

HP = highest number of independent claims paid for, if greater than 3.

3. APPLICATION SIZE FEE

If the specification and drawings exceed 100 sheets of paper (excluding electronically filed sequence or computer listings under 37 CFR 1.52(e)), the application size fee due is $260 ($130 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).

Total Sheets		**Extra Sheets**		**Number of each additional 50 or fraction thereof**		**Fee ($)**		**Fee Paid ($)**
51	- 100 =	0	/ 50 =	0 (round **up** to a whole number)	x	0.00	=	0.00

4. OTHER FEE(S) **Fees Paid ($)**

Non-English Specification, $130 fee (no small entity discount) _____

Other (e.g., late filing surcharge): _____ _____

SUBMITTED BY

Signature	/mcc/	Registration No. (Attorney/Agent) 46,285	Telephone 202-776-7800
Name (Print/Type)	Mark C. Comtois		Date 05 February 2008

This collection of information is required by 37 CFR 1.136. 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 30 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.**

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Filing Date: 02/05/08

Approved for use through 7/31/2006. OMB 0651-0032
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PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number: 12/026,333

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	310
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A			N/A	510
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A			N/A	210
TOTAL CLAIMS (37 CFR 1.16(i))	73 minus 20 =	53	X$ 25		OR	X$50	2650
INDEPENDENT CLAIMS (37 CFR 1.16(h))	6 minus 3 =	* 3	X$100			X$210	630
APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $250 ($125 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).						
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))			185			370	
			TOTAL	0		TOTAL	4310

* If the difference in column 1 is less than zero, enter "0" in column 2.

APPLICATION AS AMENDED – PART II

AMENDMENT A

	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE ($)	SMALL ENTITY ADDI-TIONAL FEE ($)	OR	OTHER THAN SMALL ENTITY RATE ($)	OTHER THAN SMALL ENTITY ADDI-TIONAL FEE ($)
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))					N/A		OR	N/A	
					TOTAL ADD'T FEE		OR	TOTAL ADD'T FEE	

AMENDMENT B

	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE ($)	ADDI-TIONAL FEE ($)	OR	RATE ($)	ADDI-TIONAL FEE ($)
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))					N/A		OR	N/A	
					TOTAL ADD'T FEE		OR	TOTAL ADD'T 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 number found in the appropriate box in column 1.

This collection of information is required by 37 CFR 1.16. 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, 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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