US008406753B2

(12) **United States Patent**
Alles et al.

(10) **Patent No.: US 8,406,753 B2**
(45) **Date of Patent: Mar. 26, 2013**

(54) **SYSTEM AND METHOD FOR GENERATING A LOCATION ESTIMATE USING UNIFORM AND NON-UNIFORM GRID POINTS**

(75) Inventors: **Martin Alles**, Vienna, VA (US); **John Carlson**, Dulles, VA (US); **George Maher**, Herndon, VA (US); **Selcuk Mazlum**, Leesburg, VA (US)

(73) Assignee: **Andrew LLC**, Hickory, NC (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1135 days.

(21) Appl. No.: **12/026,480**

(22) Filed: **Feb. 5, 2008**

(65) **Prior Publication Data**

US 2008/0188237 A1 Aug. 7, 2008

Related U.S. Application Data

(60) Provisional application No. 60/899,379, filed on Feb. 5, 2007.

(51) **Int. Cl.**
H04W 4/00 (2009.01)
H04W 24/00 (2009.01)

(52) **U.S. Cl.** **455/422.1**; 455/425

(58) **Field of Classification Search** 455/422.1, 455/423, 425, 433, 404.2, 456.1–456.3, 435.1–435.5; 340/870.04–870.05, 988–989, 991, 995.18, 340/995.25, 423.19; 342/357.2–357.25, 342/357.62; 702/85, 94–95, 150
See application file for complete search history.

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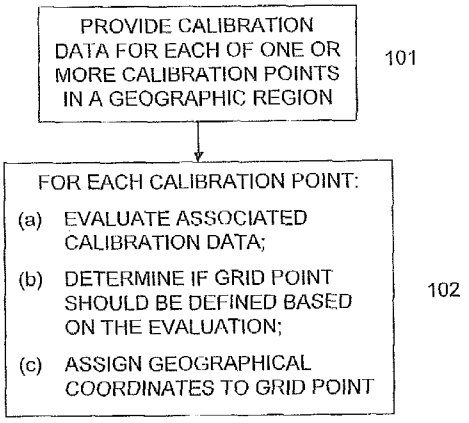
Primary Examiner — Melody Mehrpour
Assistant Examiner — Emem Stephen
(74) *Attorney, Agent, or Firm* — Duane Morris LLP

(57) **ABSTRACT**

The location of a wireless mobile device may be estimated using, at least in part, one or more pre-existing Network Measurement Reports ("NMRs") which include calibration data for a number of locations within a geographic region. The calibration data for these locations is gathered and analyzed so that particular grid points within the geographic region can be determined and associated with a particular set or sets of calibration data from, for example, one or more NMRs. Sets of grid points may be evaluated as a function of parameters of the calibration data, and a set of grid points may be selected as a function of a predetermined criteria. The location of a mobile device in the geographic region may then be determined as a function of the predetermined criteria.

57 Claims, 72 Drawing Sheets



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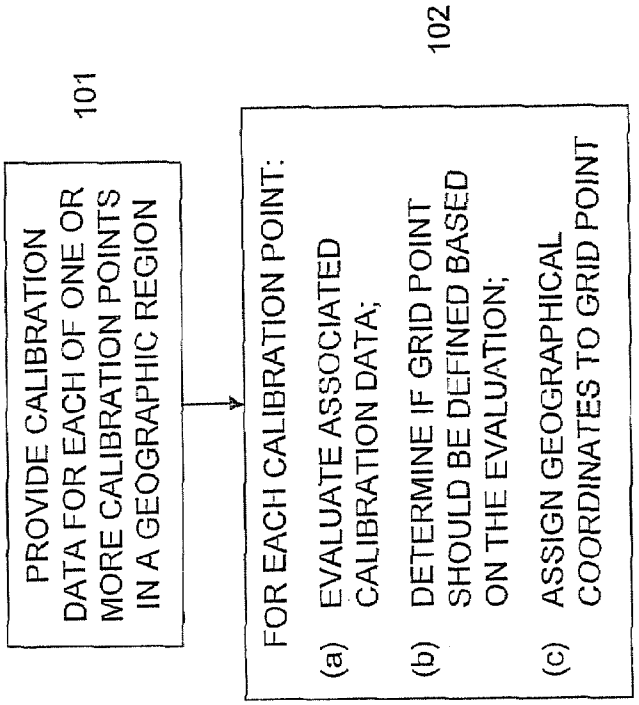

PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
101
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
102

FIGURE 1

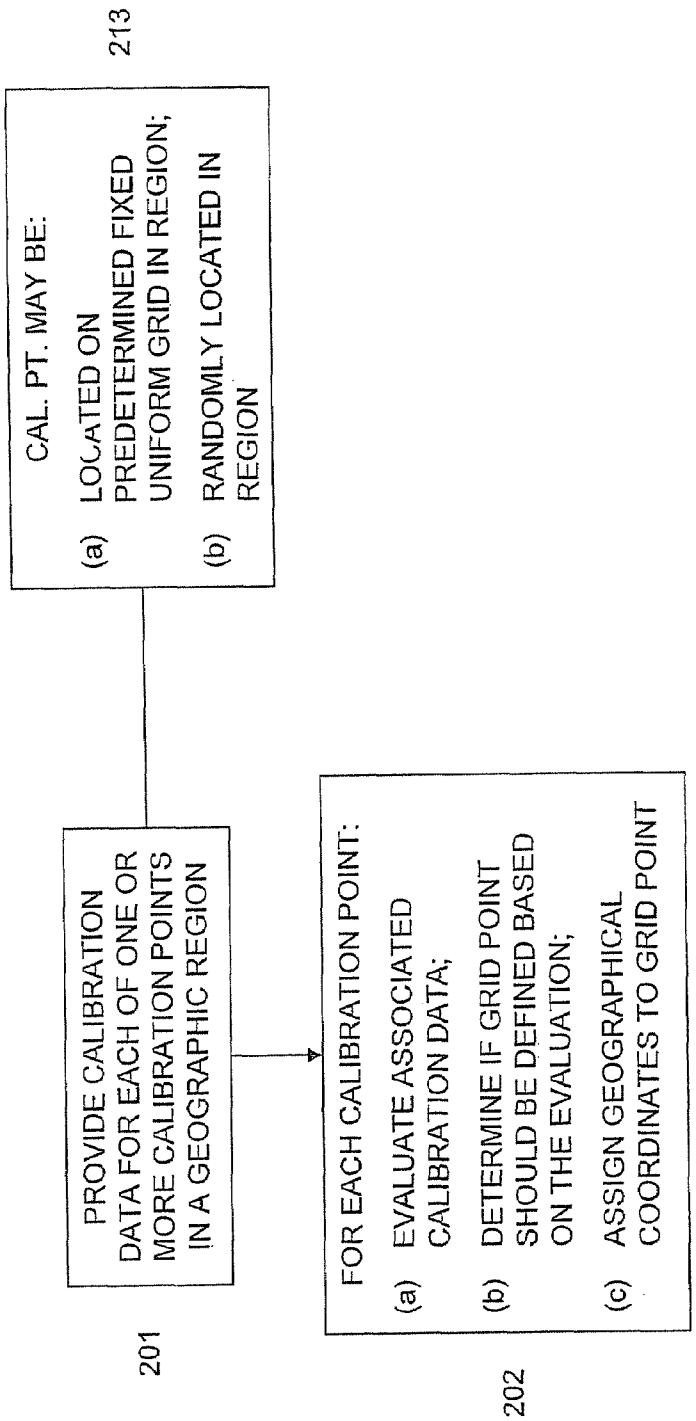

PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
201
CAL. PT. MAY BE:
(a) LOCATED ON PREDETERMINED FIXED UNIFORM GRID IN REGION;
(b) RANDOMLY LOCATED IN REGION
213
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
202

FIGURE 2

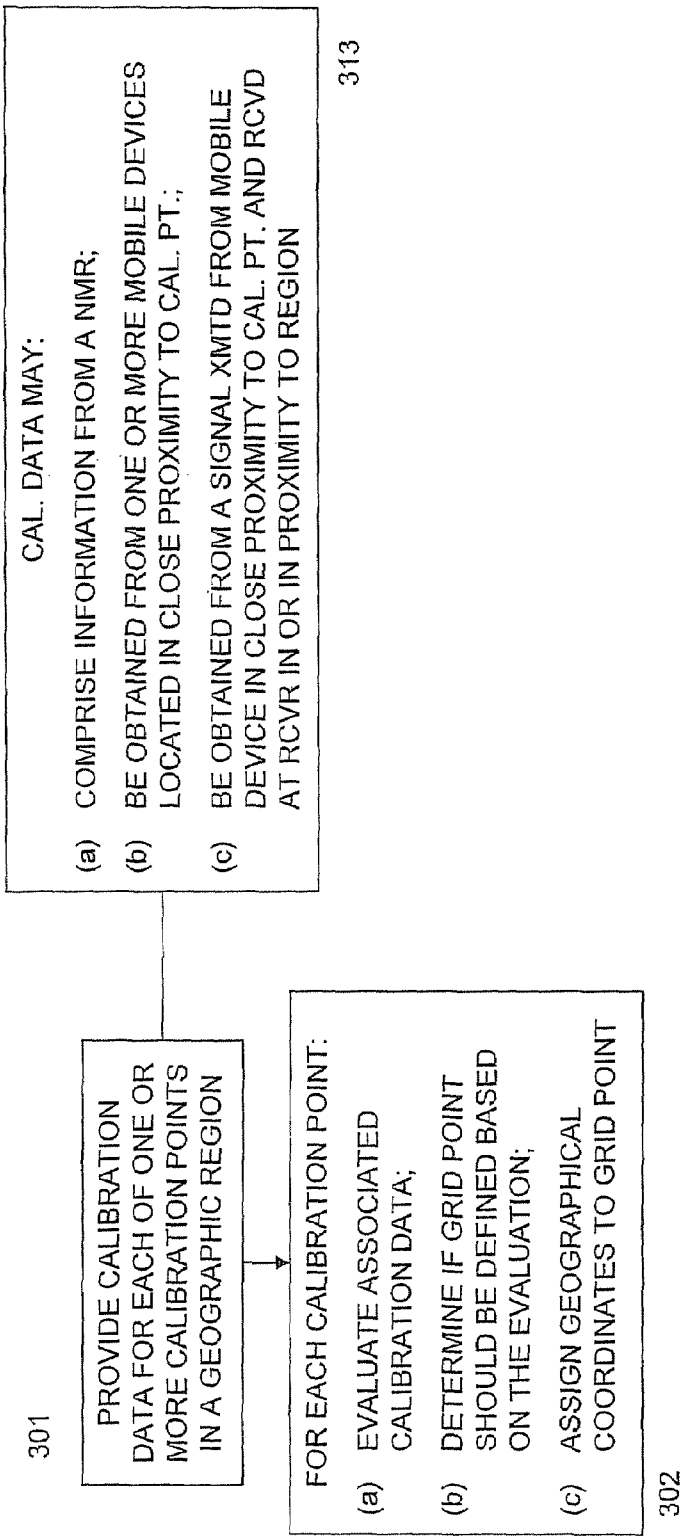

301
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
CAL. DATA MAY:
(a) COMPRISE INFORMATION FROM A NMR;
(b) BE OBTAINED FROM ONE OR MORE MOBILE DEVICES LOCATED IN CLOSE PROXIMITY TO CAL. PT.;
(c) BE OBTAINED FROM A SIGNAL XMTD FROM MOBILE DEVICE IN CLOSE PROXIMITY TO CAL. PT. AND RCVD AT RCVR IN OR IN PROXIMITY TO REGION
313
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
302

FIGURE 3

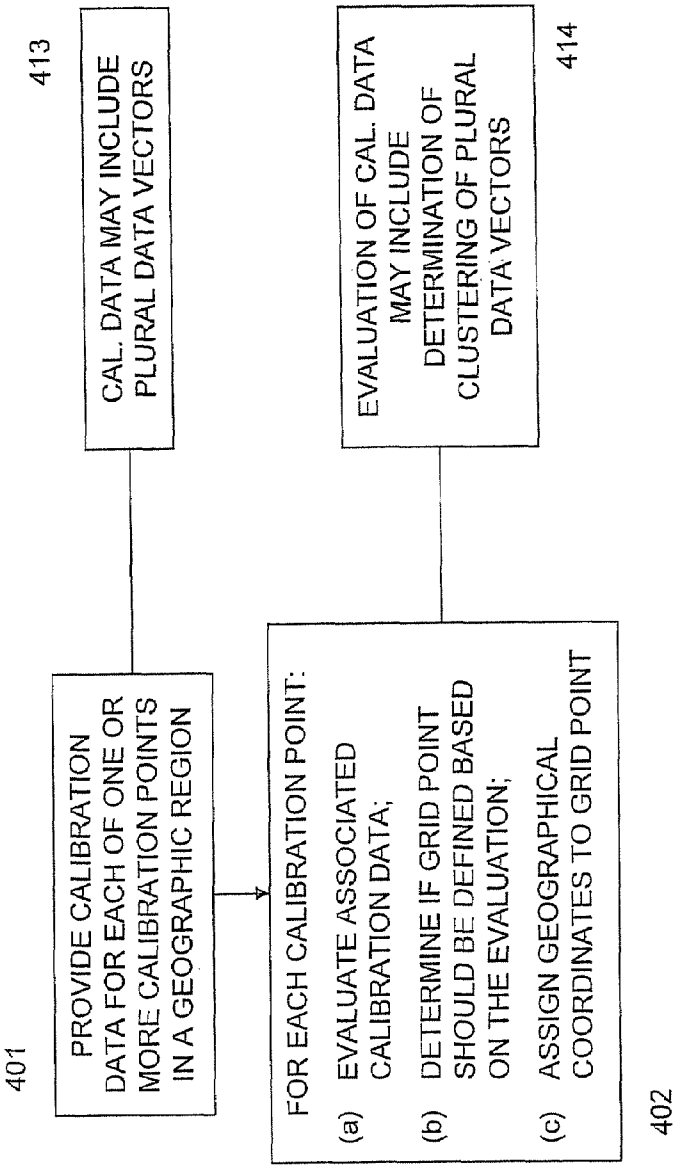

401
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
413
CAL. DATA MAY INCLUDE PLURAL DATA VECTORS
402
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
414
EVALUATION OF CAL. DATA MAY INCLUDE DETERMINATION OF CLUSTERING OF PLURAL DATA VECTORS

FIGURE 4

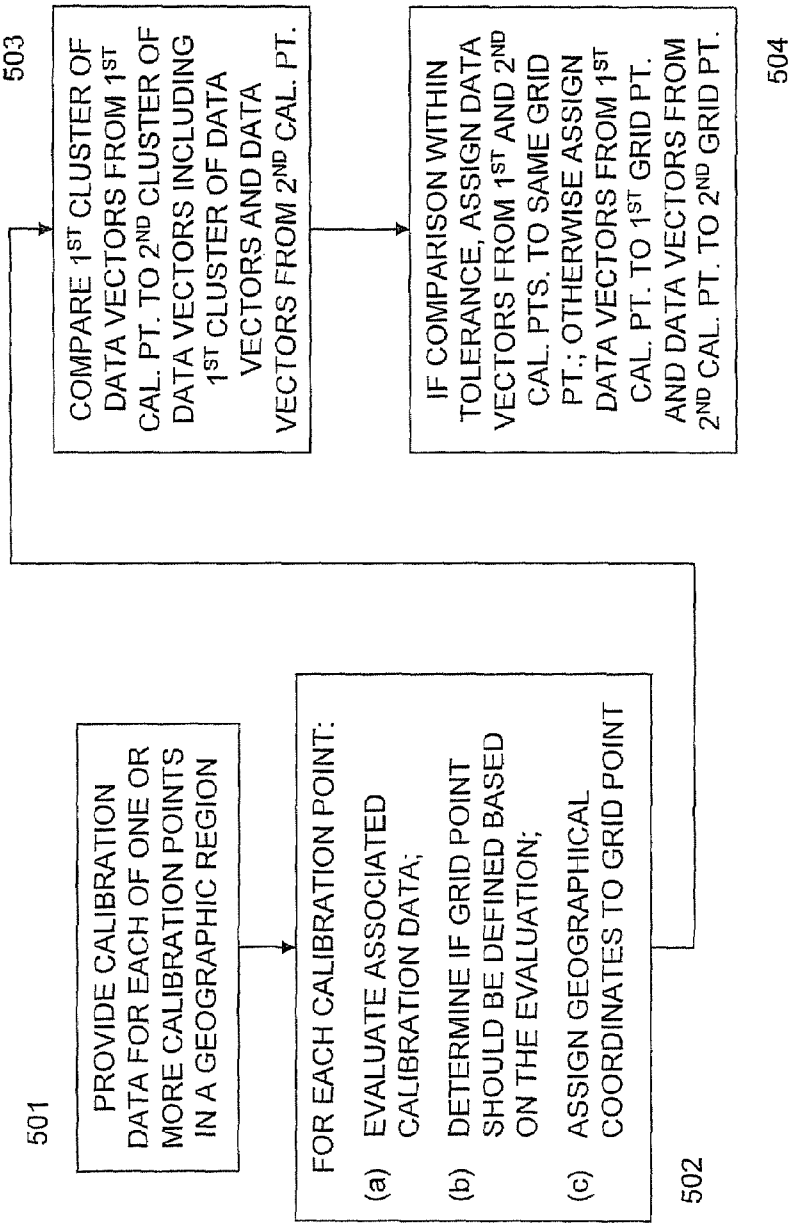

501
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
502
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
503
COMPARE 1ST CLUSTER OF DATA VECTORS FROM 1ST CAL. PT. TO 2ND CLUSTER OF DATA VECTORS INCLUDING 1ST CLUSTER OF DATA VECTORS AND DATA VECTORS FROM 2ND CAL. PT.
504
IF COMPARISON WITHIN TOLERANCE, ASSIGN DATA VECTORS FROM 1ST AND 2ND CAL. PTS. TO SAME GRID PT.; OTHERWISE ASSIGN DATA VECTORS FROM 1ST CAL. PT. TO 1ST GRID PT. AND DATA VECTORS FROM 2ND CAL. PT. TO 2ND GRID PT.

FIGURE 5

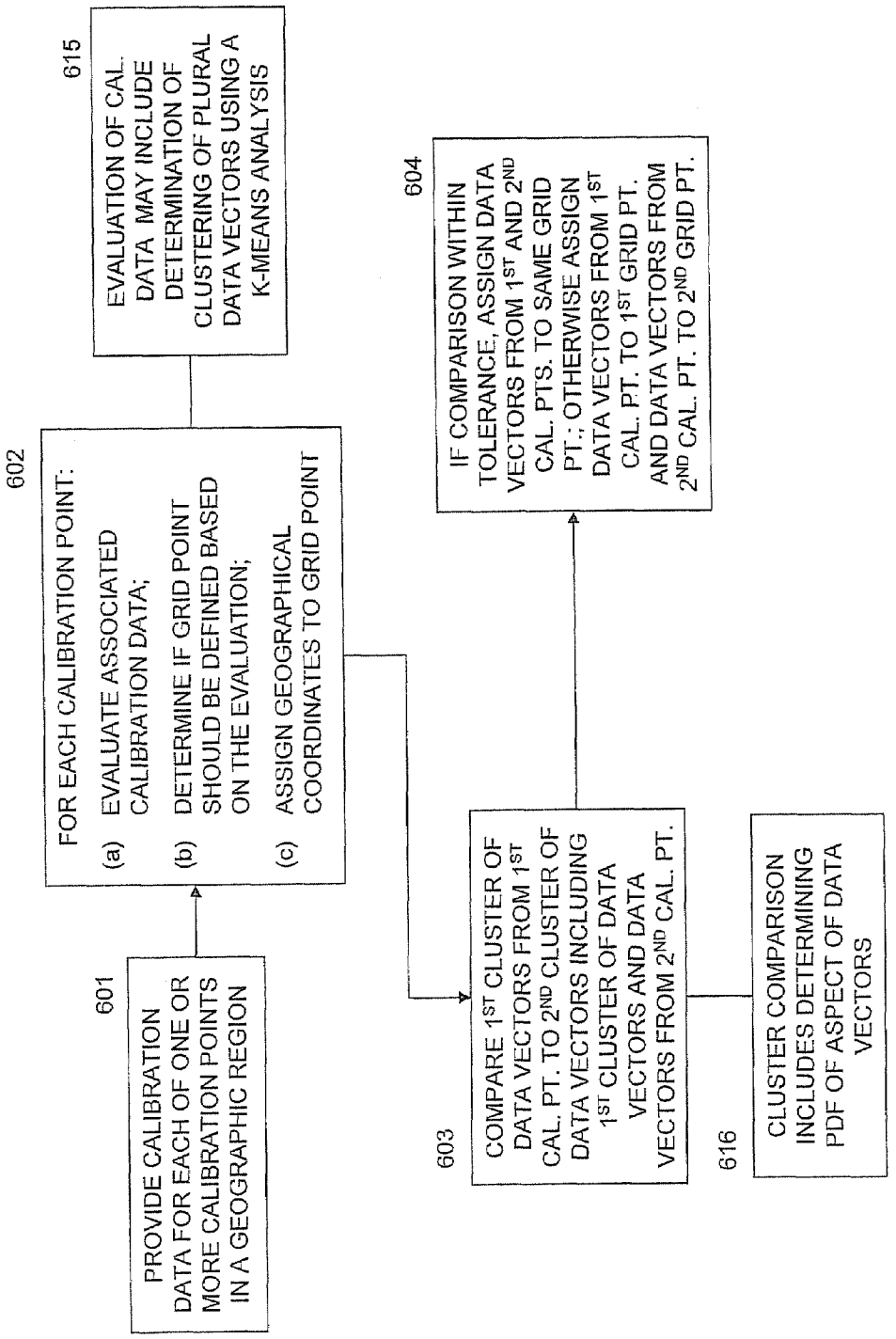

601
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
602
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
615
EVALUATION OF CAL. DATA MAY INCLUDE DETERMINATION OF CLUSTERING OF PLURAL DATA VECTORS USING A K-MEANS ANALYSIS
603
COMPARE 1ST CLUSTER OF DATA VECTORS FROM 1ST CAL. PT. TO 2ND CLUSTER OF DATA VECTORS INCLUDING 1ST CLUSTER OF DATA VECTORS AND DATA VECTORS FROM 2ND CAL. PT.
604
IF COMPARISON WITHIN TOLERANCE, ASSIGN DATA VECTORS FROM 1ST AND 2ND CAL. PTS. TO SAME GRID PT.; OTHERWISE ASSIGN DATA VECTORS FROM 1ST CAL. PT. TO 1ST GRID PT. AND DATA VECTORS FROM 2ND CAL. PT. TO 2ND GRID PT.
616
CLUSTER COMPARISON INCLUDES DETERMINING PDF OF ASPECT OF DATA VECTORS

FIGURE 6

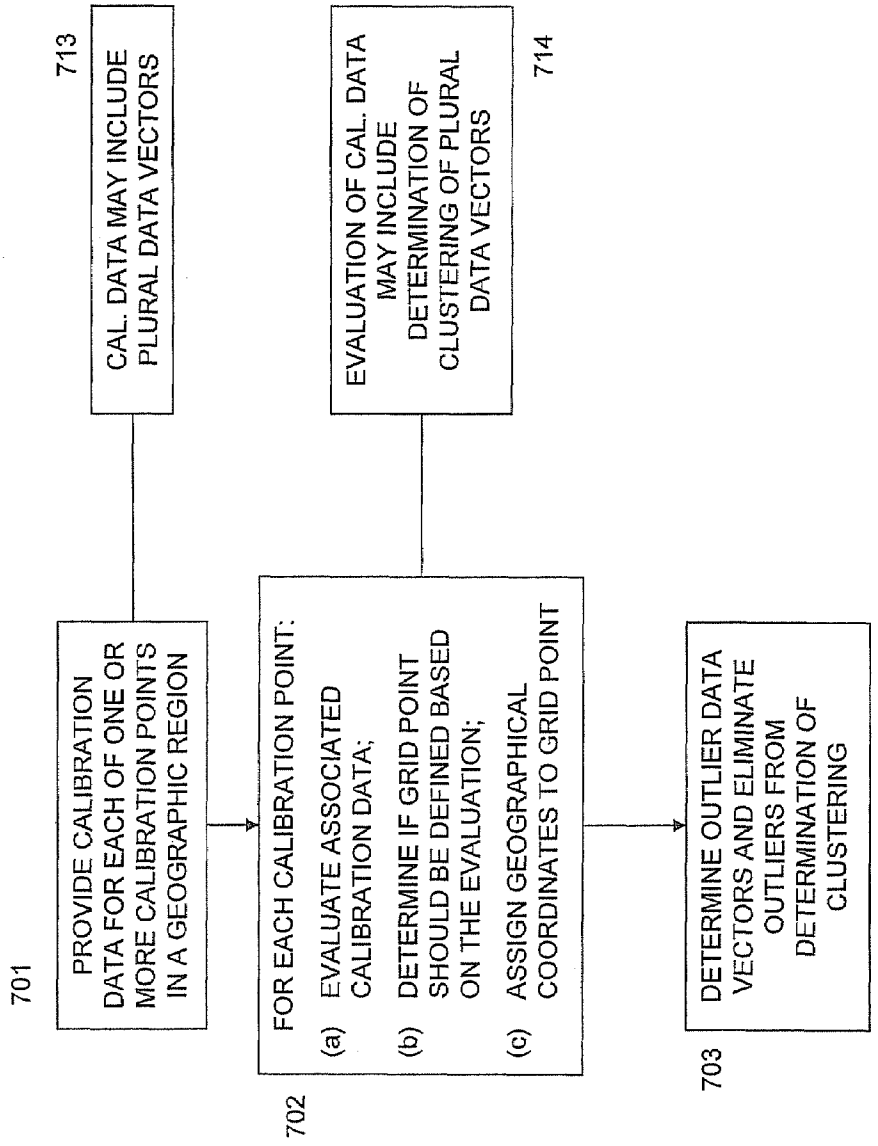

701
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
713
CAL. DATA MAY INCLUDE PLURAL DATA VECTORS
702
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
714
EVALUATION OF CAL. DATA MAY INCLUDE DETERMINATION OF CLUSTERING OF PLURAL DATA VECTORS
703
DETERMINE OUTLIER DATA VECTORS AND ELIMINATE OUTLIERS FROM DETERMINATION OF CLUSTERING

FIGURE 7

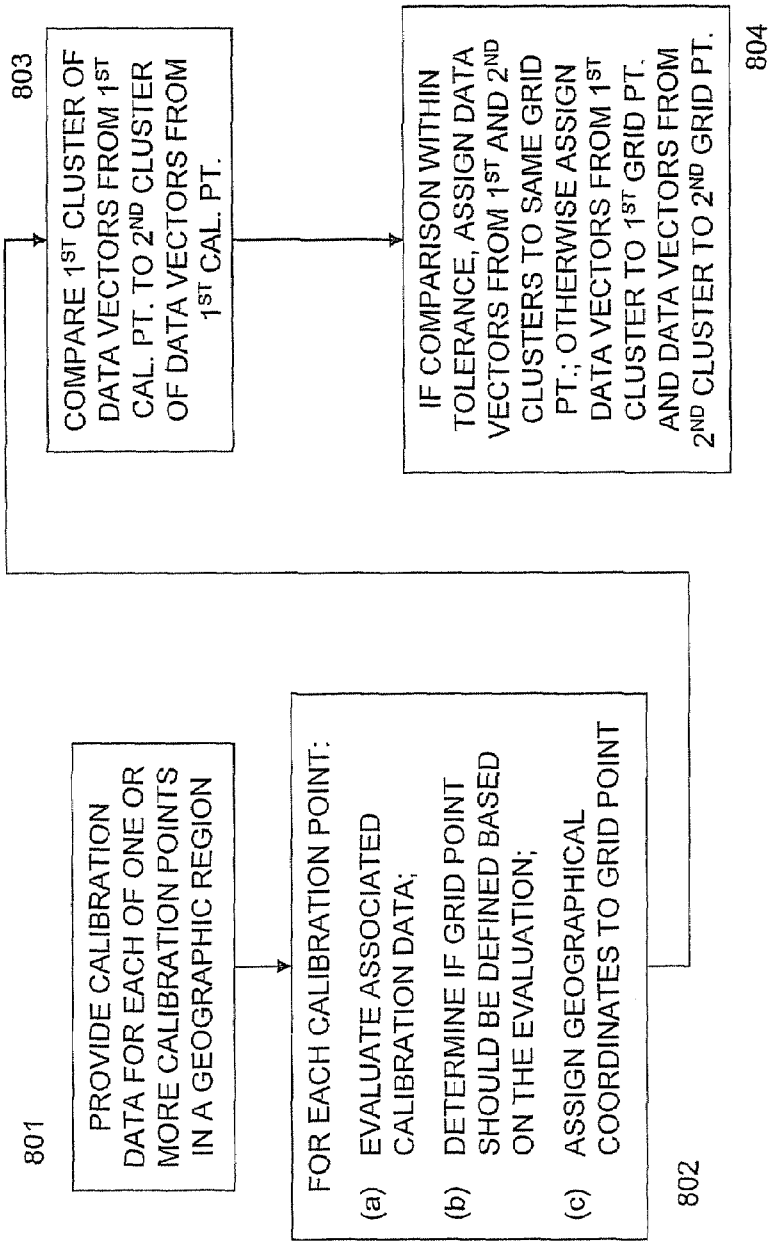

801
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
802
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
803
COMPARE 1ST CLUSTER OF DATA VECTORS FROM 1ST CAL. PT. TO 2ND CLUSTER OF DATA VECTORS FROM 1ST CAL. PT.
804
IF COMPARISON WITHIN TOLERANCE, ASSIGN DATA VECTORS FROM 1ST AND 2ND CLUSTERS TO SAME GRID PT.; OTHERWISE ASSIGN DATA VECTORS FROM 1ST CLUSTER TO 1ST GRID PT. AND DATA VECTORS FROM 2ND CLUSTER TO 2ND GRID PT.

FIGURE 8

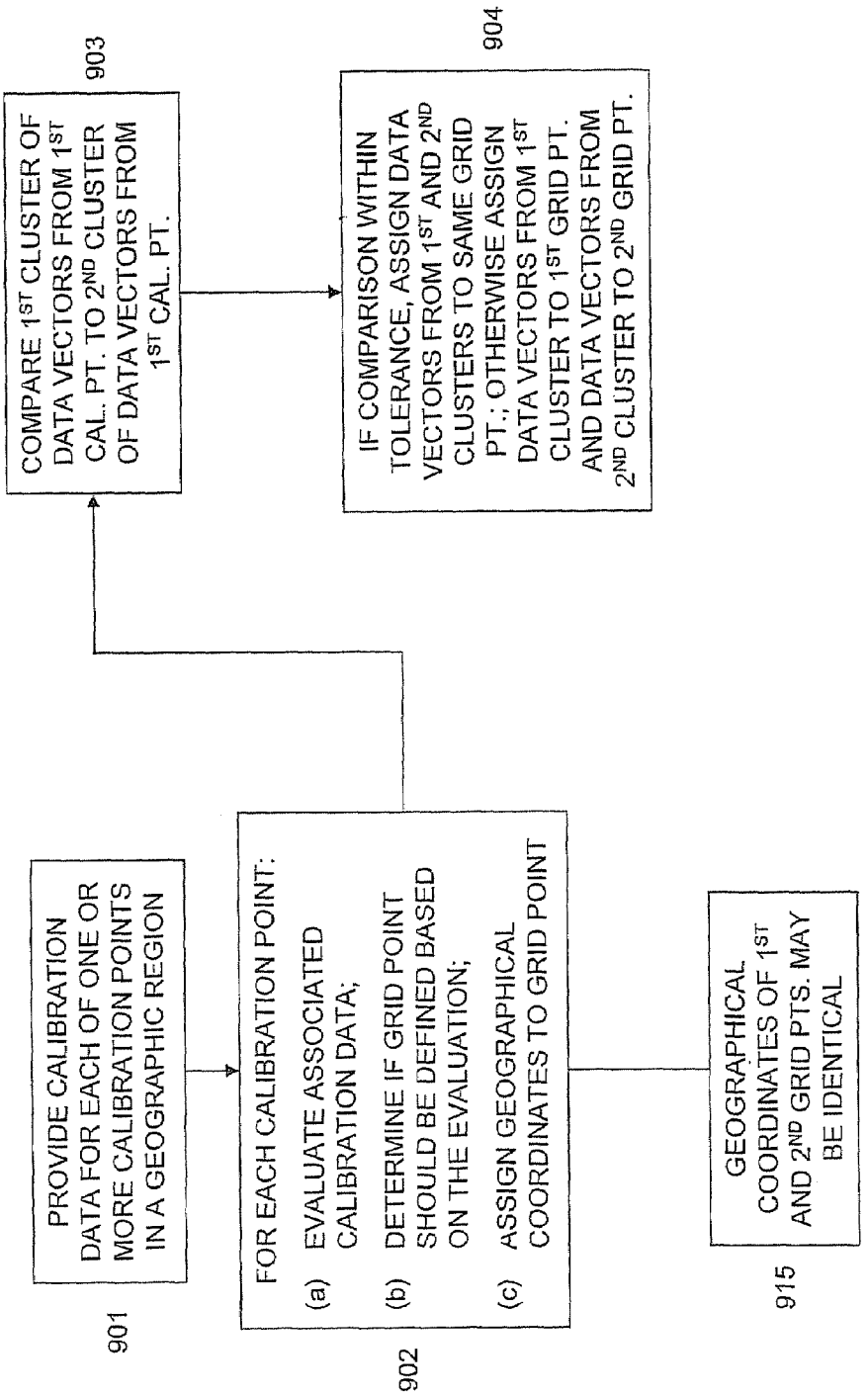

PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
901
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
902
COMPARE 1ST CLUSTER OF DATA VECTORS FROM 1ST CAL. PT. TO 2ND CLUSTER OF DATA VECTORS FROM 1ST CAL. PT.
903
IF COMPARISON WITHIN TOLERANCE, ASSIGN DATA VECTORS FROM 1ST AND 2ND CLUSTERS TO SAME GRID PT.; OTHERWISE ASSIGN DATA VECTORS FROM 1ST CLUSTER TO 1ST GRID PT. AND DATA VECTORS FROM 2ND CLUSTER TO 2ND GRID PT.
904
GEOGRAPHICAL COORDINATES OF 1ST AND 2ND GRID PTS. MAY BE IDENTICAL
915

FIGURE 9

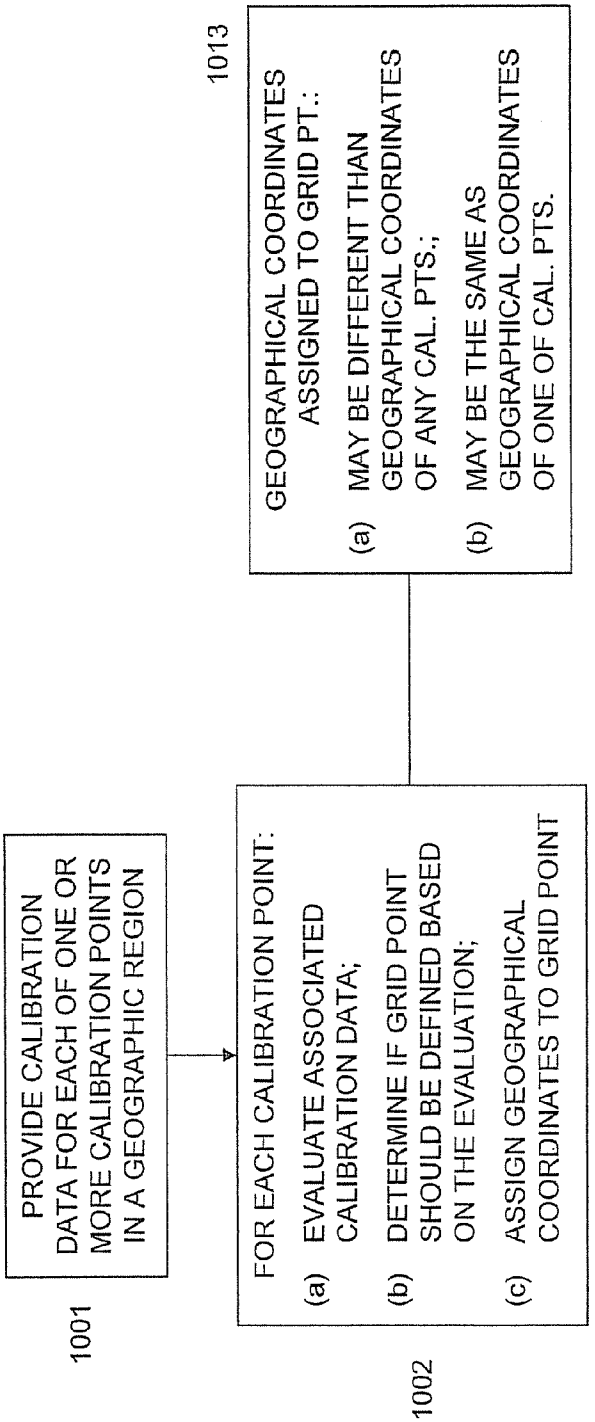

1001
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
1002
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
1013
GEOGRAPHICAL COORDINATES ASSIGNED TO GRID PT.:
(a) MAY BE DIFFERENT THAN GEOGRAPHICAL COORDINATES OF ANY CAL. PTS.;
(b) MAY BE THE SAME AS GEOGRAPHICAL COORDINATES OF ONE OF CAL. PTS.

FIGURE 10

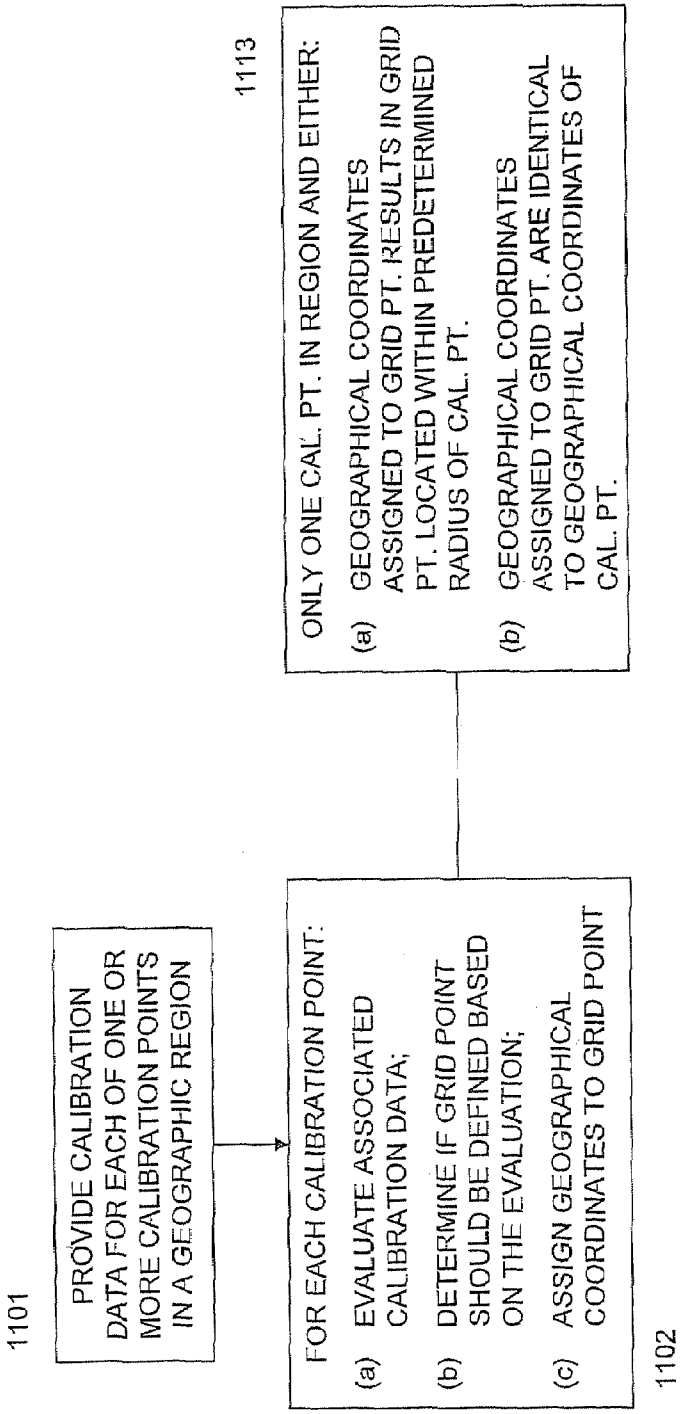

1101
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
1102
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
1113
ONLY ONE CAL. PT. IN REGION AND EITHER:
(a) GEOGRAPHICAL COORDINATES ASSIGNED TO GRID PT. RESULTS IN GRID PT. LOCATED WITHIN PREDETERMINED RADIUS OF CAL. PT.
(b) GEOGRAPHICAL COORDINATES ASSIGNED TO GRID PT. ARE IDENTICAL TO GEOGRAPHICAL COORDINATES OF CAL. PT.

FIGURE 11

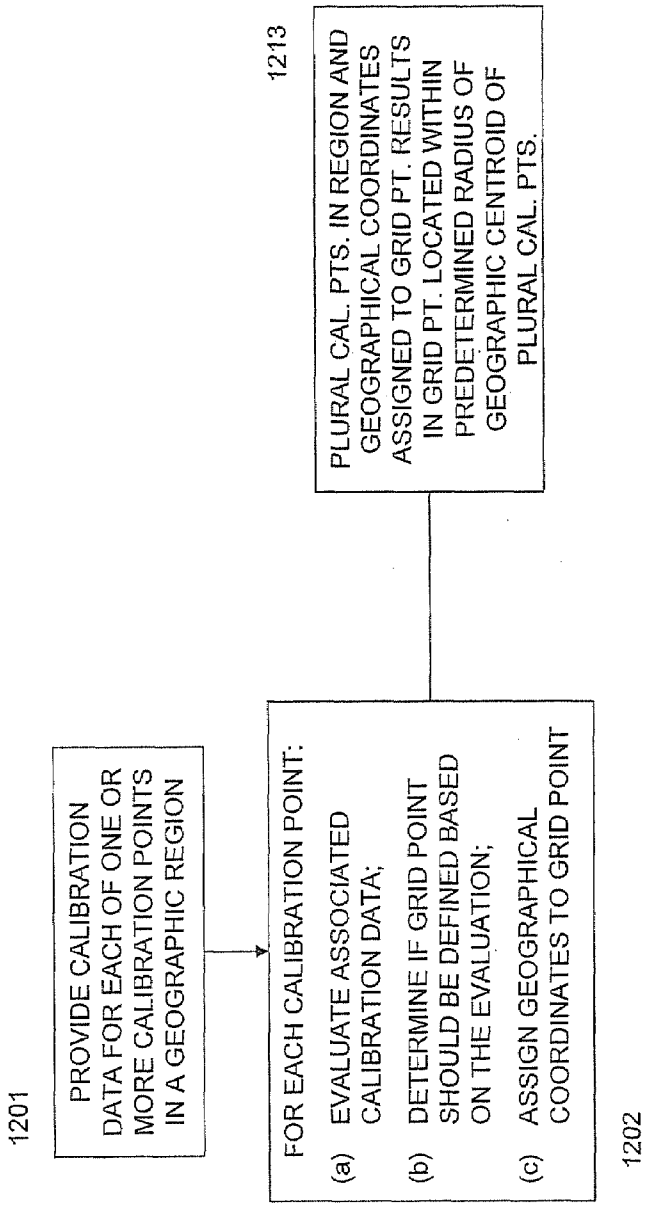

1201
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
1202
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
1213
PLURAL CAL. PTS. IN REGION AND GEOGRAPHICAL COORDINATES ASSIGNED TO GRID PT. RESULTS IN GRID PT. LOCATED WITHIN PREDETERMINED RADIUS OF GEOGRAPHIC CENTROID OF PLURAL CAL. PTS.

FIGURE 12

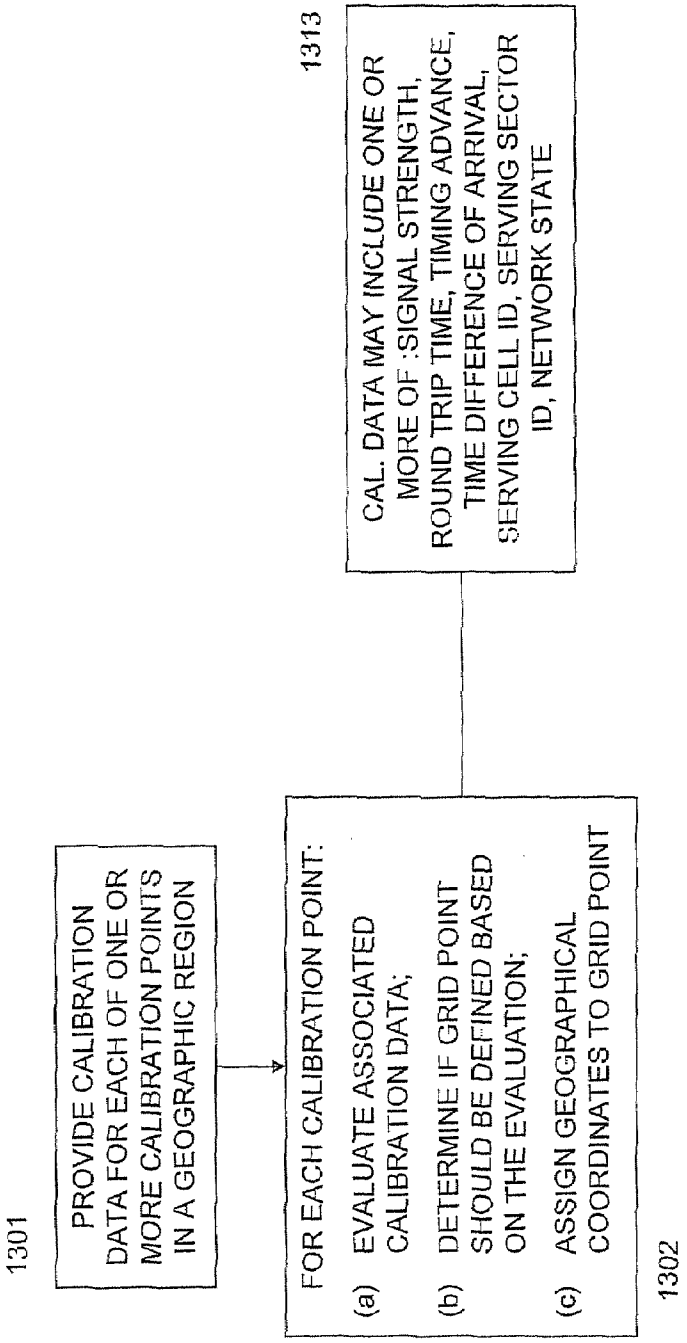

1301
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
1302
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
1313
CAL. DATA MAY INCLUDE ONE OR MORE OF :SIGNAL STRENGTH, ROUND TRIP TIME, TIMING ADVANCE, TIME DIFFERENCE OF ARRIVAL, SERVING CELL ID, SERVING SECTOR ID, NETWORK STATE

FIGURE 13

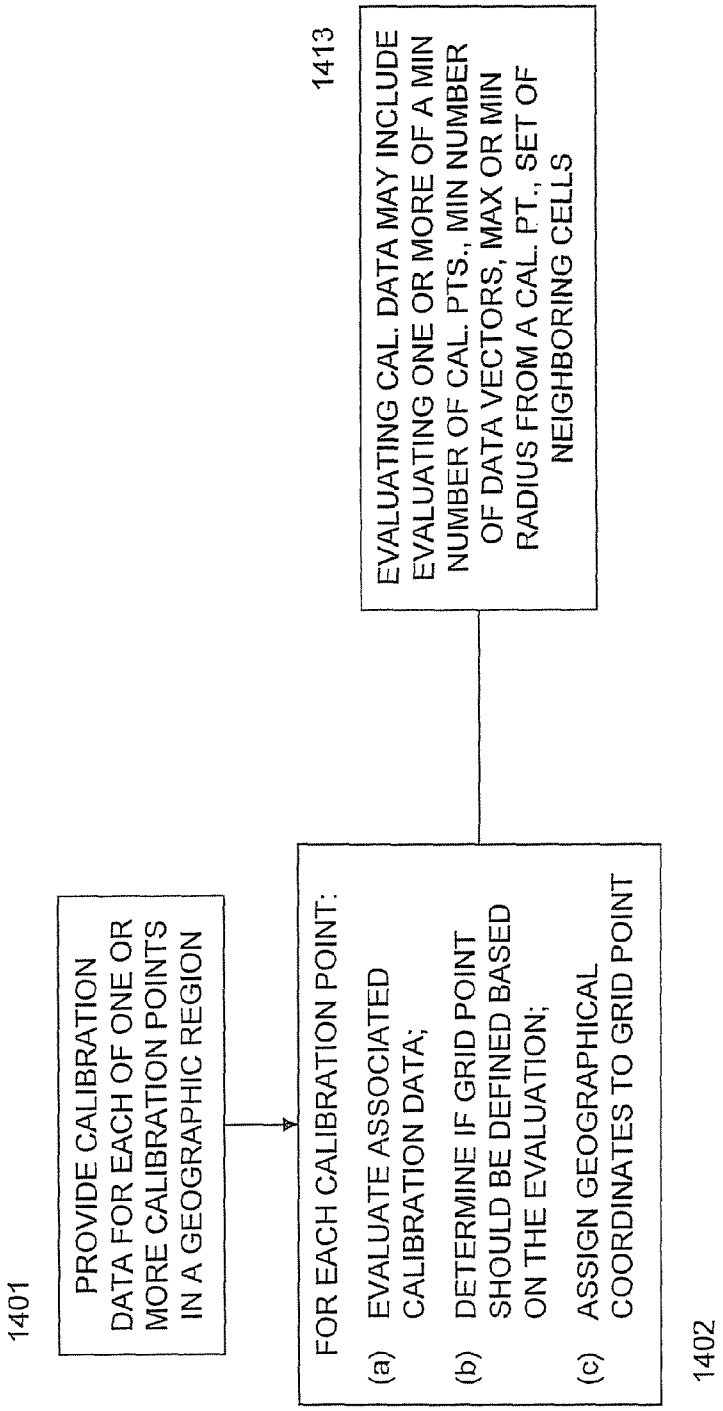
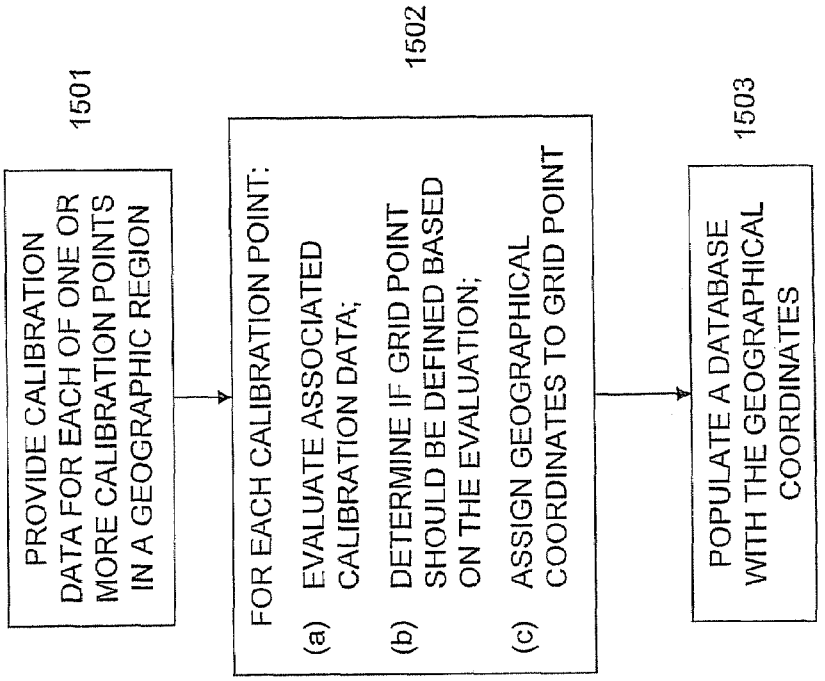

1401
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
1402
1413
EVALUATING CAL. DATA MAY INCLUDE EVALUATING ONE OR MORE OF A MIN NUMBER OF CAL. PTS., MIN NUMBER OF DATA VECTORS, MAX OR MIN RADIUS FROM A CAL. PT., SET OF NEIGHBORING CELLS

FIGURE 14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PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
1502
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
1503
POPULATE A DATABASE WITH THE GEOGRAPHICAL COORDINATES

FIGURE 15

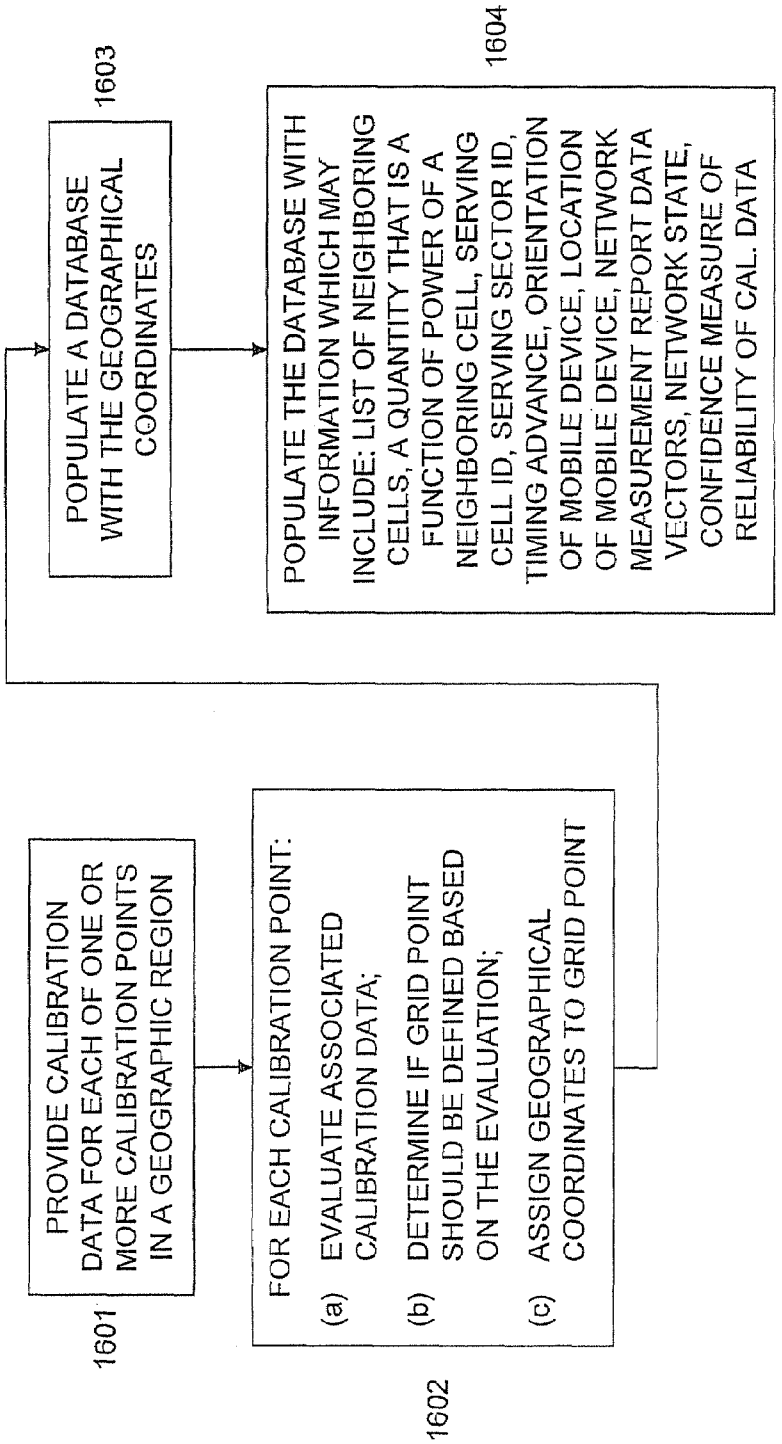

1601
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
1602
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
1603
POPULATE A DATABASE WITH THE GEOGRAPHICAL COORDINATES
1604
POPULATE THE DATABASE WITH INFORMATION WHICH MAY INCLUDE: LIST OF NEIGHBORING CELLS, A QUANTITY THAT IS A FUNCTION OF POWER OF A NEIGHBORING CELL, SERVING CELL ID, SERVING SECTOR ID, TIMING ADVANCE, ORIENTATION OF MOBILE DEVICE, LOCATION OF MOBILE DEVICE, NETWORK MEASUREMENT REPORT DATA VECTORS, NETWORK STATE, CONFIDENCE MEASURE OF RELIABILITY OF CAL. DATA

FIGURE 16

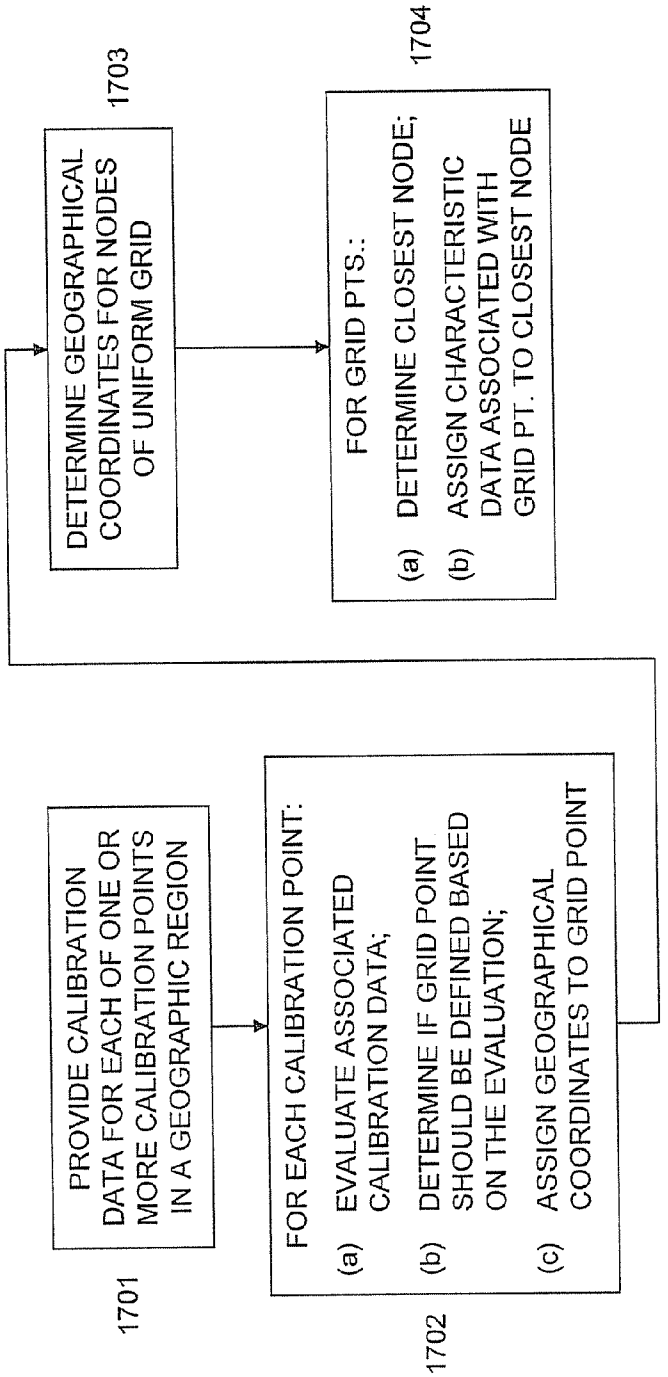

1701
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
1702
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
1703
DETERMINE GEOGRAPHICAL COORDINATES FOR NODES OF UNIFORM GRID
1704
FOR GRID PTS.:
(a) DETERMINE CLOSEST NODE;
(b) ASSIGN CHARACTERISTIC DATA ASSOCIATED WITH GRID PT. TO CLOSEST NODE

FIGURE 17

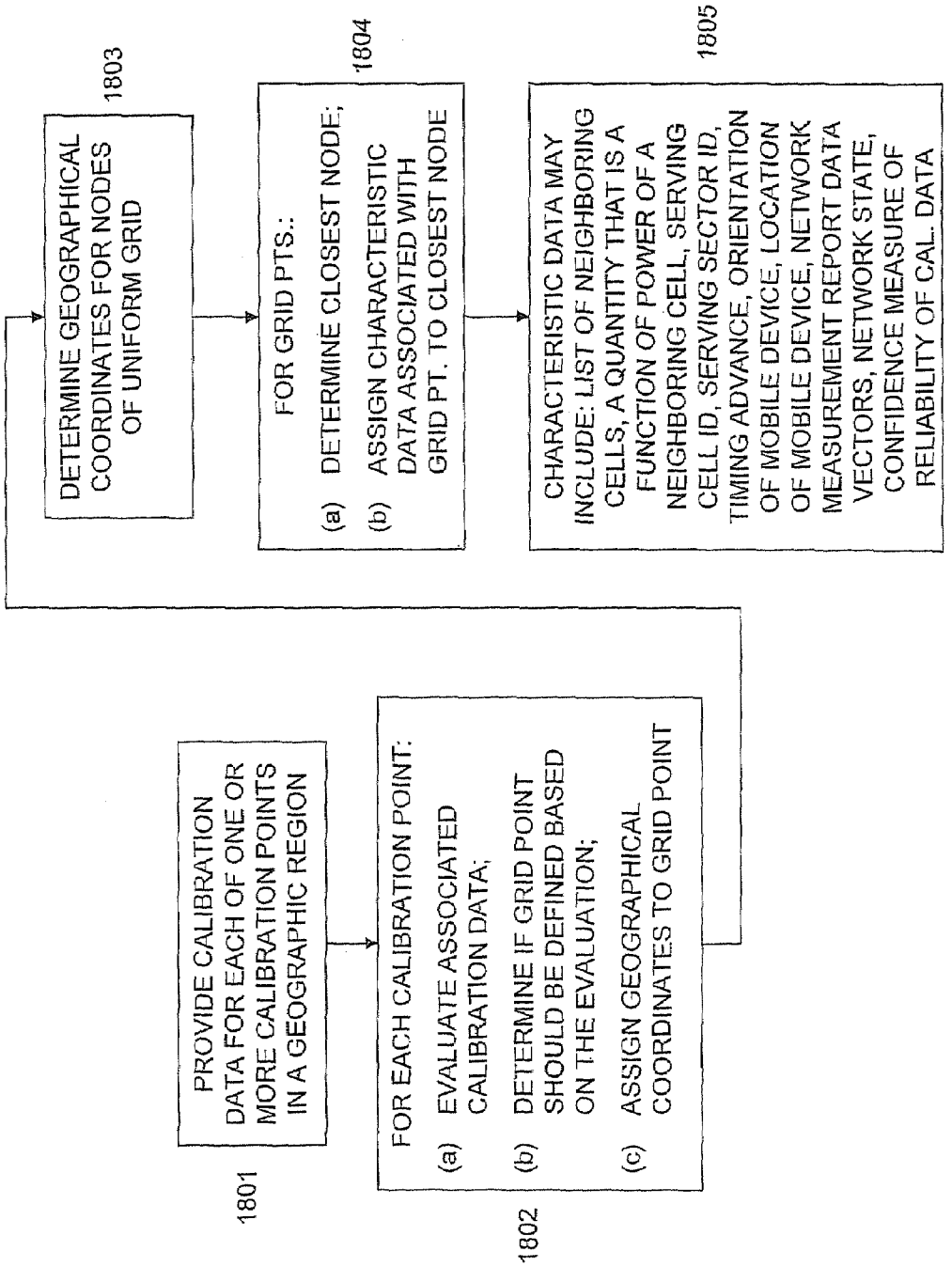

1801
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
1802
FOR EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
1803
DETERMINE GEOGRAPHICAL COORDINATES FOR NODES OF UNIFORM GRID
1804
FOR GRID PTS.:
(a) DETERMINE CLOSEST NODE;
(b) ASSIGN CHARACTERISTIC DATA ASSOCIATED WITH GRID PT. TO CLOSEST NODE
1805
CHARACTERISTIC DATA MAY INCLUDE: LIST OF NEIGHBORING CELLS, A QUANTITY THAT IS A FUNCTION OF POWER OF A NEIGHBORING CELL, SERVING CELL ID, SERVING SECTOR ID, TIMING ADVANCE, ORIENTATION OF MOBILE DEVICE, LOCATION OF MOBILE DEVICE, NETWORK MEASUREMENT REPORT DATA VECTORS, NETWORK STATE, CONFIDENCE MEASURE OF RELIABILITY OF CAL. DATA

FIGURE 18

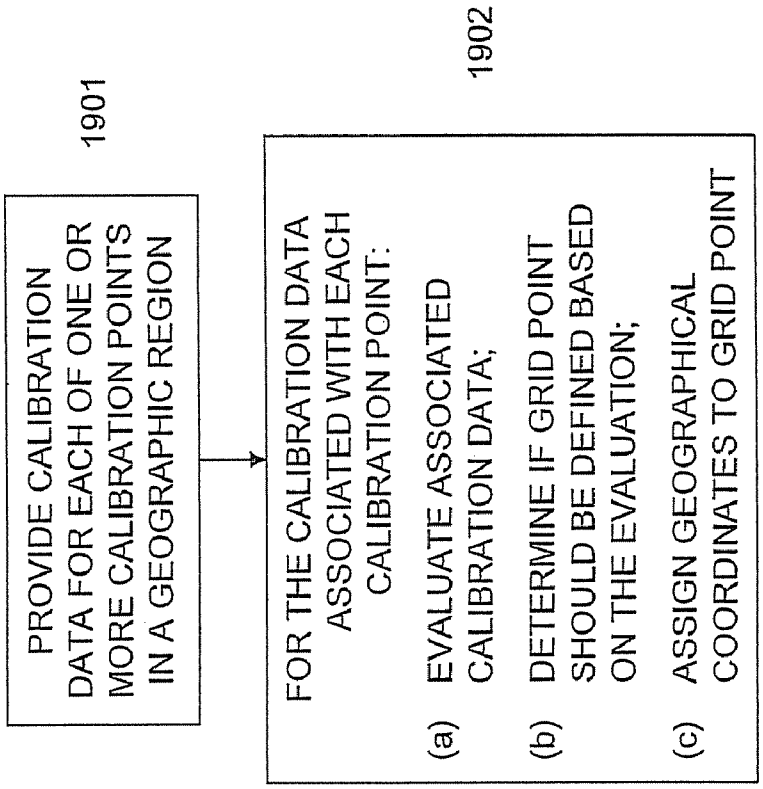

1901
PROVIDE CALIBRATION DATA FOR EACH OF ONE OR MORE CALIBRATION POINTS IN A GEOGRAPHIC REGION
1902
FOR THE CALIBRATION DATA ASSOCIATED WITH EACH CALIBRATION POINT:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT

FIGURE 19

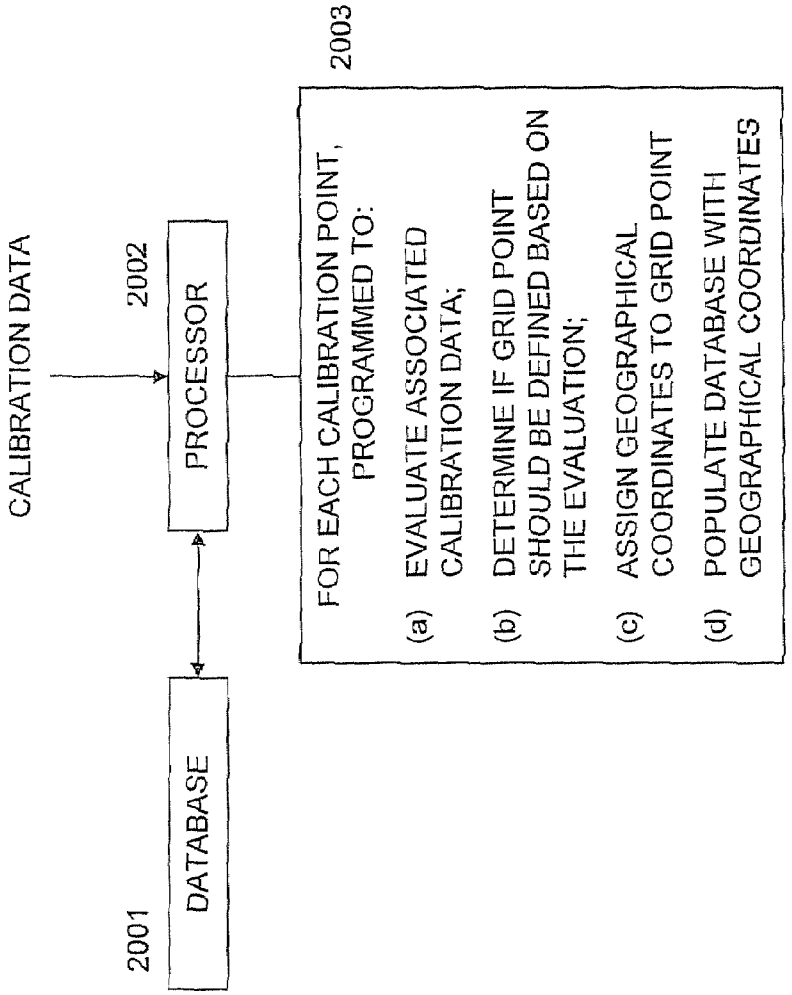

CALIBRATION DATA
2002
PROCESSOR
2001
DATABASE
2003
FOR EACH CALIBRATION POINT, PROGRAMMED TO:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
(d) POPULATE DATABASE WITH GEOGRAPHICAL COORDINATES

FIGURE 20

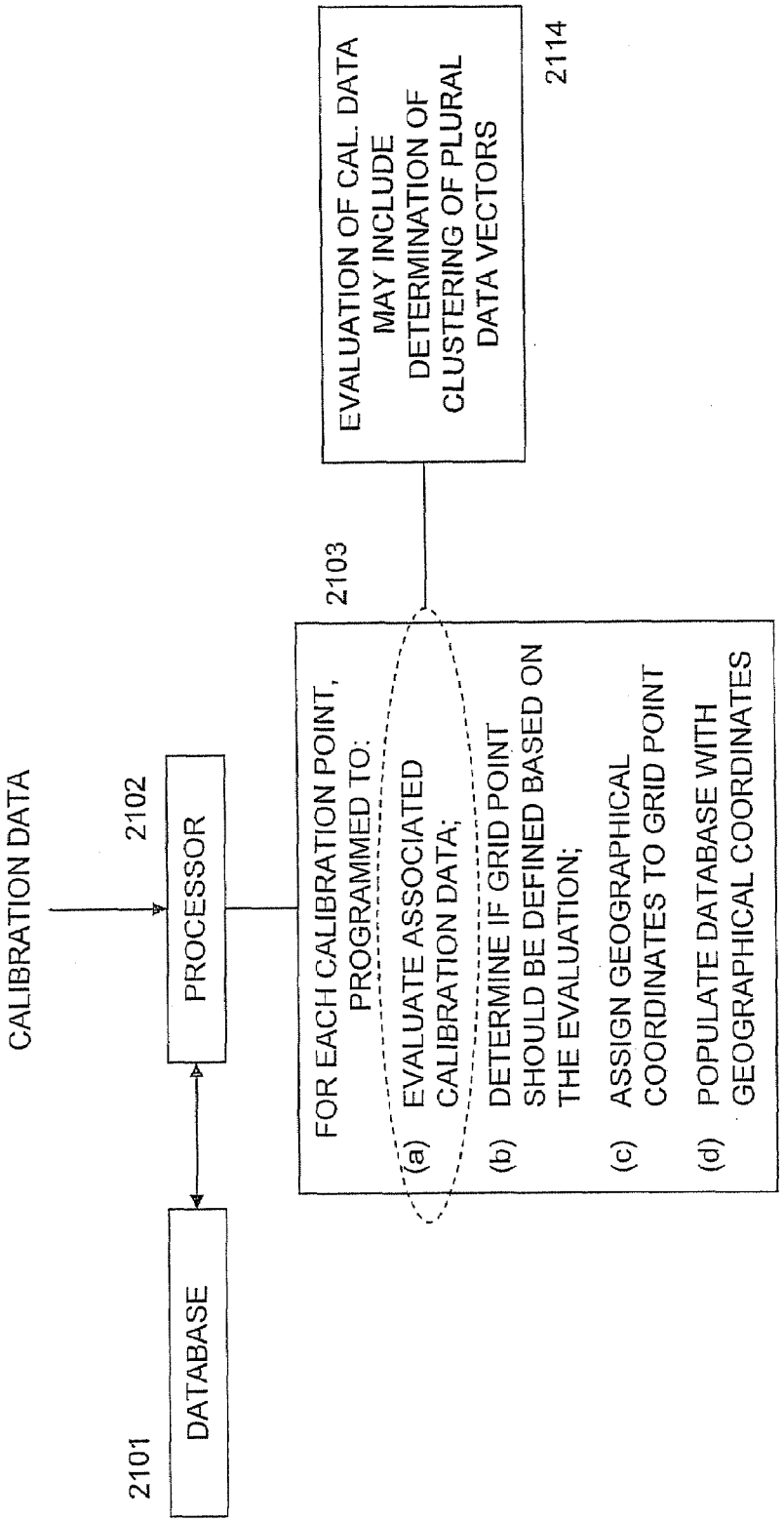

CALIBRATION DATA
2102
PROCESSOR
2101
DATABASE
2103
FOR EACH CALIBRATION POINT, PROGRAMMED TO:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
(d) POPULATE DATABASE WITH GEOGRAPHICAL COORDINATES
EVALUATION OF CAL. DATA MAY INCLUDE DETERMINATION OF CLUSTERING OF PLURAL DATA VECTORS
2114

FIGURE 21

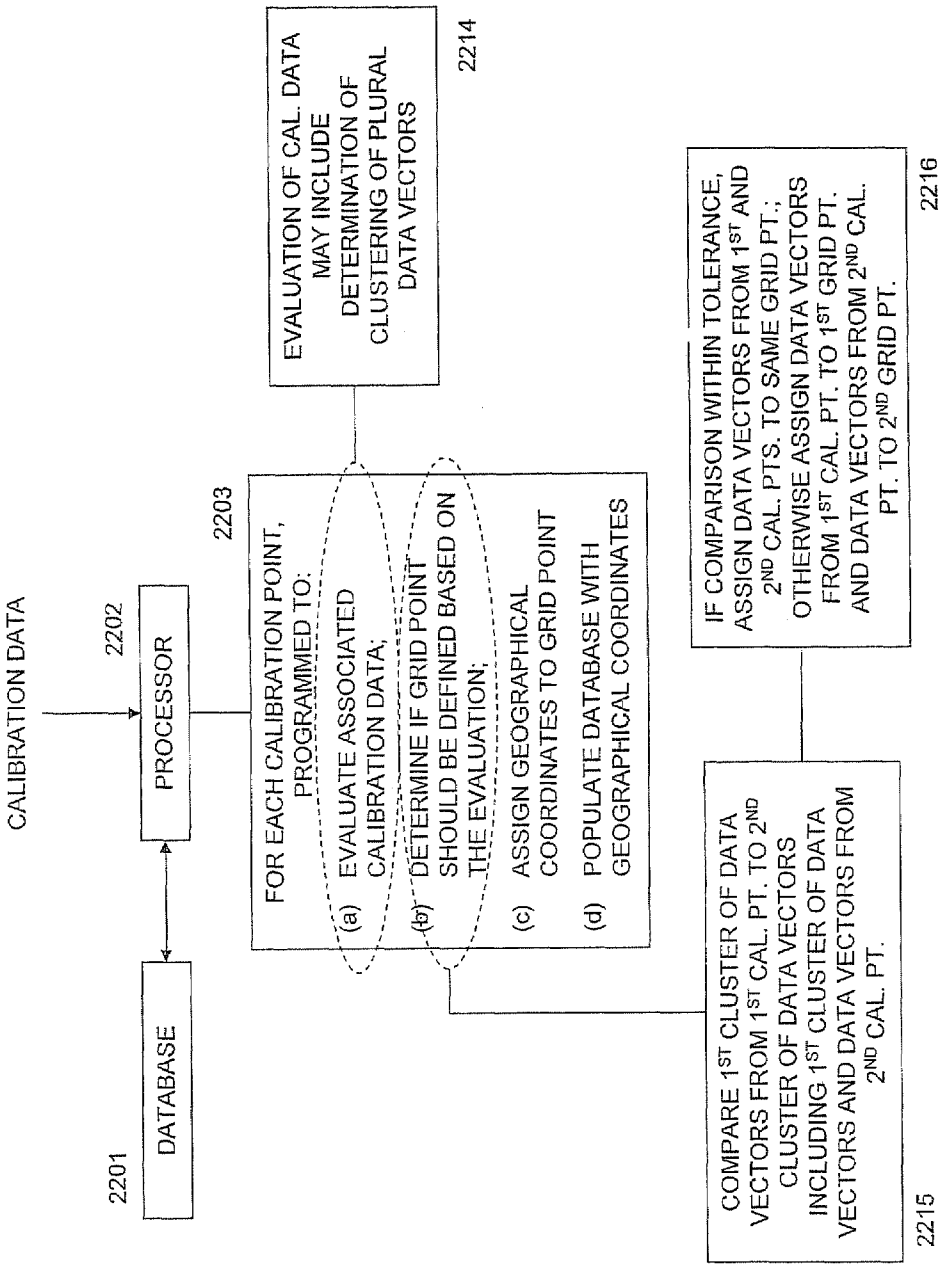

CALIBRATION DATA
2202
PROCESSOR
2201
DATABASE
2203
FOR EACH CALIBRATION POINT, PROGRAMMED TO:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
(d) POPULATE DATABASE WITH GEOGRAPHICAL COORDINATES
EVALUATION OF CAL. DATA MAY INCLUDE DETERMINATION OF CLUSTERING OF PLURAL DATA VECTORS
2214
COMPARE 1ST CLUSTER OF DATA VECTORS FROM 1ST CAL. PT. TO 2ND CLUSTER OF DATA VECTORS INCLUDING 1ST CLUSTER OF DATA VECTORS AND DATA VECTORS FROM 2ND CAL. PT.
2215
IF COMPARISON WITHIN TOLERANCE, ASSIGN DATA VECTORS FROM 1ST AND 2ND CAL. PTS. TO SAME GRID PT.; OTHERWISE ASSIGN DATA VECTORS FROM 1ST CAL. PT. TO 1ST GRID PT. AND DATA VECTORS FROM 2ND CAL. PT. TO 2ND GRID PT.
2216

FIGURE 22

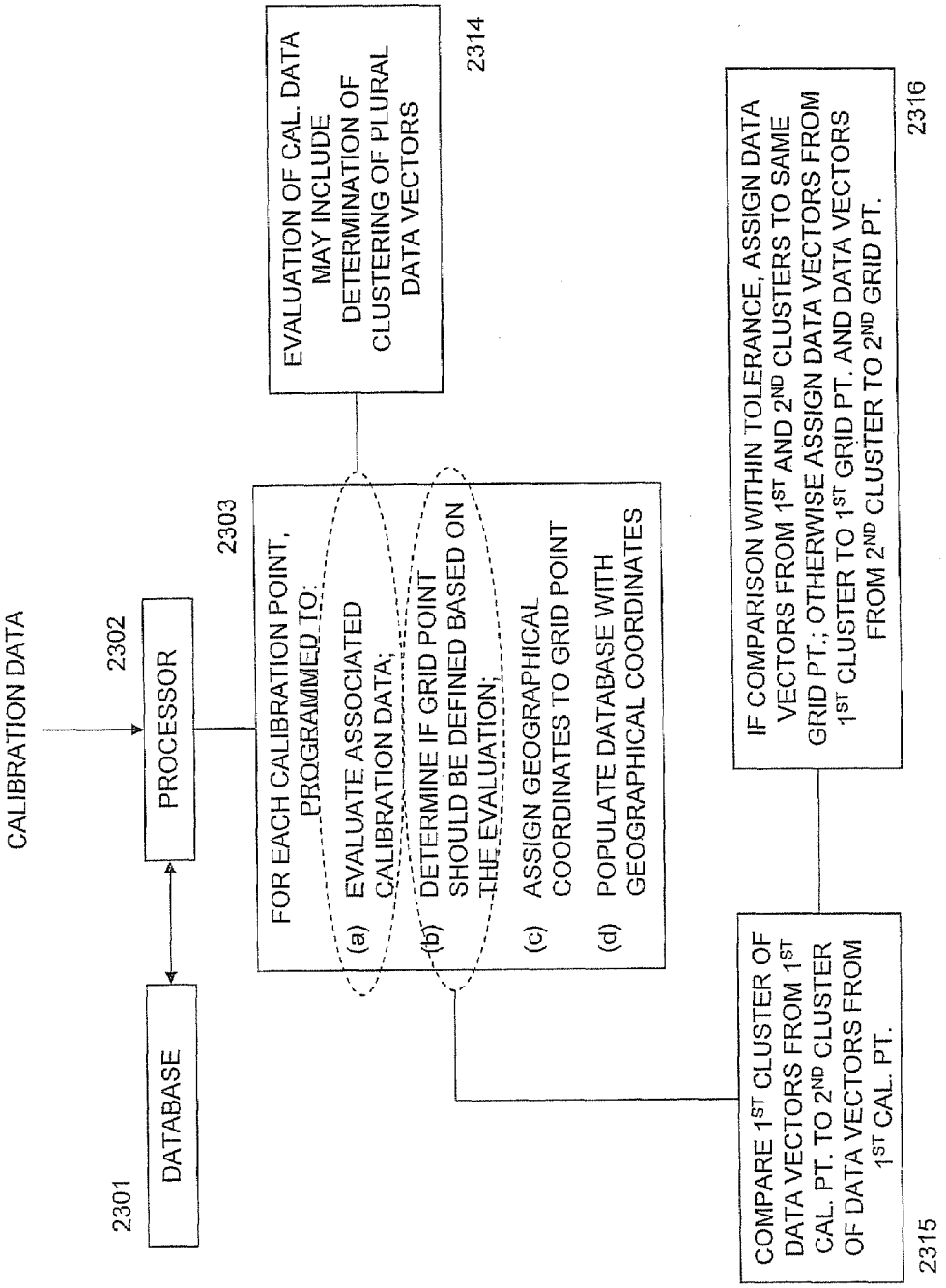

CALIBRATION DATA
2302
PROCESSOR
2301
DATABASE
2303
FOR EACH CALIBRATION POINT, PROGRAMMED TO:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
(d) POPULATE DATABASE WITH GEOGRAPHICAL COORDINATES
2314
EVALUATION OF CAL. DATA MAY INCLUDE DETERMINATION OF CLUSTERING OF PLURAL DATA VECTORS
2315
COMPARE 1ST CLUSTER OF DATA VECTORS FROM 1ST CAL. PT. TO 2ND CLUSTER OF DATA VECTORS FROM 1ST CAL. PT.
2316
IF COMPARISON WITHIN TOLERANCE, ASSIGN DATA VECTORS FROM 1ST AND 2ND CLUSTERS TO SAME GRID PT.; OTHERWISE ASSIGN DATA VECTORS FROM 1ST CLUSTER TO 1ST GRID PT. AND DATA VECTORS FROM 2ND CLUSTER TO 2ND GRID PT.

FIGURE 23

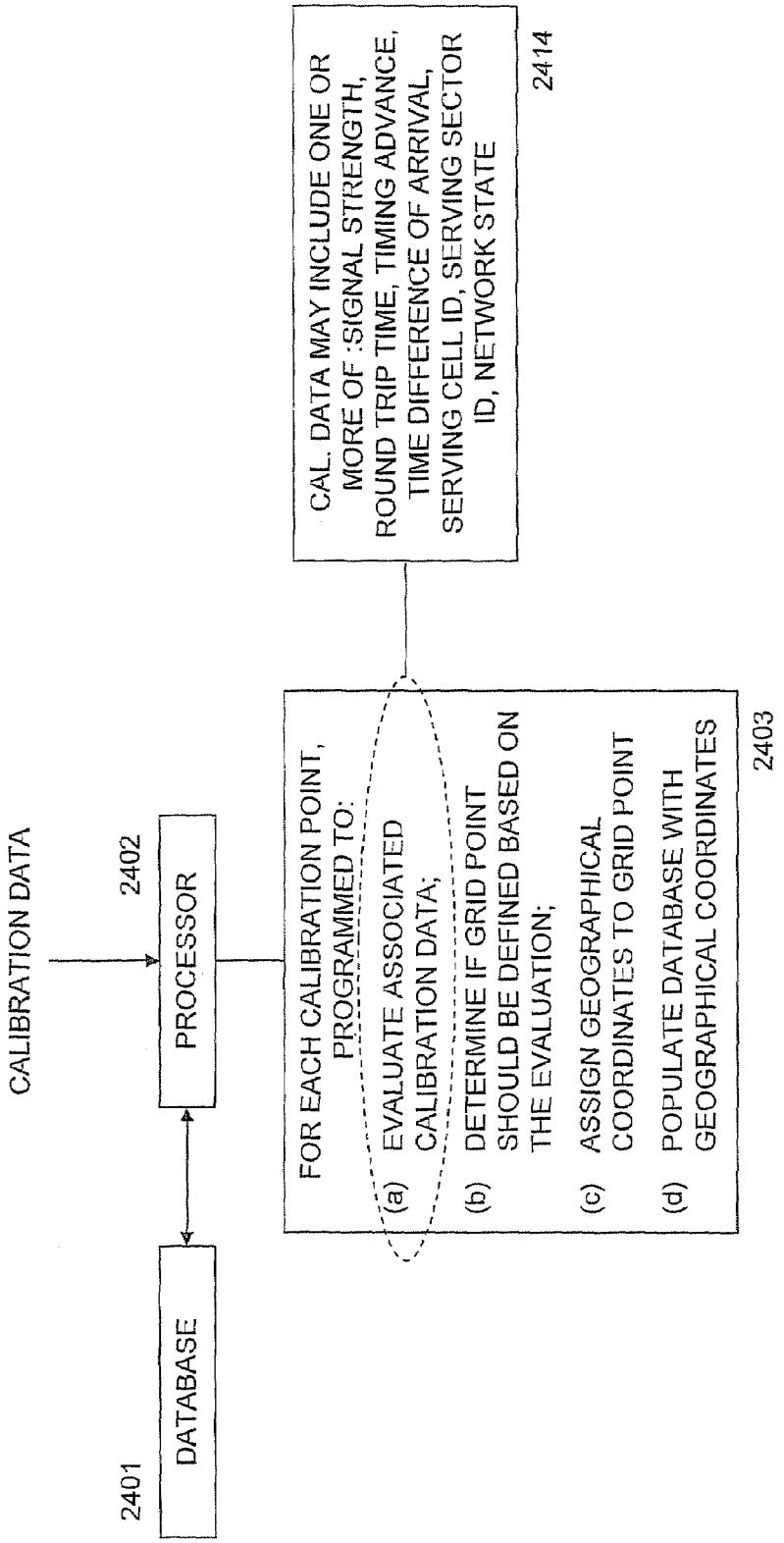

CALIBRATION DATA
2402
PROCESSOR
2401
DATABASE
FOR EACH CALIBRATION POINT, PROGRAMMED TO:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
(d) POPULATE DATABASE WITH GEOGRAPHICAL COORDINATES
2403
CAL. DATA MAY INCLUDE ONE OR MORE OF :SIGNAL STRENGTH, ROUND TRIP TIME, TIMING ADVANCE, TIME DIFFERENCE OF ARRIVAL, SERVING CELL ID, SERVING SECTOR ID, NETWORK STATE
2414

FIGURE 24

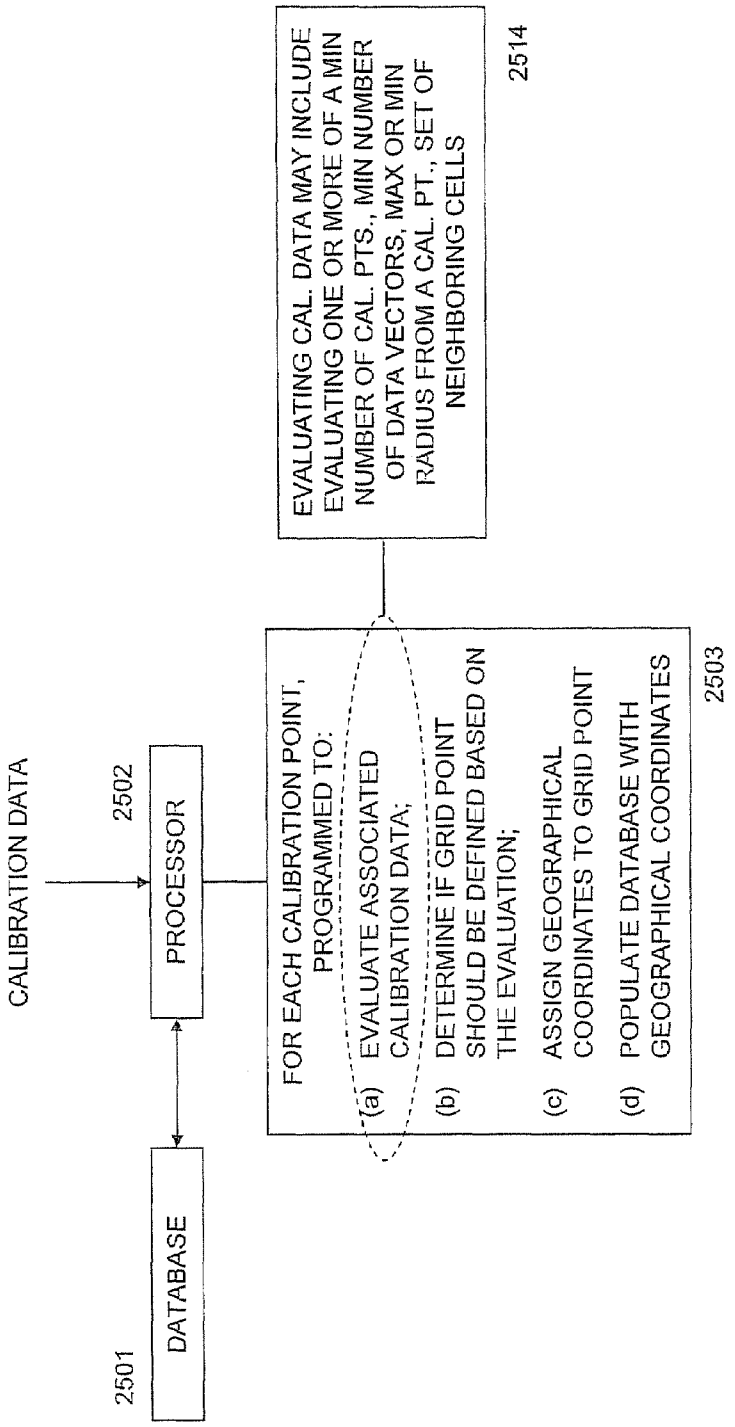

CALIBRATION DATA
2502
PROCESSOR
2501
DATABASE
FOR EACH CALIBRATION POINT, PROGRAMMED TO:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
(d) POPULATE DATABASE WITH GEOGRAPHICAL COORDINATES
2503
EVALUATING CAL. DATA MAY INCLUDE EVALUATING ONE OR MORE OF A MIN NUMBER OF CAL. PTS., MIN NUMBER OF DATA VECTORS, MAX OR MIN RADIUS FROM A CAL. PT., SET OF NEIGHBORING CELLS
2514

FIGURE 25

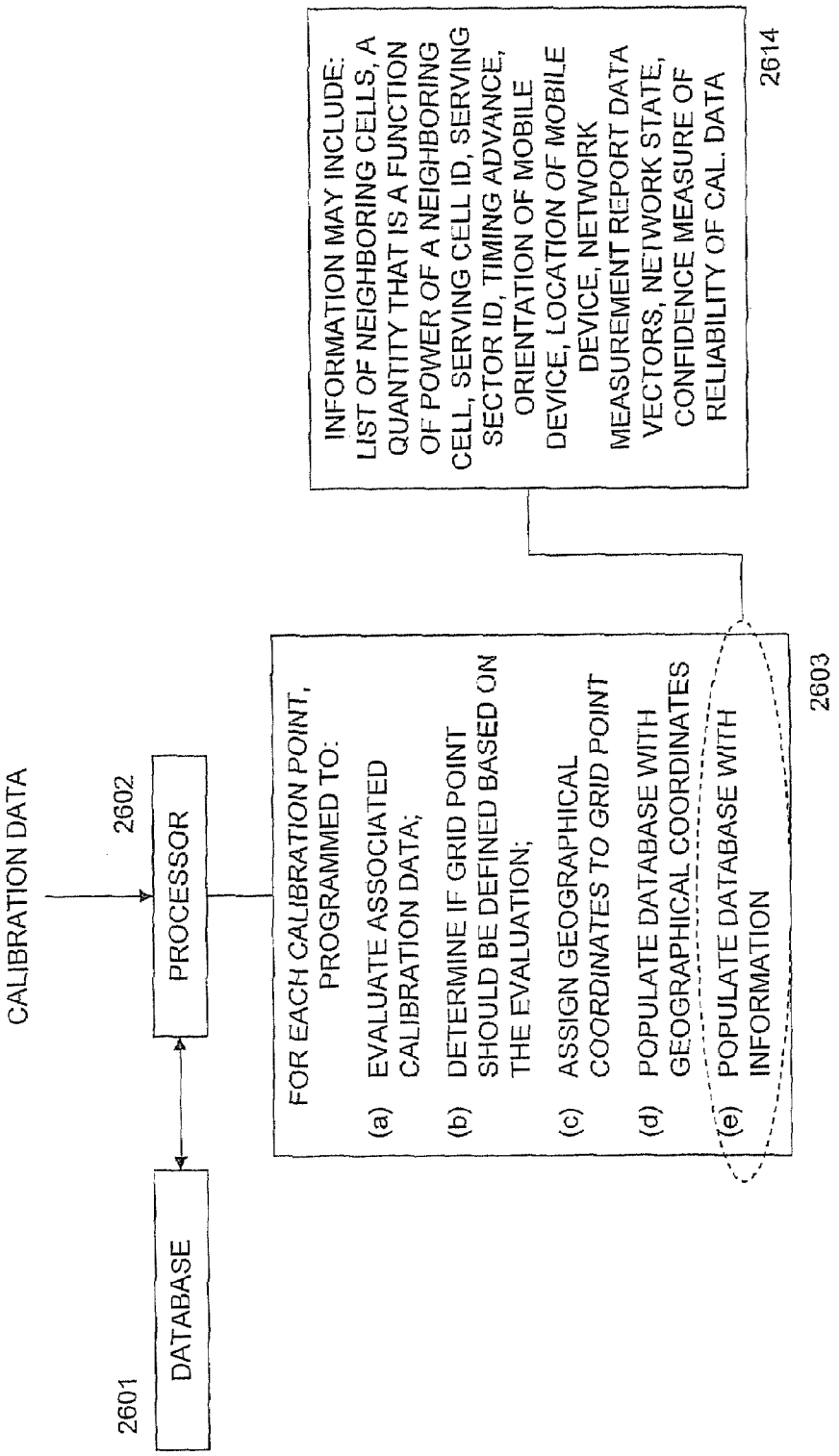

CALIBRATION DATA
2602
PROCESSOR
2601
DATABASE
FOR EACH CALIBRATION POINT, PROGRAMMED TO:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
(d) POPULATE DATABASE WITH GEOGRAPHICAL COORDINATES
(e) POPULATE DATABASE WITH INFORMATION
2603
INFORMATION MAY INCLUDE: LIST OF NEIGHBORING CELLS, A QUANTITY THAT IS A FUNCTION OF POWER OF A NEIGHBORING CELL, SERVING CELL ID, SERVING SECTOR ID, TIMING ADVANCE, ORIENTATION OF MOBILE DEVICE, LOCATION OF MOBILE DEVICE, NETWORK MEASUREMENT REPORT DATA VECTORS, NETWORK STATE, CONFIDENCE MEASURE OF RELIABILITY OF CAL. DATA
2614

FIGURE 26

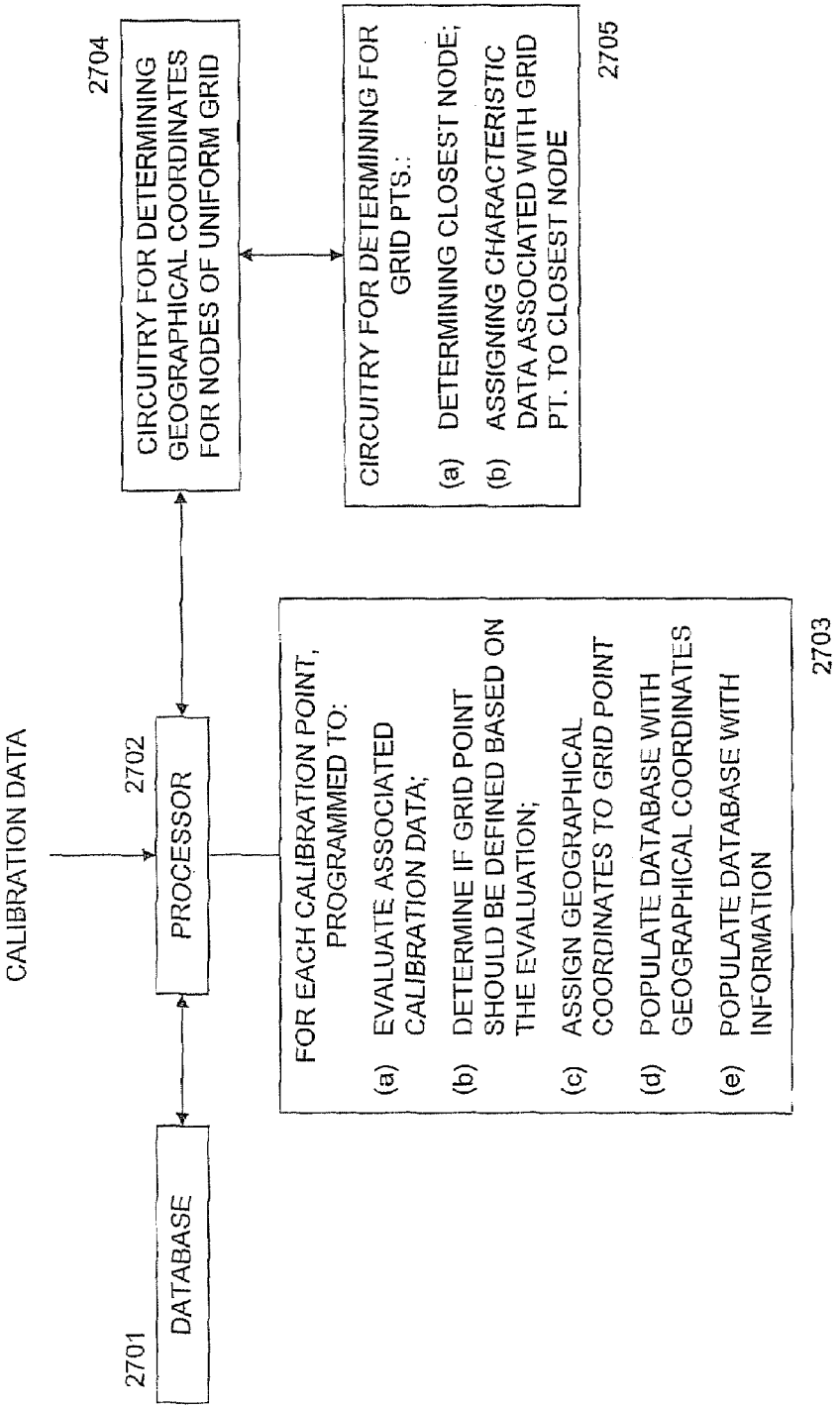

CALIBRATION DATA
2701
DATABASE
2702
PROCESSOR
FOR EACH CALIBRATION POINT, PROGRAMMED TO:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
(d) POPULATE DATABASE WITH GEOGRAPHICAL COORDINATES
(e) POPULATE DATABASE WITH INFORMATION
2703
2704
CIRCUITRY FOR DETERMINING GEOGRAPHICAL COORDINATES FOR NODES OF UNIFORM GRID
CIRCUITRY FOR DETERMINING FOR GRID PTS.:
(a) DETERMINING CLOSEST NODE;
(b) ASSIGNING CHARACTERISTIC DATA ASSOCIATED WITH GRID PT. TO CLOSEST NODE
2705

FIGURE 27

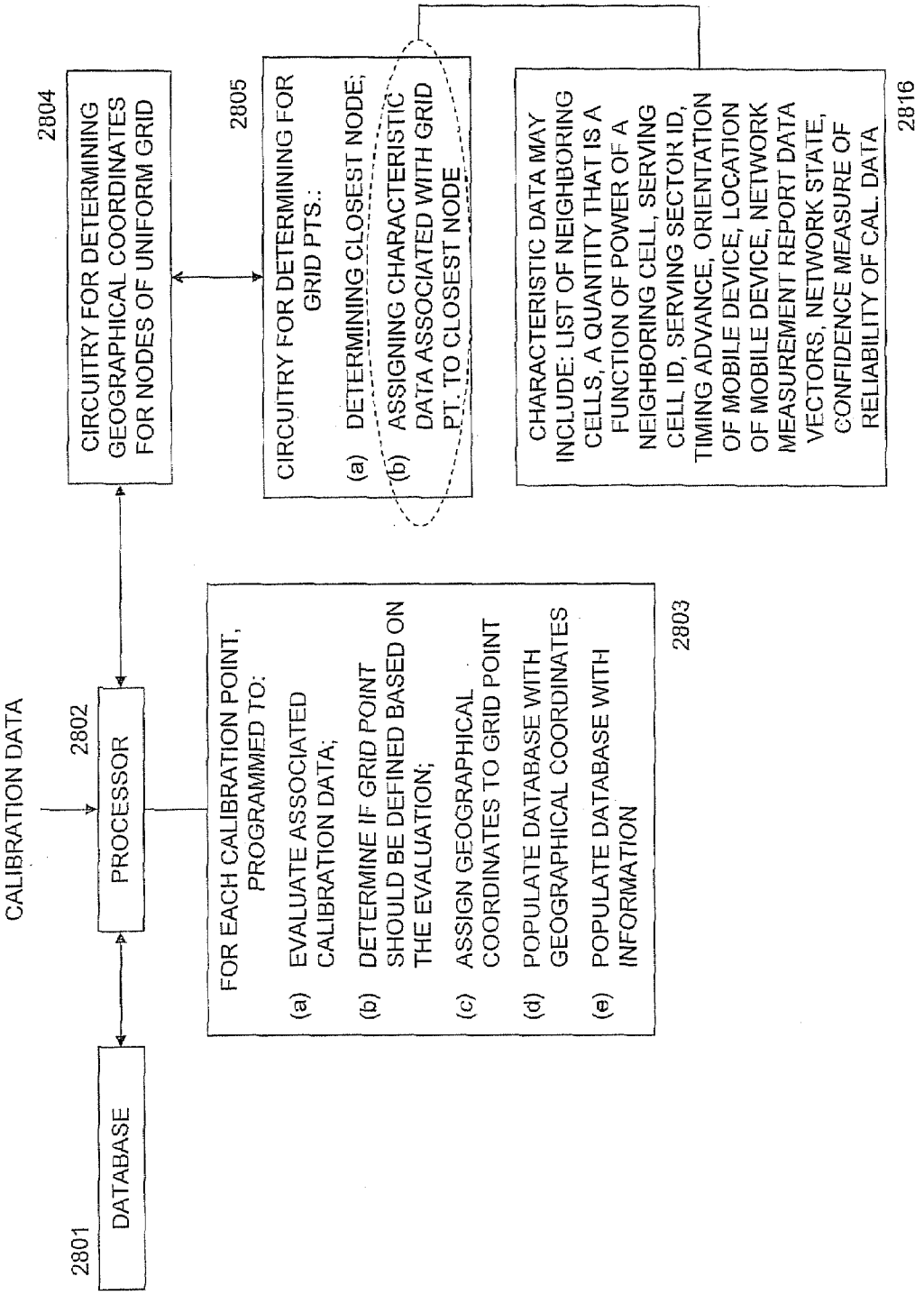

CALIBRATION DATA
2801
DATABASE
2802
PROCESSOR
FOR EACH CALIBRATION POINT, PROGRAMMED TO:
(a) EVALUATE ASSOCIATED CALIBRATION DATA;
(b) DETERMINE IF GRID POINT SHOULD BE DEFINED BASED ON THE EVALUATION;
(c) ASSIGN GEOGRAPHICAL COORDINATES TO GRID POINT
(d) POPULATE DATABASE WITH GEOGRAPHICAL COORDINATES
(e) POPULATE DATABASE WITH INFORMATION
2803
2804
CIRCUITRY FOR DETERMINING GEOGRAPHICAL COORDINATES FOR NODES OF UNIFORM GRID
2805
CIRCUITRY FOR DETERMINING FOR GRID PTS.:
(a) DETERMINING CLOSEST NODE;
(b) ASSIGNING CHARACTERISTIC DATA ASSOCIATED WITH GRID PT. TO CLOSEST NODE
CHARACTERISTIC DATA MAY INCLUDE: LIST OF NEIGHBORING CELLS, A QUANTITY THAT IS A FUNCTION OF POWER OF A NEIGHBORING CELL, SERVING CELL ID, SERVING SECTOR ID, TIMING ADVANCE, ORIENTATION OF MOBILE DEVICE, LOCATION OF MOBILE DEVICE, NETWORK MEASUREMENT REPORT DATA VECTORS, NETWORK STATE, CONFIDENCE MEASURE OF RELIABILITY OF CAL. DATA
2816

FIGURE 28

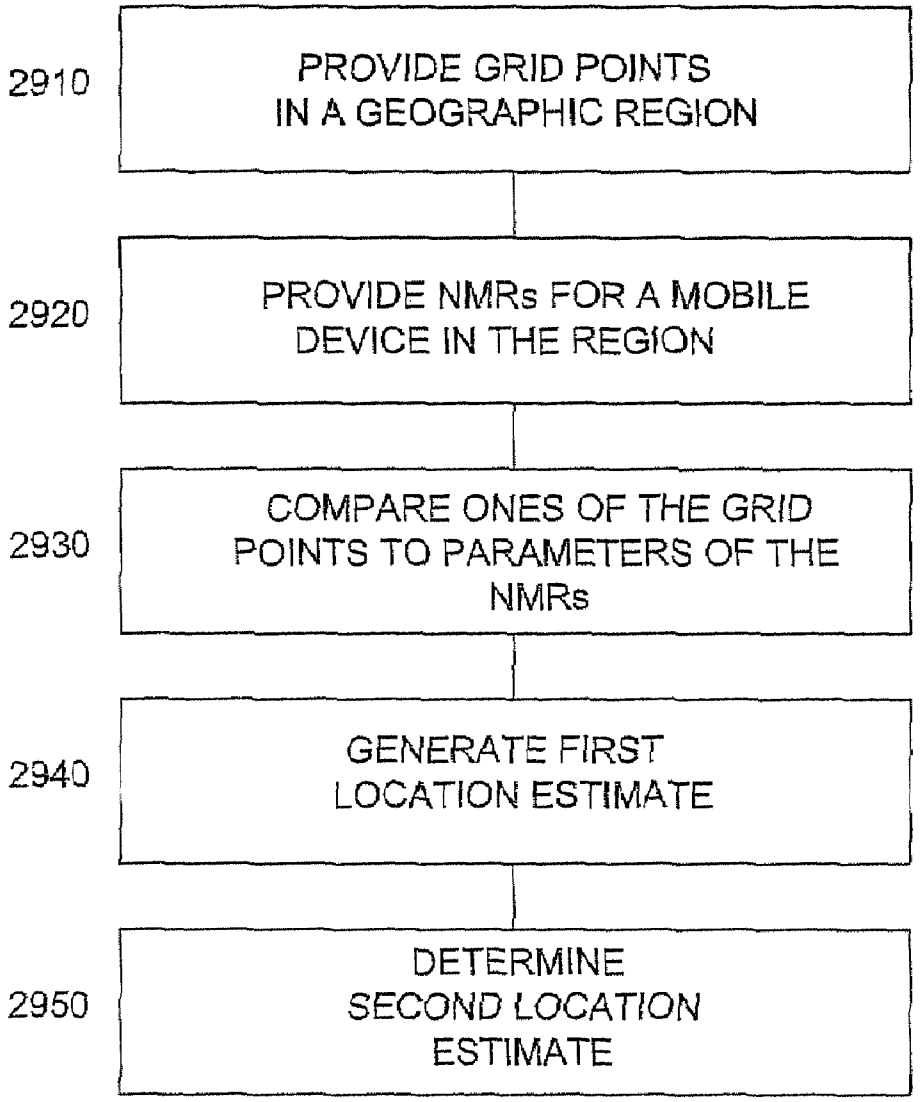

2910
PROVIDE GRID POINTS IN A GEOGRAPHIC REGION
2920
PROVIDE NMRs FOR A MOBILE DEVICE IN THE REGION
2930
COMPARE ONES OF THE GRID POINTS TO PARAMETERS OF THE NMRs
2940
GENERATE FIRST LOCATION ESTIMATE
2950
DETERMINE SECOND LOCATION ESTIMATE

FIG. 29

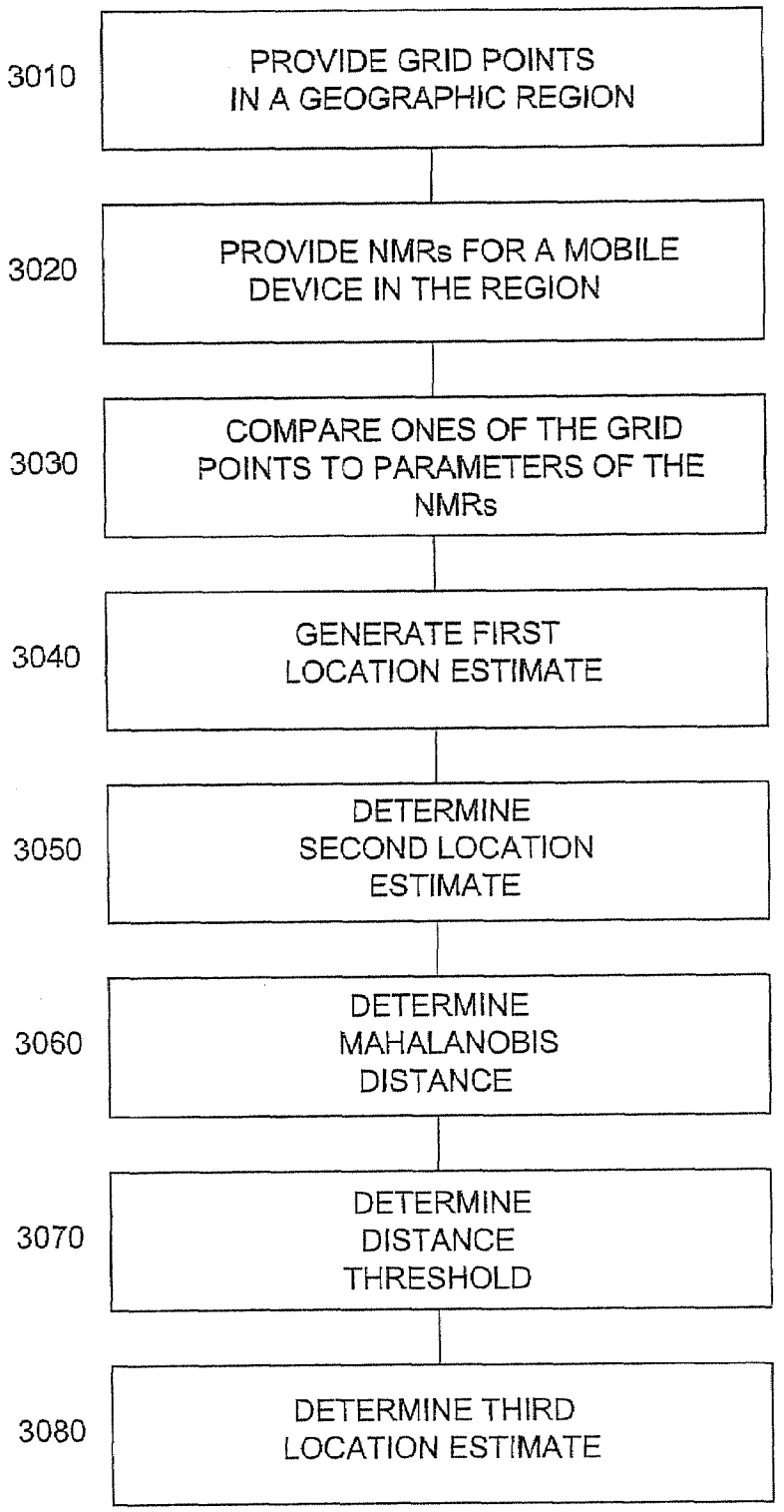

3010
PROVIDE GRID POINTS IN A GEOGRAPHIC REGION
3020
PROVIDE NMRs FOR A MOBILE DEVICE IN THE REGION
3030
COMPARE ONES OF THE GRID POINTS TO PARAMETERS OF THE NMRs
3040
GENERATE FIRST LOCATION ESTIMATE
3050
DETERMINE SECOND LOCATION ESTIMATE
3060
DETERMINE MAHALANOBIS DISTANCE
3070
DETERMINE DISTANCE THRESHOLD
3080
DETERMINE THIRD LOCATION ESTIMATE

FIG. 30

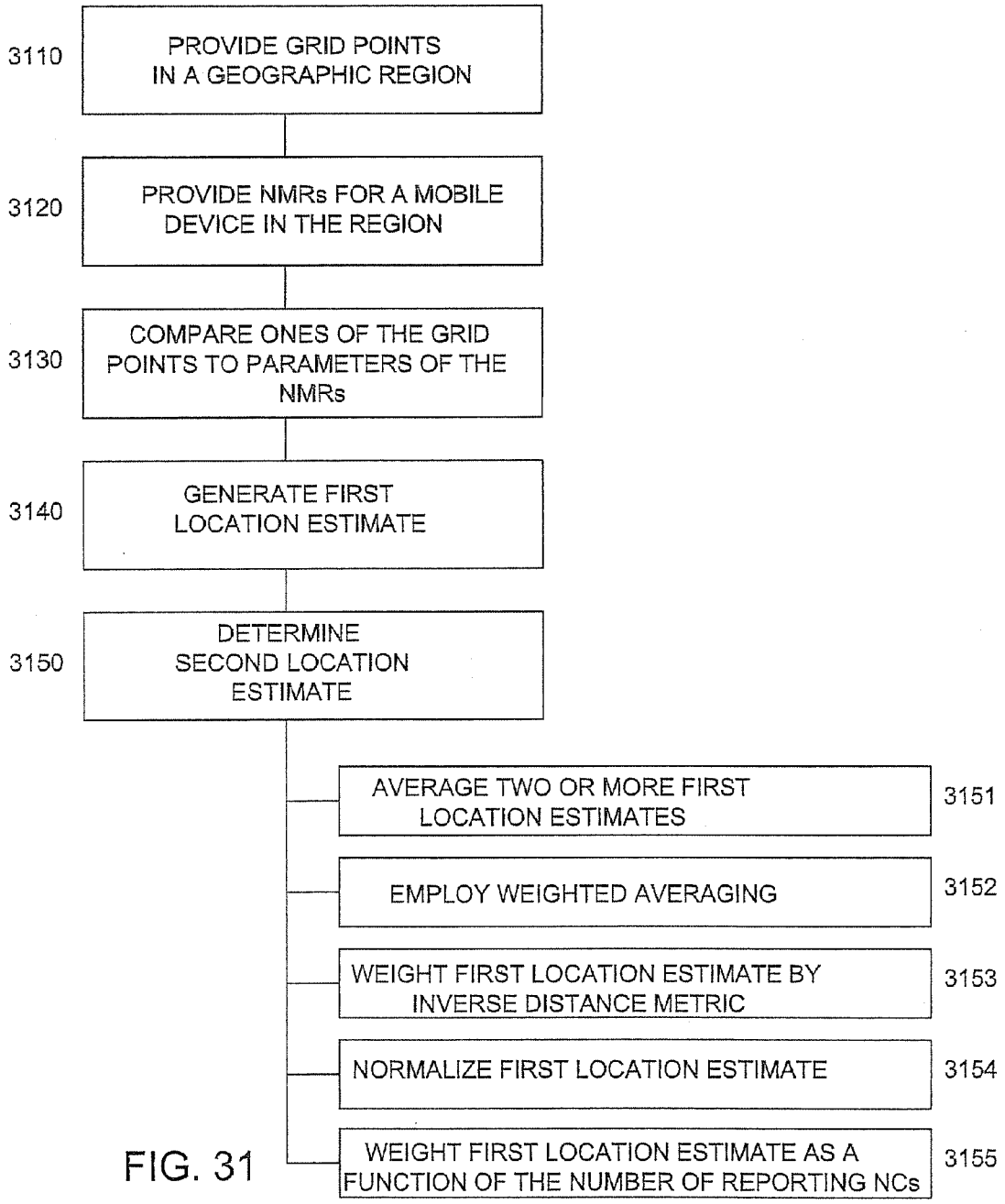

3110
PROVIDE GRID POINTS IN A GEOGRAPHIC REGION
3120
PROVIDE NMRs FOR A MOBILE DEVICE IN THE REGION
3130
COMPARE ONES OF THE GRID POINTS TO PARAMETERS OF THE NMRs
3140
GENERATE FIRST LOCATION ESTIMATE
3150
DETERMINE SECOND LOCATION ESTIMATE
AVERAGE TWO OR MORE FIRST LOCATION ESTIMATES
3151
EMPLOY WEIGHTED AVERAGING
3152
WEIGHT FIRST LOCATION ESTIMATE BY INVERSE DISTANCE METRIC
3153
NORMALIZE FIRST LOCATION ESTIMATE
3154
WEIGHT FIRST LOCATION ESTIMATE AS A FUNCTION OF THE NUMBER OF REPORTING NCs
3155

FIG. 31

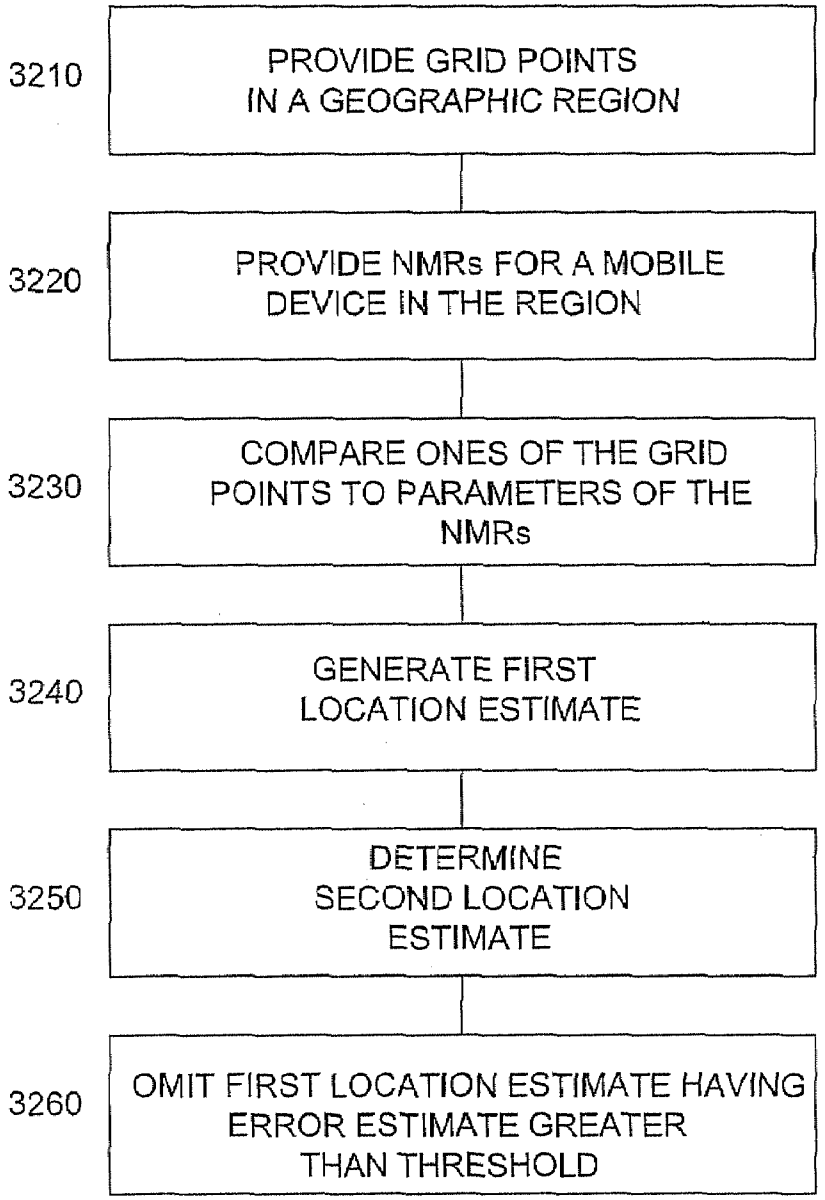

3210
PROVIDE GRID POINTS IN A GEOGRAPHIC REGION
3220
PROVIDE NMRs FOR A MOBILE DEVICE IN THE REGION
3230
COMPARE ONES OF THE GRID POINTS TO PARAMETERS OF THE NMRs
3240
GENERATE FIRST LOCATION ESTIMATE
3250
DETERMINE SECOND LOCATION ESTIMATE
3260
OMIT FIRST LOCATION ESTIMATE HAVING ERROR ESTIMATE GREATER THAN THRESHOLD

FIG. 32

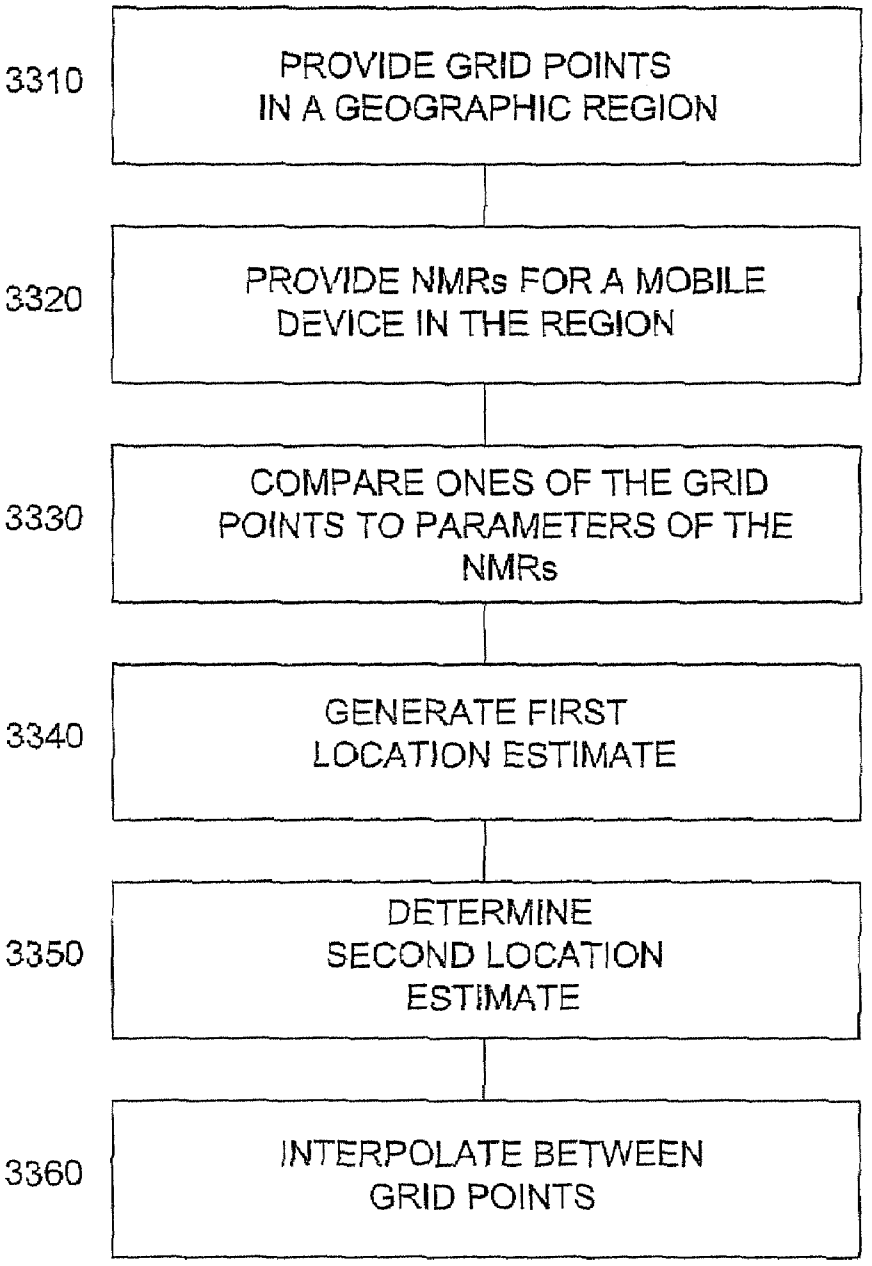

3310
PROVIDE GRID POINTS IN A GEOGRAPHIC REGION
3320
PROVIDE NMRs FOR A MOBILE DEVICE IN THE REGION
3330
COMPARE ONES OF THE GRID POINTS TO PARAMETERS OF THE NMRs
3340
GENERATE FIRST LOCATION ESTIMATE
3350
DETERMINE SECOND LOCATION ESTIMATE
3360
INTERPOLATE BETWEEN GRID POINTS

FIG. 33

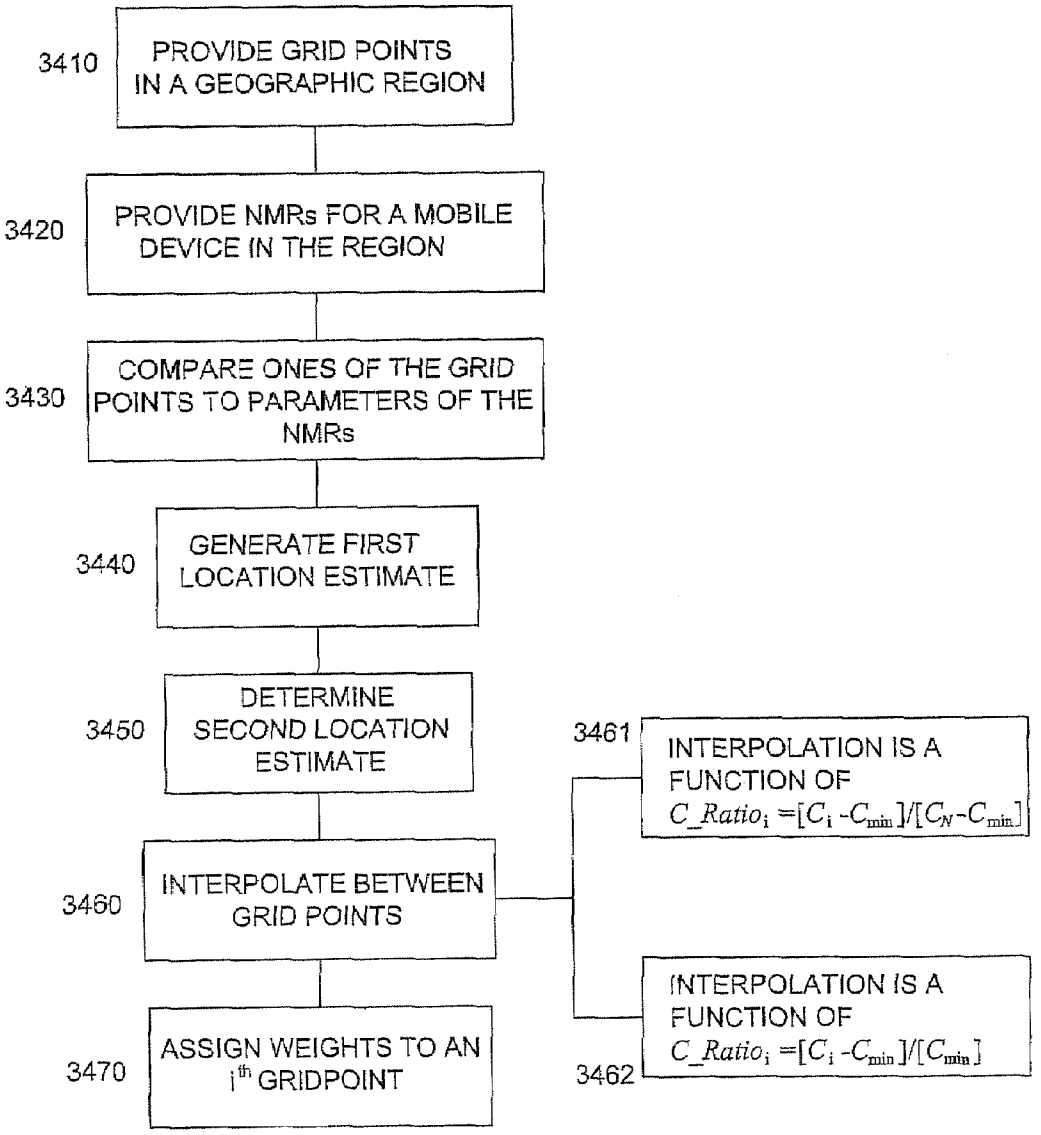

3410
PROVIDE GRID POINTS IN A GEOGRAPHIC REGION
3420
PROVIDE NMRs FOR A MOBILE DEVICE IN THE REGION
3430
COMPARE ONES OF THE GRID POINTS TO PARAMETERS OF THE NMRs
3440
GENERATE FIRST LOCATION ESTIMATE
3450
DETERMINE SECOND LOCATION ESTIMATE
3460
INTERPOLATE BETWEEN GRID POINTS
3470
ASSIGN WEIGHTS TO AN ith GRIDPOINT
3461
INTERPOLATION IS A FUNCTION OF $C_Ratio_i = [C_i - C_{min}]/[C_N - C_{min}]$
3462
INTERPOLATION IS A FUNCTION OF $C_Ratio_i = [C_i - C_{min}]/[C_{min}]$

FIG. 34

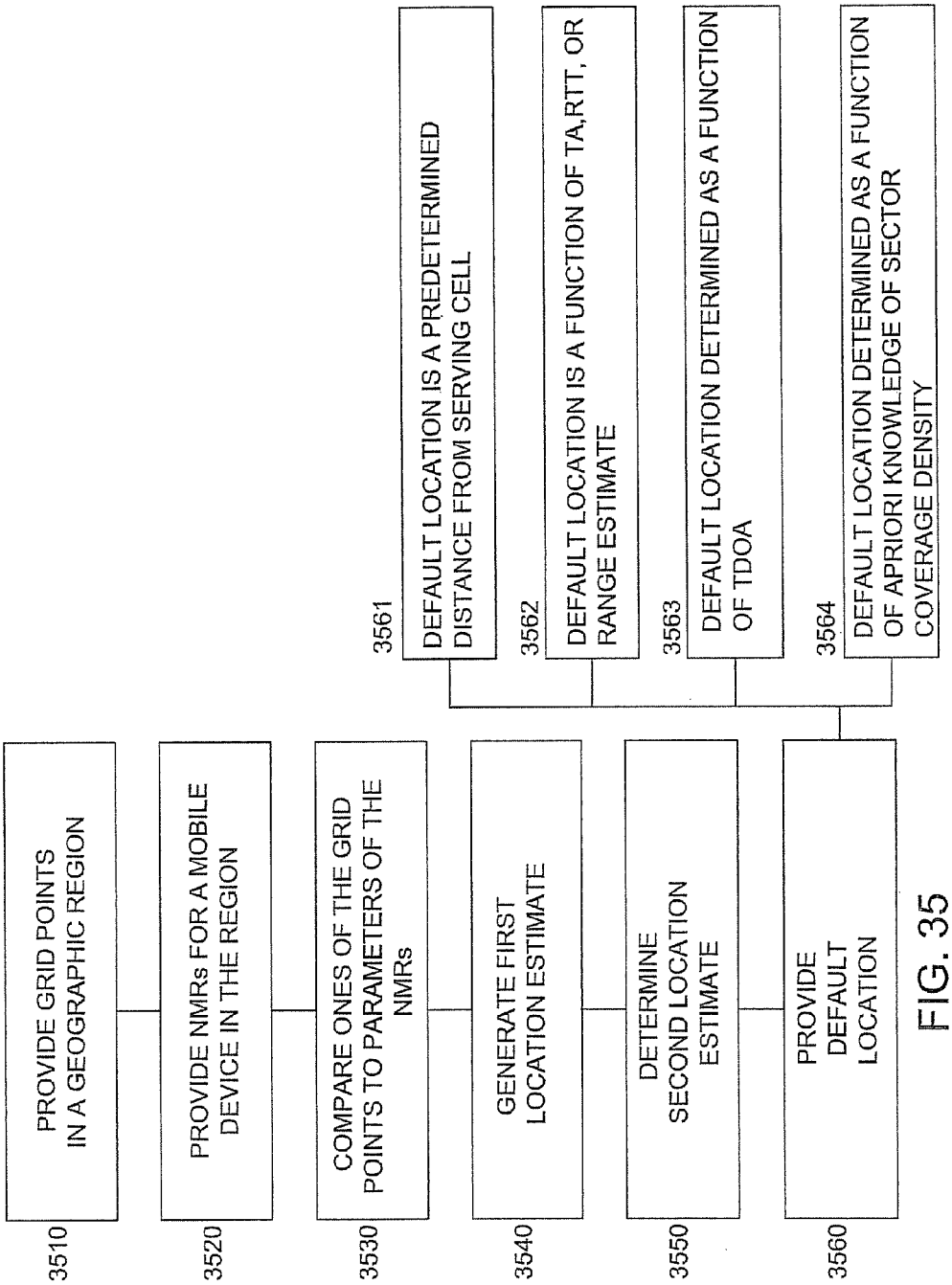

3510
PROVIDE GRID POINTS IN A GEOGRAPHIC REGION
3520
PROVIDE NMRs FOR A MOBILE DEVICE IN THE REGION
3530
COMPARE ONES OF THE GRID POINTS TO PARAMETERS OF THE NMRs
3540
GENERATE FIRST LOCATION ESTIMATE
3550
DETERMINE SECOND LOCATION ESTIMATE
3560
PROVIDE DEFAULT LOCATION
3561
DEFAULT LOCATION IS A PREDETERMINED DISTANCE FROM SERVING CELL
3562
DEFAULT LOCATION IS A FUNCTION OF TA,RTT, OR RANGE ESTIMATE
3563
DEFAULT LOCATION DETERMINED AS A FUNCTION OF TDOA
3564
DEFAULT LOCATION DETERMINED AS A FUNCTION OF APRIORI KNOWLEDGE OF SECTOR COVERAGE DENSITY

FIG. 35

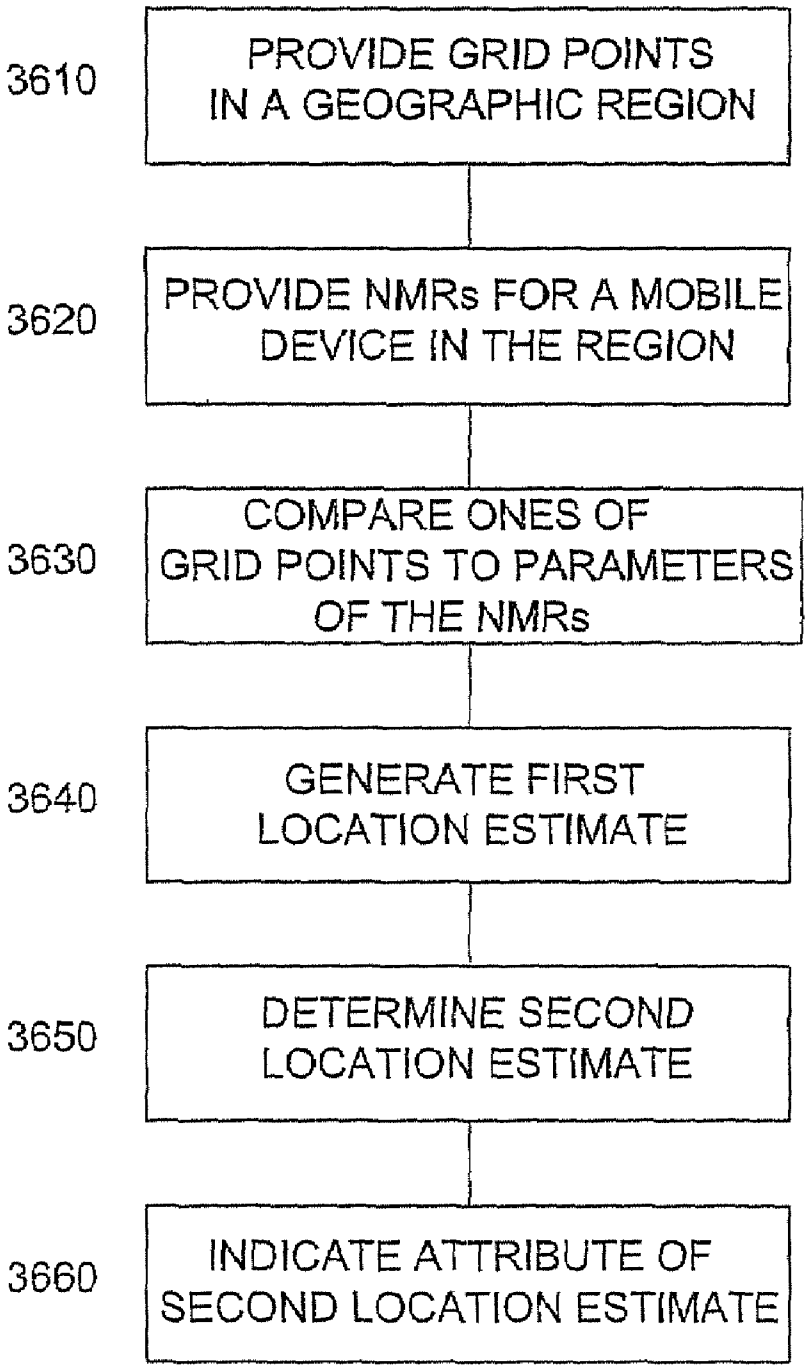

3610
PROVIDE GRID POINTS IN A GEOGRAPHIC REGION
3620
PROVIDE NMRs FOR A MOBILE DEVICE IN THE REGION
3630
COMPARE ONES OF GRID POINTS TO PARAMETERS OF THE NMRs
3640
GENERATE FIRST LOCATION ESTIMATE
3650
DETERMINE SECOND LOCATION ESTIMATE
3660
INDICATE ATTRIBUTE OF SECOND LOCATION ESTIMATE

FIG. 36

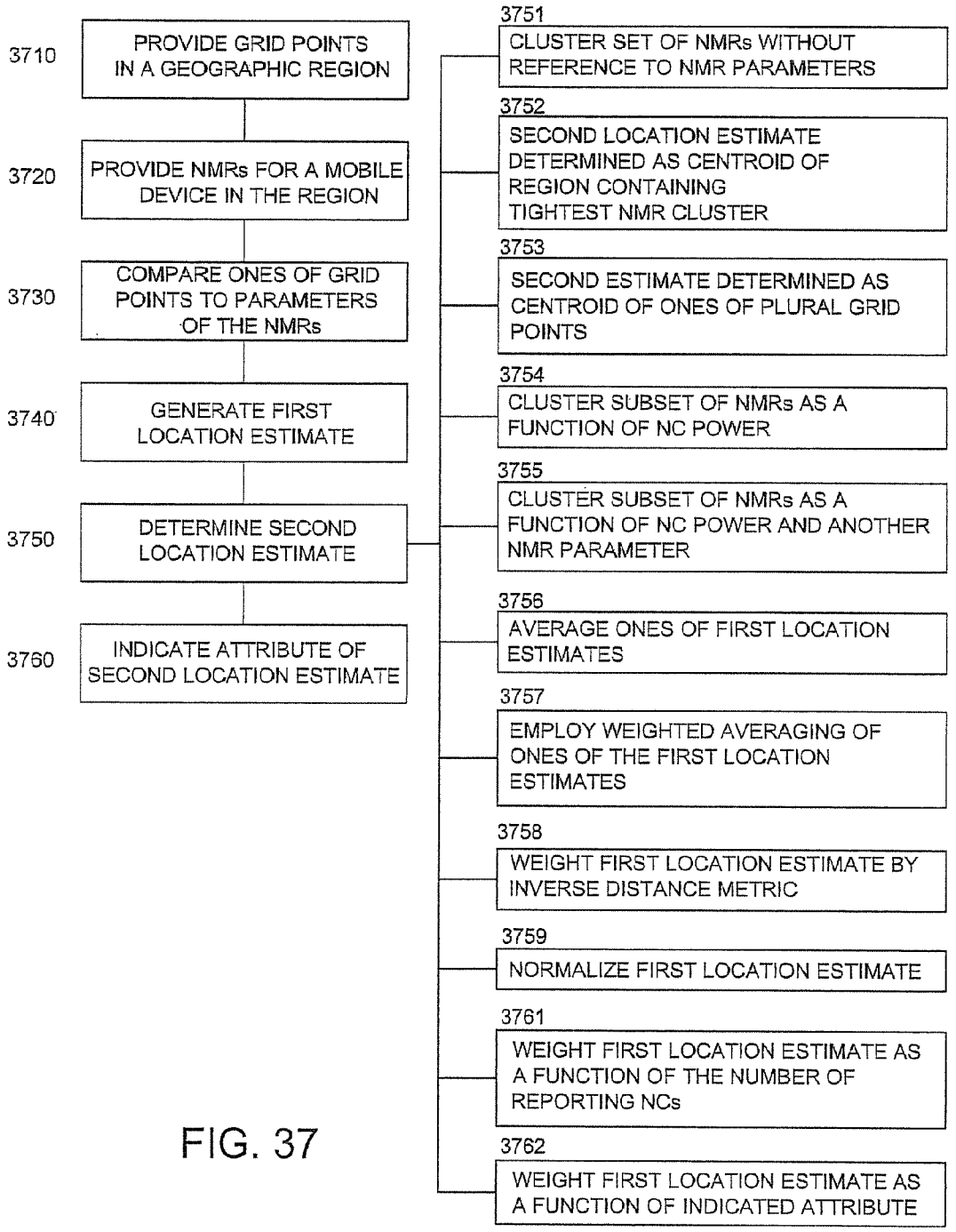

3710
PROVIDE GRID POINTS IN A GEOGRAPHIC REGION
3720
PROVIDE NMRs FOR A MOBILE DEVICE IN THE REGION
3730
COMPARE ONES OF GRID POINTS TO PARAMETERS OF THE NMRs
3740
GENERATE FIRST LOCATION ESTIMATE
3750
DETERMINE SECOND LOCATION ESTIMATE
3760
INDICATE ATTRIBUTE OF SECOND LOCATION ESTIMATE
3751
CLUSTER SET OF NMRs WITHOUT REFERENCE TO NMR PARAMETERS
3752
SECOND LOCATION ESTIMATE DETERMINED AS CENTROID OF REGION CONTAINING TIGHTEST NMR CLUSTER
3753
SECOND ESTIMATE DETERMINED AS CENTROID OF ONES OF PLURAL GRID POINTS
3754
CLUSTER SUBSET OF NMRs AS A FUNCTION OF NC POWER
3755
CLUSTER SUBSET OF NMRs AS A FUNCTION OF NC POWER AND ANOTHER NMR PARAMETER
3756
AVERAGE ONES OF FIRST LOCATION ESTIMATES
3757
EMPLOY WEIGHTED AVERAGING OF ONES OF THE FIRST LOCATION ESTIMATES
3758
WEIGHT FIRST LOCATION ESTIMATE BY INVERSE DISTANCE METRIC
3759
NORMALIZE FIRST LOCATION ESTIMATE
3761
WEIGHT FIRST LOCATION ESTIMATE AS A FUNCTION OF THE NUMBER OF REPORTING NCs
3762
WEIGHT FIRST LOCATION ESTIMATE AS A FUNCTION OF INDICATED ATTRIBUTE

FIG. 37

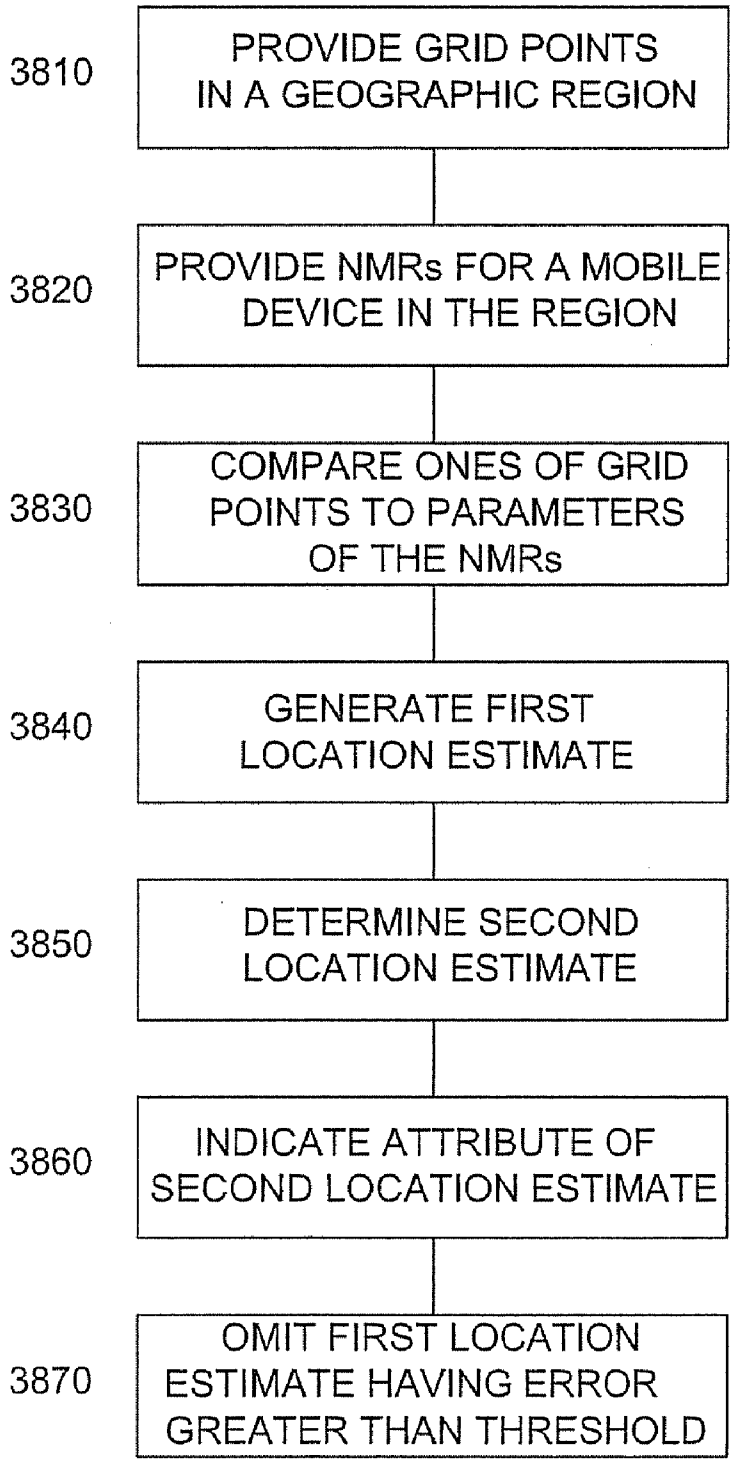

3810
PROVIDE GRID POINTS IN A GEOGRAPHIC REGION
3820
PROVIDE NMRs FOR A MOBILE DEVICE IN THE REGION
3830
COMPARE ONES OF GRID POINTS TO PARAMETERS OF THE NMRs
3840
GENERATE FIRST LOCATION ESTIMATE
3850
DETERMINE SECOND LOCATION ESTIMATE
3860
INDICATE ATTRIBUTE OF SECOND LOCATION ESTIMATE
3870
OMIT FIRST LOCATION ESTIMATE HAVING ERROR GREATER THAN THRESHOLD

FIG. 38

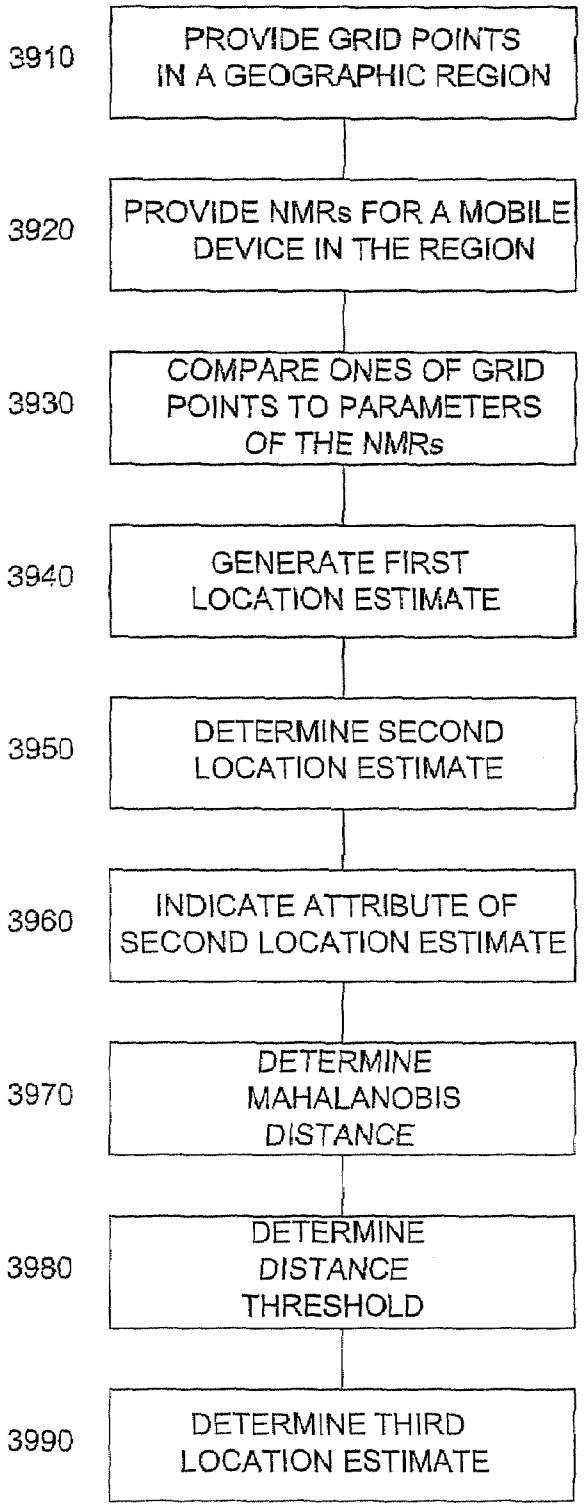

3910
PROVIDE GRID POINTS IN A GEOGRAPHIC REGION
3920
PROVIDE NMRs FOR A MOBILE DEVICE IN THE REGION
3930
COMPARE ONES OF GRID POINTS TO PARAMETERS OF THE NMRs
3940
GENERATE FIRST LOCATION ESTIMATE
3950
DETERMINE SECOND LOCATION ESTIMATE
3960
INDICATE ATTRIBUTE OF SECOND LOCATION ESTIMATE
3970
DETERMINE MAHALANOBIS DISTANCE
3980
DETERMINE DISTANCE THRESHOLD
3990
DETERMINE THIRD LOCATION ESTIMATE

FIG. 39

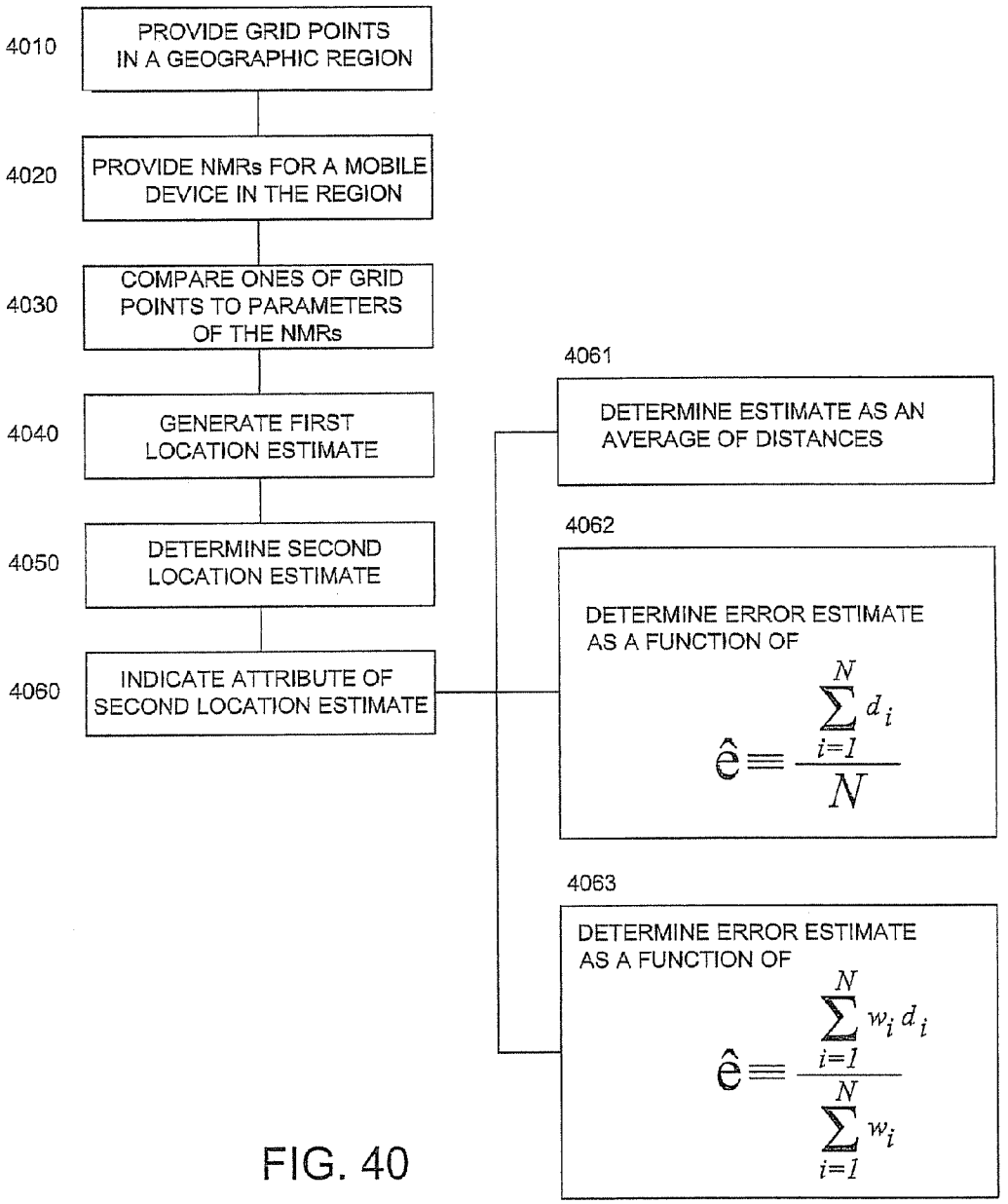
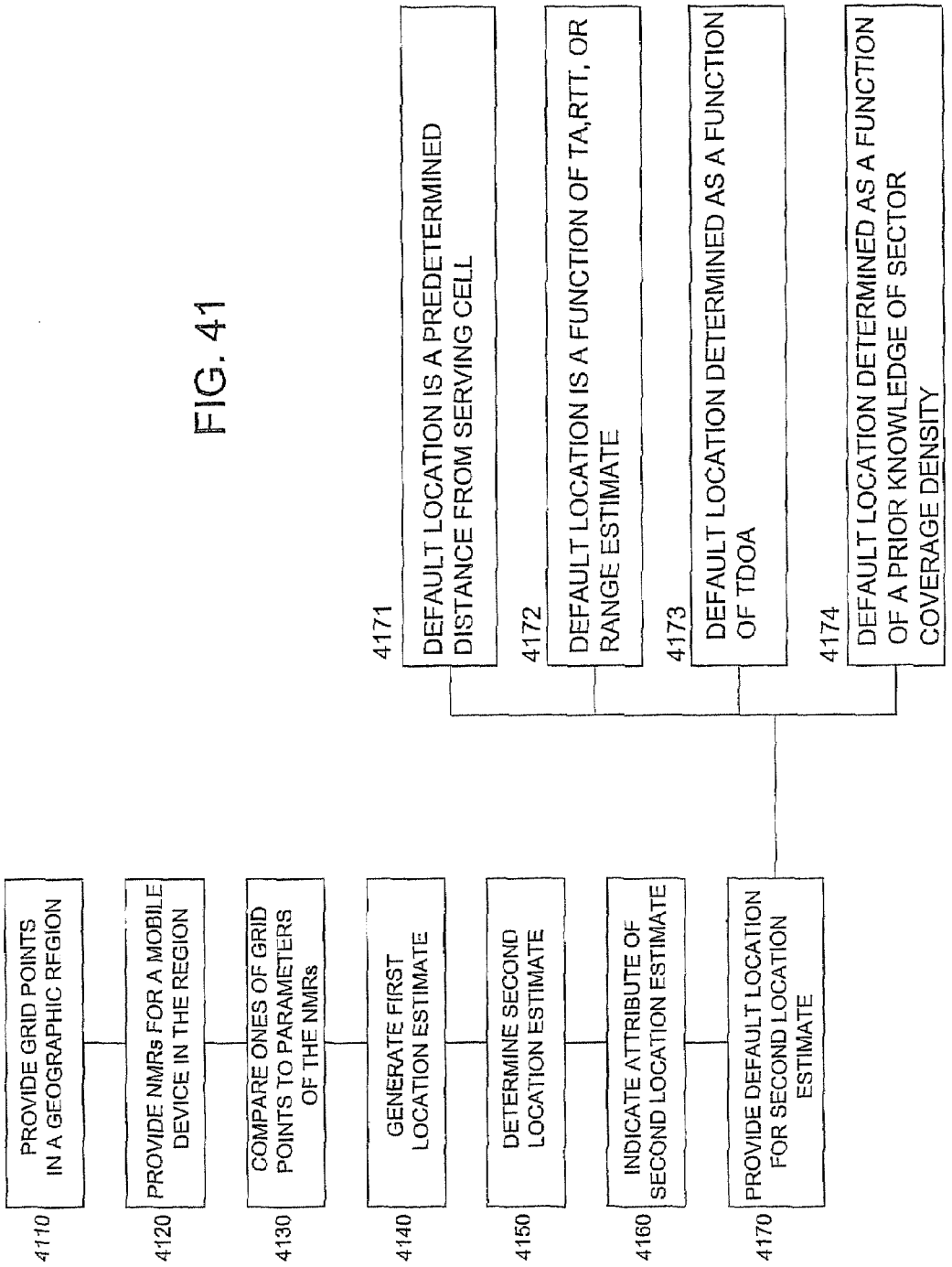

4010
PROVIDE GRID POINTS IN A GEOGRAPHIC REGION
4020
PROVIDE NMRs FOR A MOBILE DEVICE IN THE REGION
4030
COMPARE ONES OF GRID POINTS TO PARAMETERS OF THE NMRs
4040
GENERATE FIRST LOCATION ESTIMATE
4050
DETERMINE SECOND LOCATION ESTIMATE
4060
INDICATE ATTRIBUTE OF SECOND LOCATION ESTIMATE
4061
DETERMINE ESTIMATE AS AN AVERAGE OF DISTANCES
4062
DETERMINE ERROR ESTIMATE AS A FUNCTION OF
$\hat{e} \equiv \frac{\sum_{i=1}^{N} d_i}{N}$
4063
DETERMINE ERROR ESTIMATE AS A FUNCTION OF
$\hat{e} \equiv \frac{\sum_{i=1}^{N} w_i d_i}{\sum_{i=1}^{N} w_i}$

FIG. 40

FIG. 41


4110
PROVIDE GRID POINTS IN A GEOGRAPHIC RFGION
4120
PROVIDE NMRs FOR A MOBILE DEVICE IN THE REGION
4130
COMPARE ONES OF GRID POINTS TO PARAMETERS OF THE NMRs
4140
GENERATE FIRST LOCATION ESTIMATE
4150
DETERMINE SECOND LOCATION ESTIMATE
4160
INDICATE ATTRIBUTE OF SECOND LOCATION ESTIMATE
4170
PROVIDE DEFAULT LOCATION FOR SECOND LOCATION ESTIMATE
4171
DEFAULT LOCATION IS A PREDETERMINED DISTANCE FROM SERVING CELL
4172
DEFAULT LOCATION IS A FUNCTION OF TA,RTT, OR RANGE ESTIMATE
4173
DEFAULT LOCATION DETERMINED AS A FUNCTION OF TDOA
4174
DEFAULT LOCATION DETERMINED AS A FUNCTION OF A PRIOR KNOWLEDGE OF SECTOR COVERAGE DENSITY

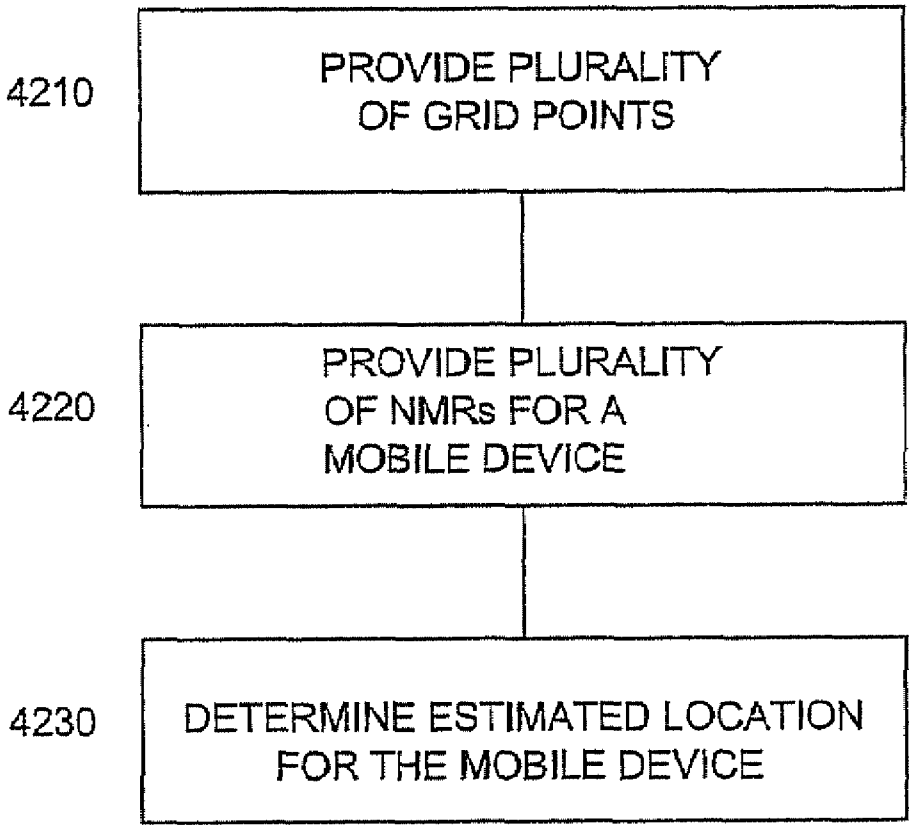

4210
PROVIDE PLURALITY OF GRID POINTS
4220
PROVIDE PLURALITY OF NMRs FOR A MOBILE DEVICE
4230
DETERMINE ESTIMATED LOCATION FOR THE MOBILE DEVICE

FIG. 42

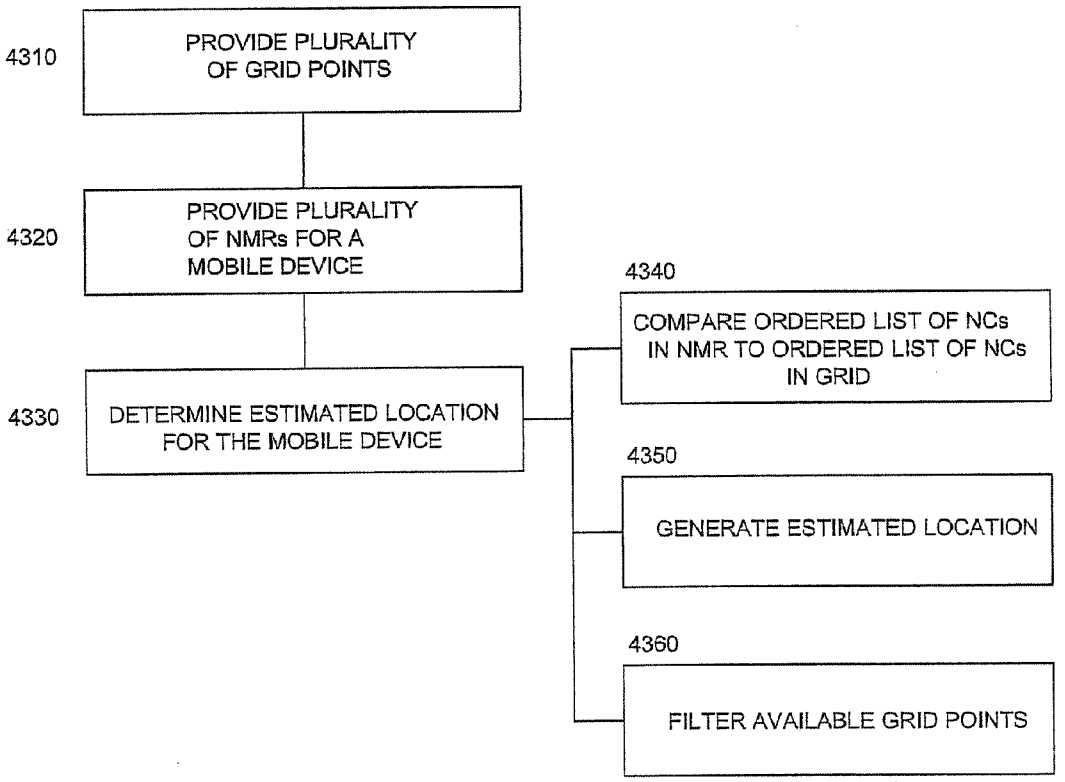

4310
PROVIDE PLURALITY OF GRID POINTS
4320
PROVIDE PLURALITY OF NMRs FOR A MOBILE DEVICE
4330
DETERMINE ESTIMATED LOCATION FOR THE MOBILE DEVICE
4340
COMPARE ORDERED LIST OF NCs IN NMR TO ORDERED LIST OF NCs IN GRID
4350
GENERATE ESTIMATED LOCATION
4360
FILTER AVAILABLE GRID POINTS

FIG. 43

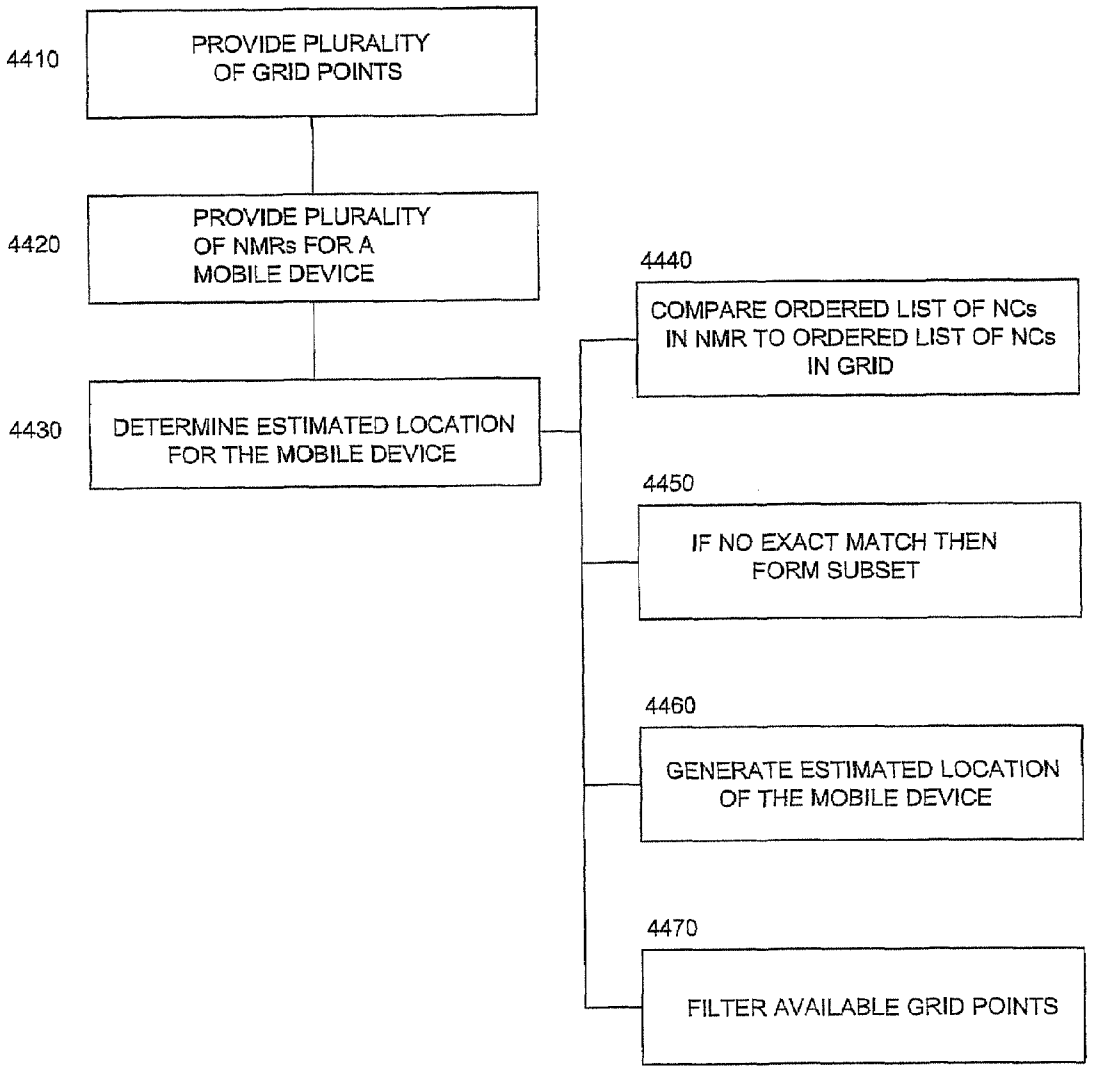

4410
PROVIDE PLURALITY OF GRID POINTS
4420
PROVIDE PLURALITY OF NMRs FOR A MOBILE DEVICE
4430
DETERMINE ESTIMATED LOCATION FOR THE MOBILE DEVICE
4440
COMPARE ORDERED LIST OF NCs IN NMR TO ORDERED LIST OF NCs IN GRID
4450
IF NO EXACT MATCH THEN FORM SUBSET
4460
GENERATE ESTIMATED LOCATION OF THE MOBILE DEVICE
4470
FILTER AVAILABLE GRID POINTS

FIG. 44

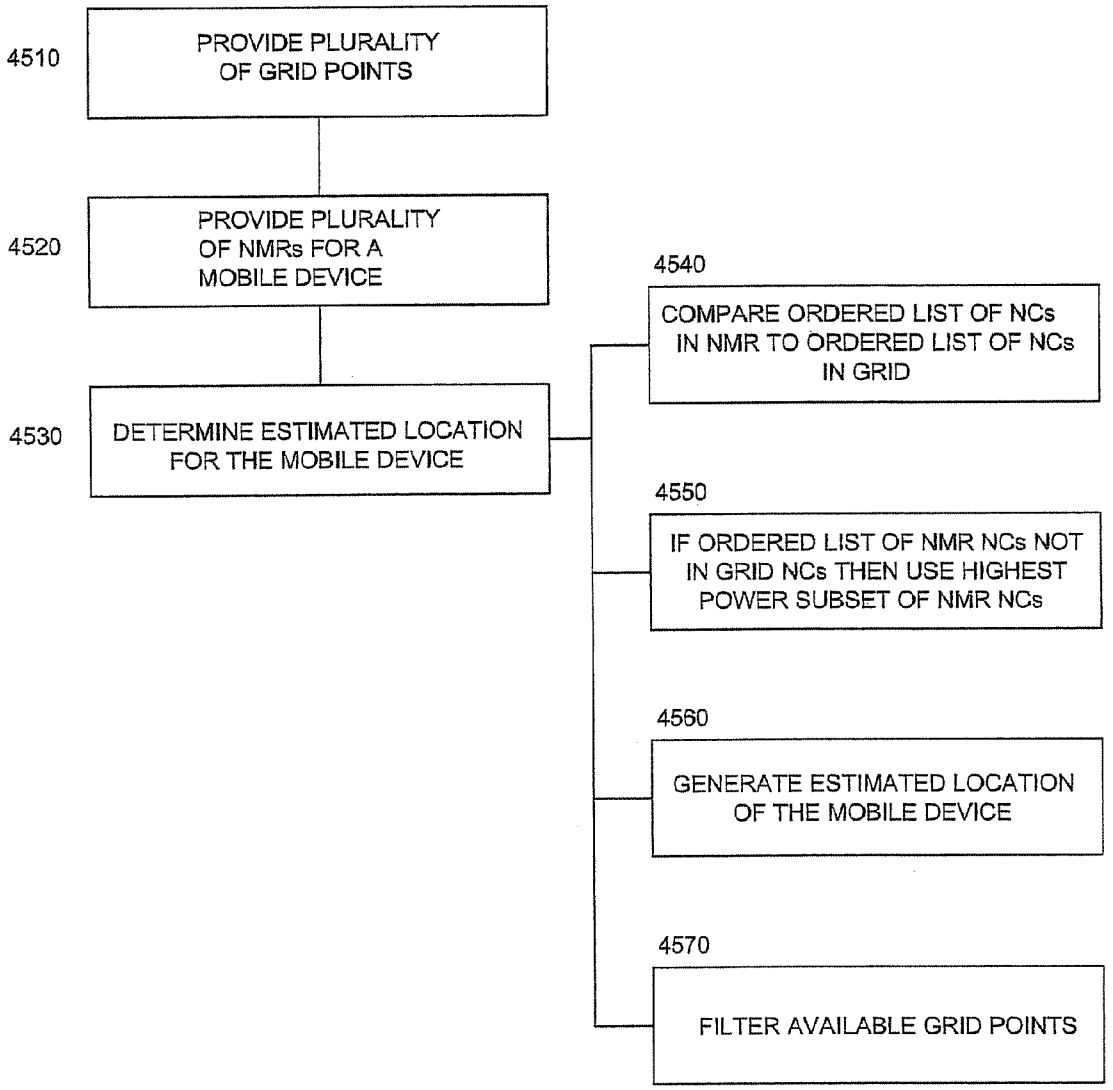

4510
PROVIDE PLURALITY OF GRID POINTS
4520
PROVIDE PLURALITY OF NMRs FOR A MOBILE DEVICE
4530
DETERMINE ESTIMATED LOCATION FOR THE MOBILE DEVICE
4540
COMPARE ORDERED LIST OF NCs IN NMR TO ORDERED LIST OF NCs IN GRID
4550
IF ORDERED LIST OF NMR NCs NOT IN GRID NCs THEN USE HIGHEST POWER SUBSET OF NMR NCs
4560
GENERATE ESTIMATED LOCATION OF THE MOBILE DEVICE
4570
FILTER AVAILABLE GRID POINTS

FIG. 45

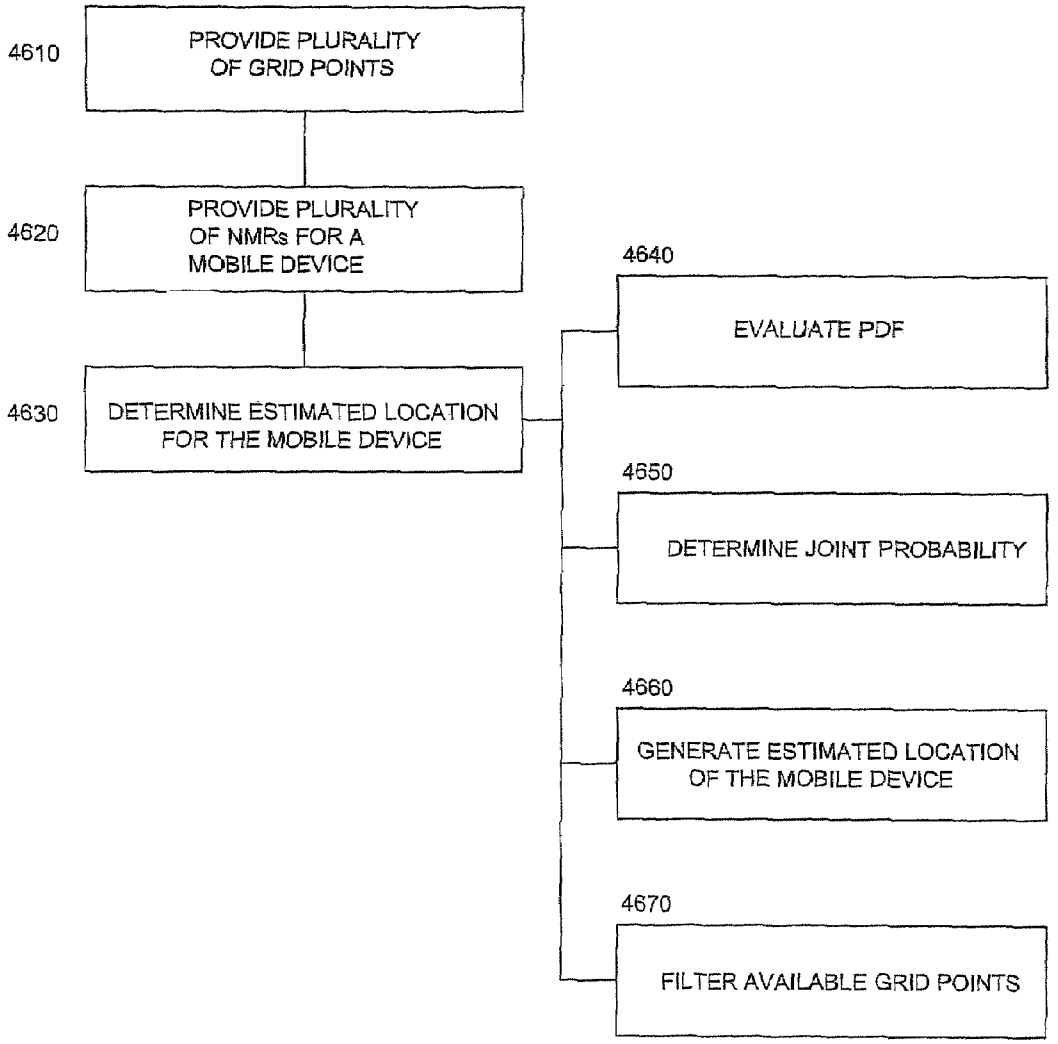

4610
PROVIDE PLURALITY OF GRID POINTS
4620
PROVIDE PLURALITY OF NMRs FOR A MOBILE DEVICE
4630
DETERMINE ESTIMATED LOCATION FOR THE MOBILE DEVICE
4640
EVALUATE PDF
4650
DETERMINE JOINT PROBABILITY
4660
GENERATE ESTIMATED LOCATION OF THE MOBILE DEVICE
4670
FILTER AVAILABLE GRID POINTS

FIG. 46

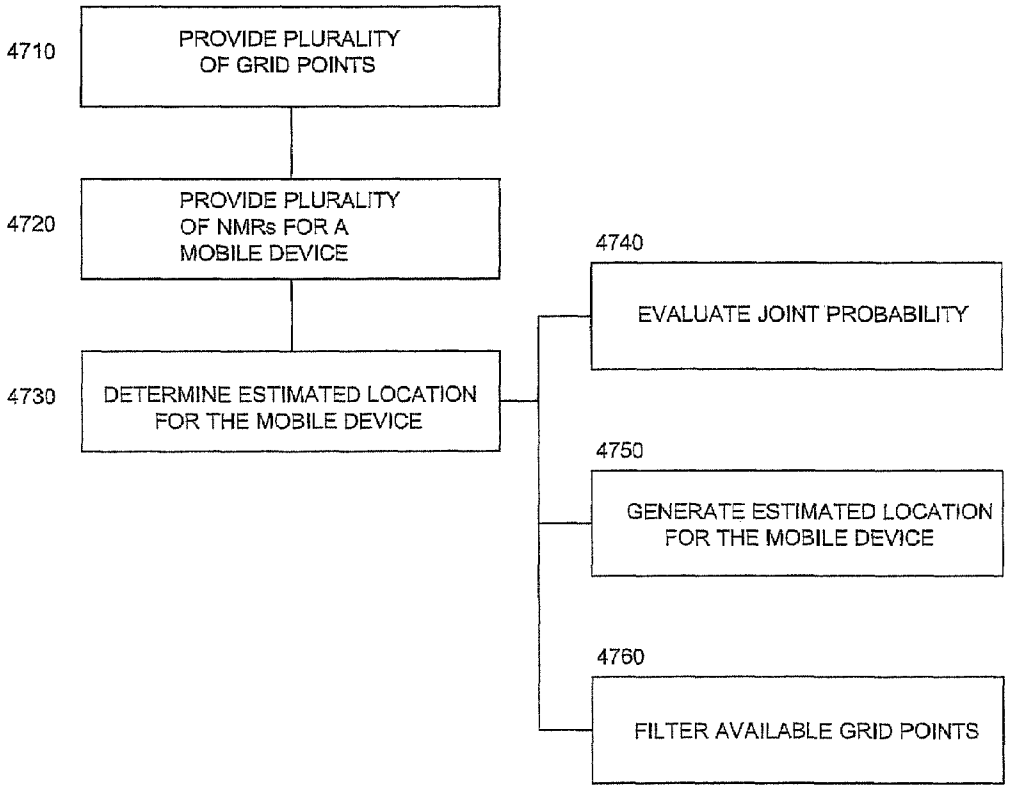

4710
PROVIDE PLURALITY OF GRID POINTS
4720
PROVIDE PLURALITY OF NMRs FOR A MOBILE DEVICE
4730
DETERMINE ESTIMATED LOCATION FOR THE MOBILE DEVICE
4740
EVALUATE JOINT PROBABILITY
4750
GENERATE ESTIMATED LOCATION FOR THE MOBILE DEVICE
4760
FILTER AVAILABLE GRID POINTS

FIG. 47

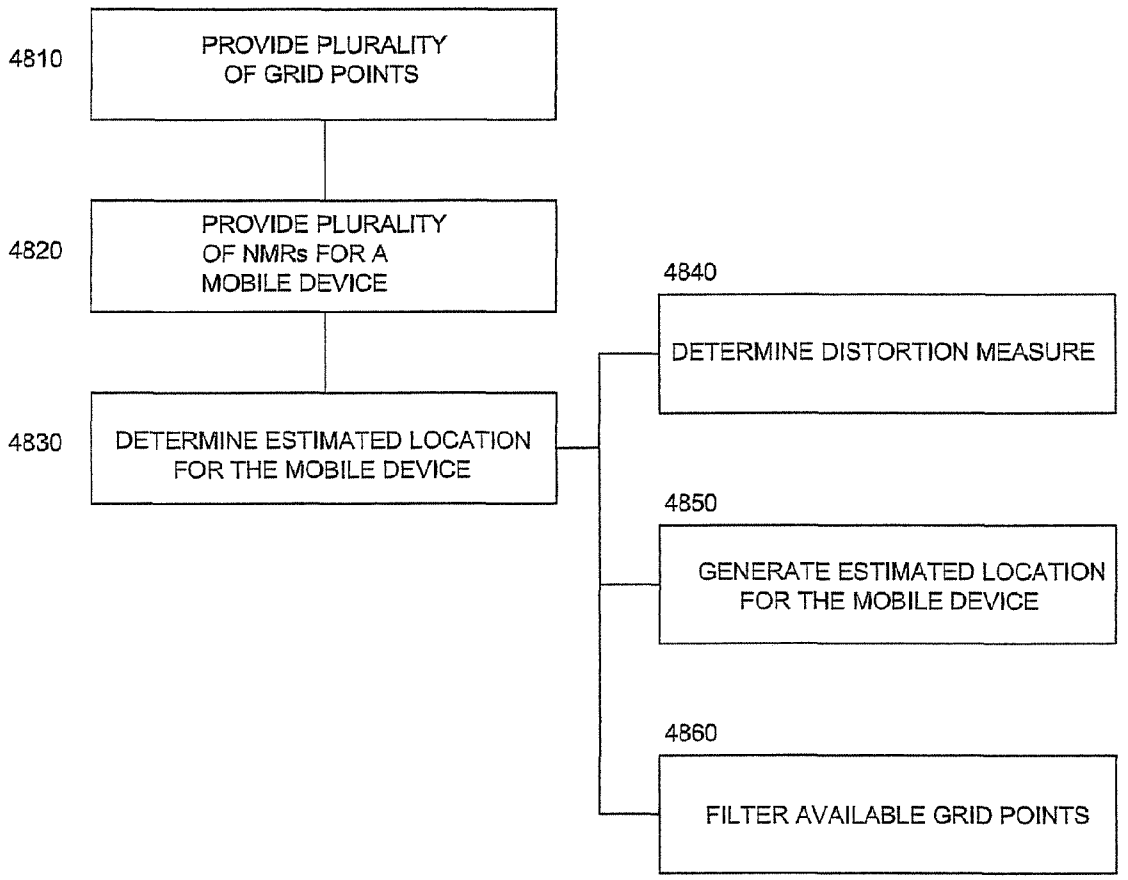

4810
PROVIDE PLURALITY OF GRID POINTS
4820
PROVIDE PLURALITY OF NMRs FOR A MOBILE DEVICE
4830
DETERMINE ESTIMATED LOCATION FOR THE MOBILE DEVICE
4840
DETERMINE DISTORTION MEASURE
4850
GENERATE ESTIMATED LOCATION FOR THE MOBILE DEVICE
4860
FILTER AVAILABLE GRID POINTS

FIG. 48

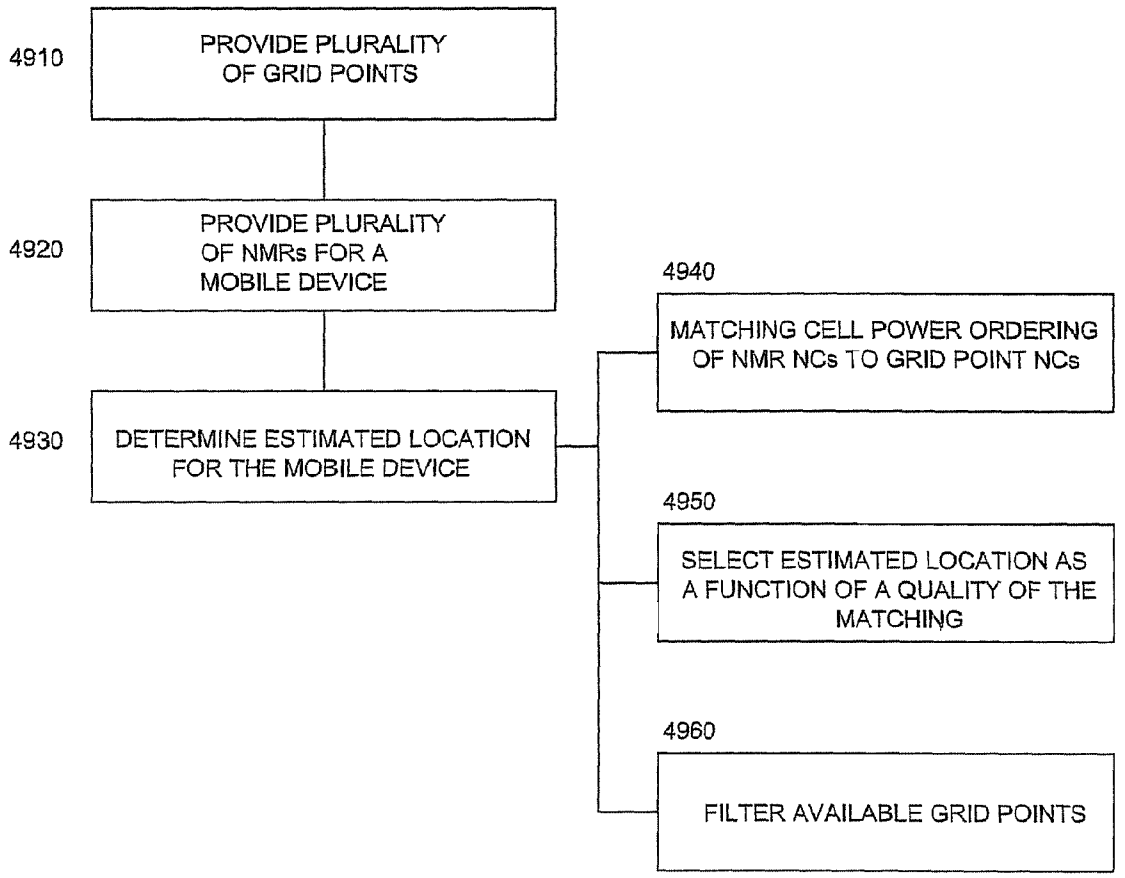

4910
PROVIDE PLURALITY OF GRID POINTS
4920
PROVIDE PLURALITY OF NMRs FOR A MOBILE DEVICE
4930
DETERMINE ESTIMATED LOCATION FOR THE MOBILE DEVICE
4940
MATCHING CELL POWER ORDERING OF NMR NCs TO GRID POINT NCs
4950
SELECT ESTIMATED LOCATION AS A FUNCTION OF A QUALITY OF THE MATCHING
4960
FILTER AVAILABLE GRID POINTS

FIG. 49

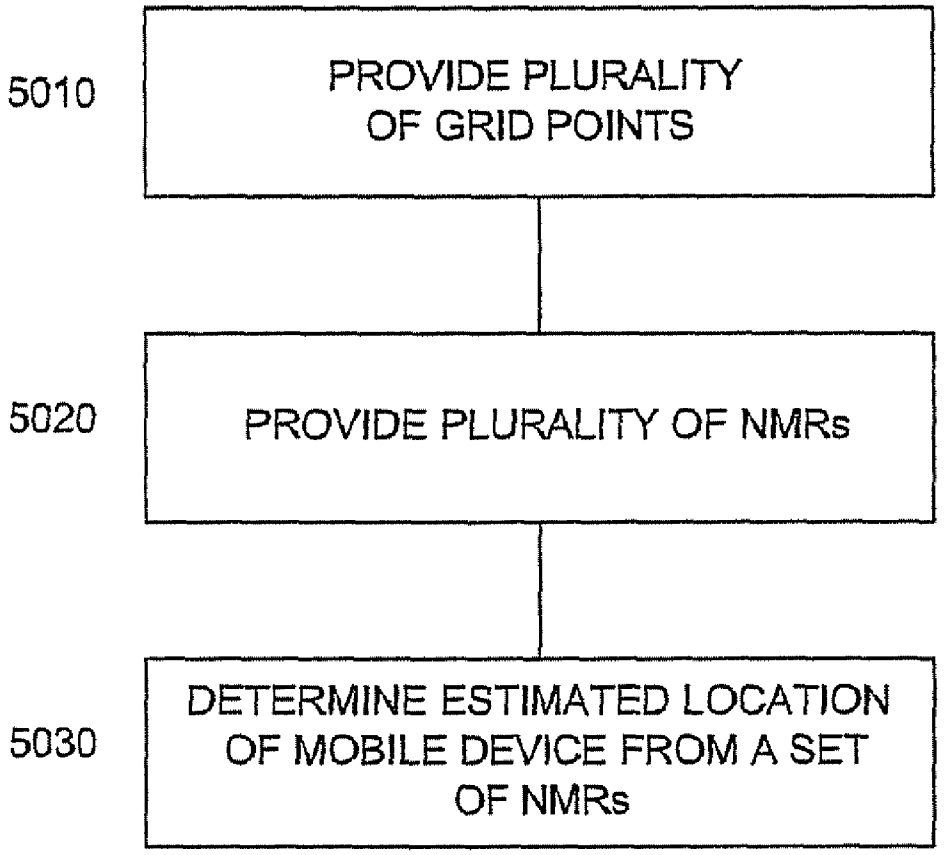

5010
PROVIDE PLURALITY OF GRID POINTS
5020
PROVIDE PLURALITY OF NMRs
5030
DETERMINE ESTIMATED LOCATION OF MOBILE DEVICE FROM A SET OF NMRs

FIG. 50

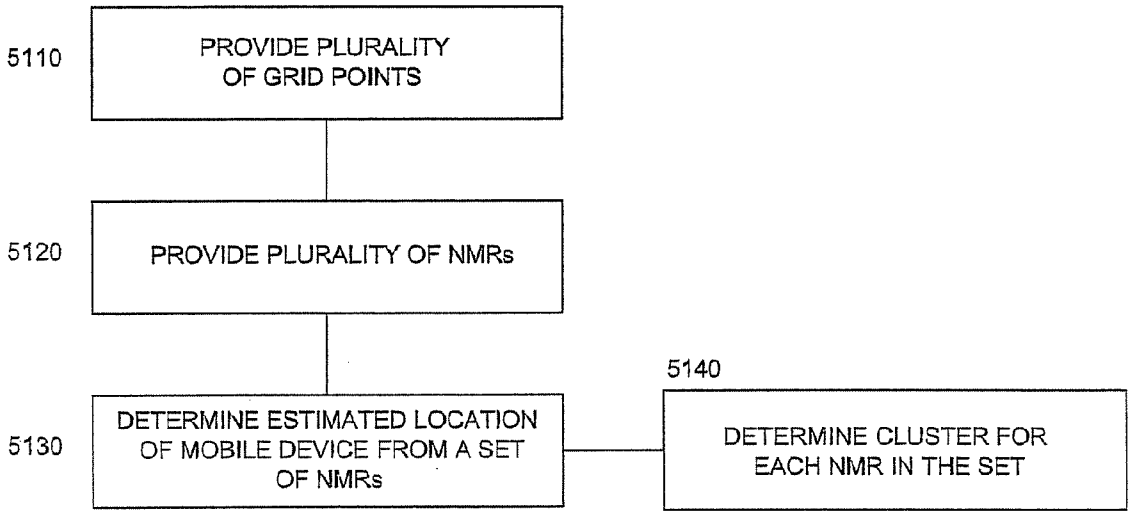

5110
PROVIDE PLURALITY OF GRID POINTS
5120
PROVIDE PLURALITY OF NMRs
5130
DETERMINE ESTIMATED LOCATION OF MOBILE DEVICE FROM A SET OF NMRs
5140
DETERMINE CLUSTER FOR EACH NMR IN THE SET

FIG. 51

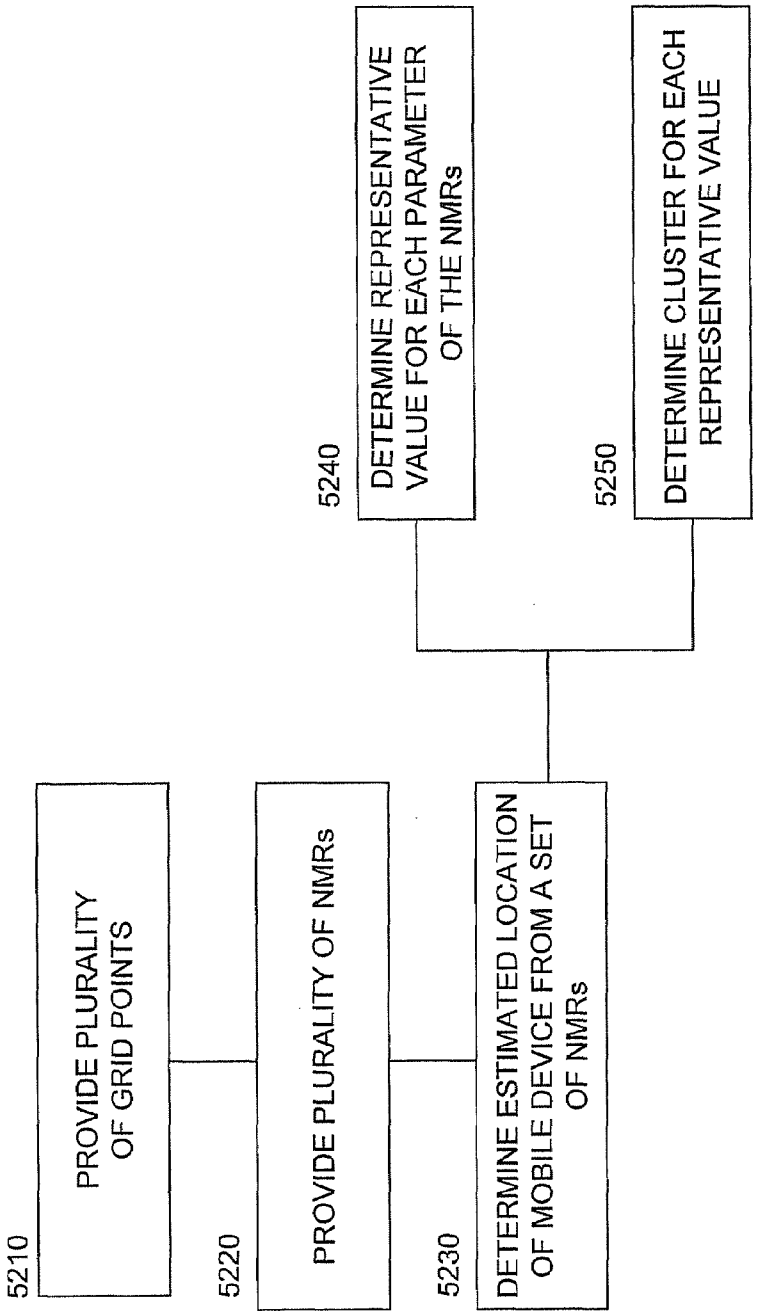

5210
PROVIDE PLURALITY OF GRID POINTS
5220
PROVIDE PLURALITY OF NMRs
5230
DETERMINE ESTIMATED LOCATION OF MOBILE DEVICE FROM A SET OF NMRs
5240
DETERMINE REPRESENTATIVE VALUE FOR EACH PARAMETER OF THE NMRs
5250
DETERMINE CLUSTER FOR EACH REPRESENTATIVE VALUE

FIGURE 52

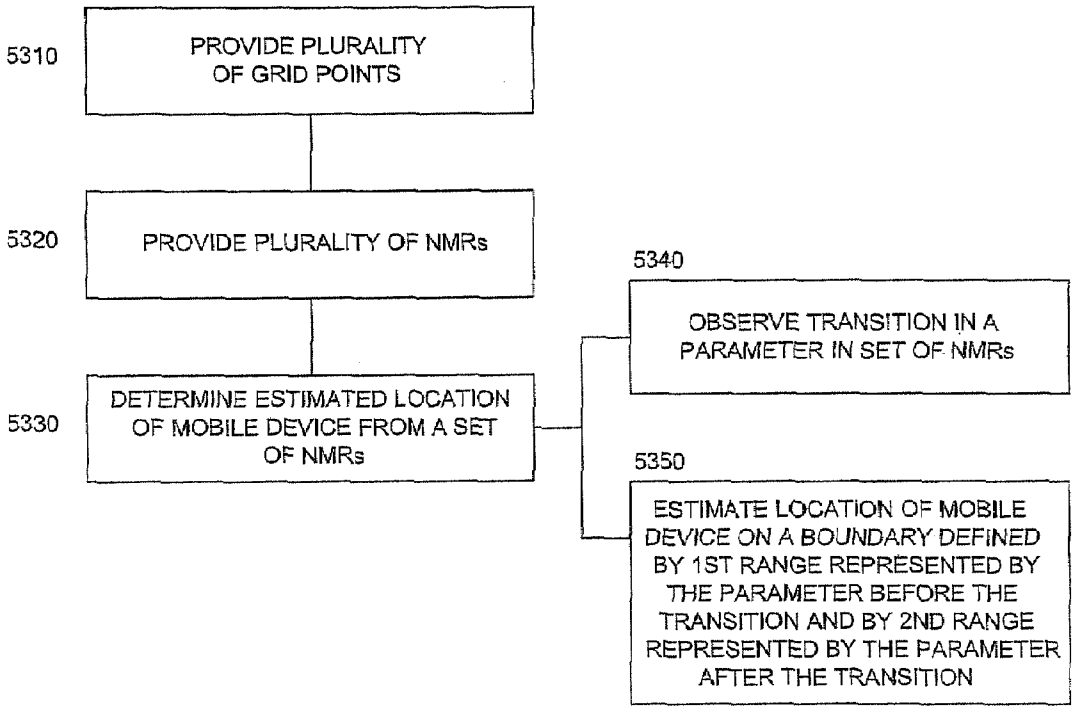

5310
PROVIDE PLURALITY OF GRID POINTS
5320
PROVIDE PLURALITY OF NMRs
5330
DETERMINE ESTIMATED LOCATION OF MOBILE DEVICE FROM A SET OF NMRs
5340
OBSERVE TRANSITION IN A PARAMETER IN SET OF NMRs
5350
ESTIMATE LOCATION OF MOBILE DEVICE ON A BOUNDARY DEFINED BY 1ST RANGE REPRESENTED BY THE PARAMETER BEFORE THE TRANSITION AND BY 2ND RANGE REPRESENTED BY THE PARAMETER AFTER THE TRANSITION

FIG. 53

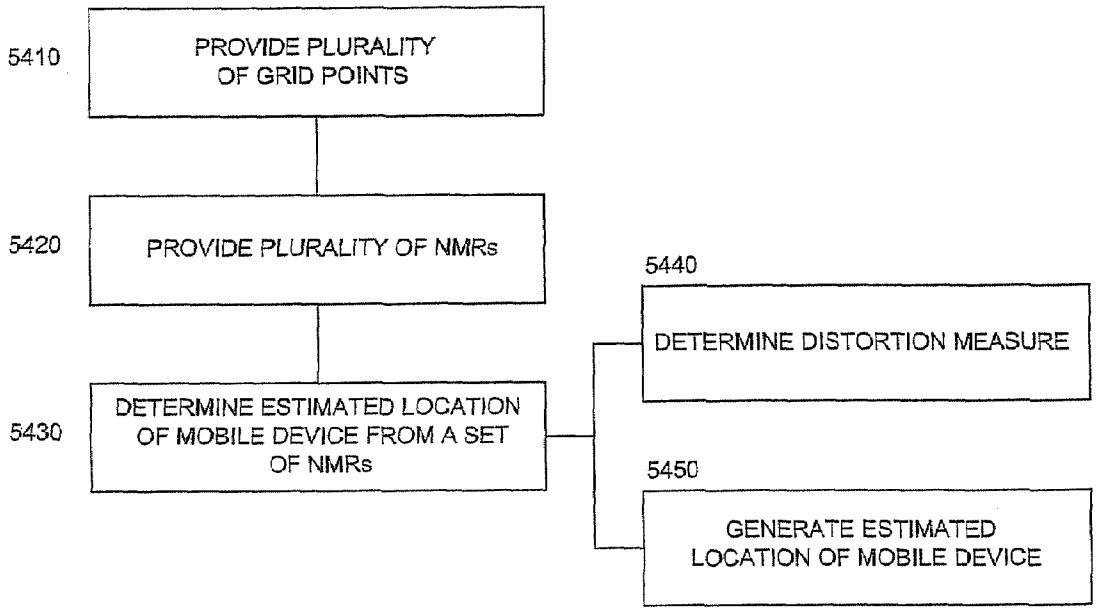

5410
PROVIDE PLURALITY OF GRID POINTS
5420
PROVIDE PLURALITY OF NMRs
5430
DETERMINE ESTIMATED LOCATION OF MOBILE DEVICE FROM A SET OF NMRs
5440
DETERMINE DISTORTION MEASURE
5450
GENERATE ESTIMATED LOCATION OF MOBILE DEVICE

FIG. 54

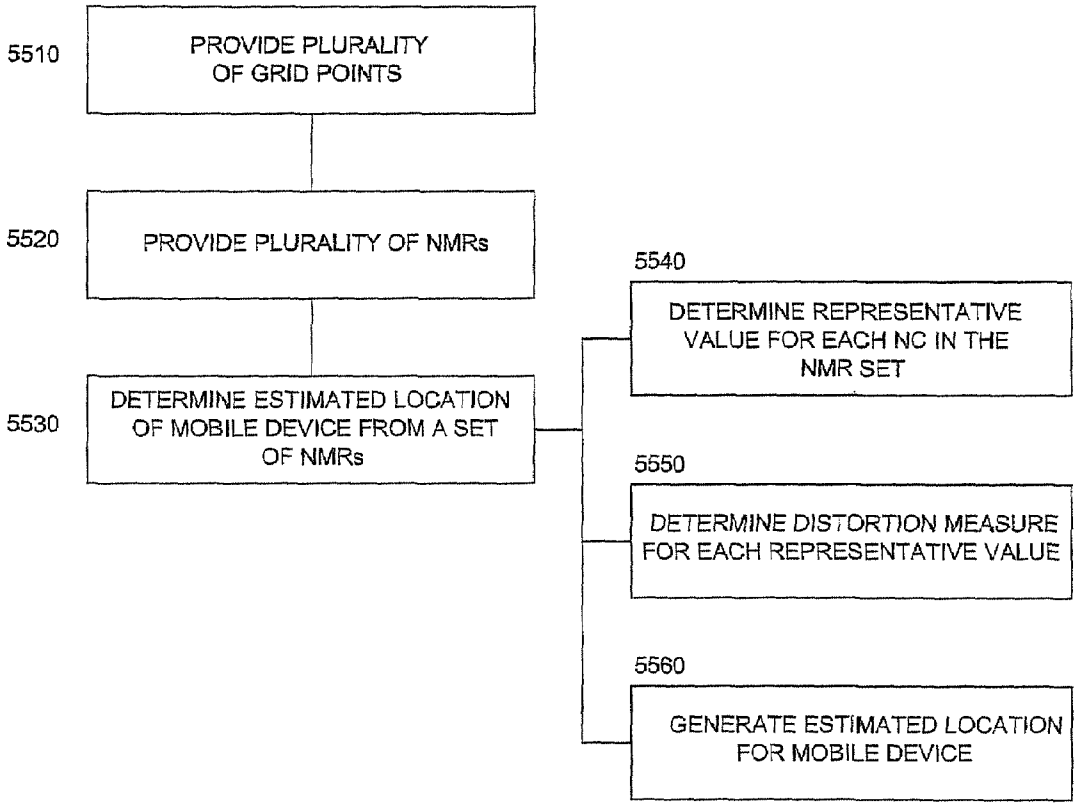

5510
PROVIDE PLURALITY OF GRID POINTS
5520
PROVIDE PLURALITY OF NMRs
5530
DETERMINE ESTIMATED LOCATION OF MOBILE DEVICE FROM A SET OF NMRs
5540
DETERMINE REPRESENTATIVE VALUE FOR EACH NC IN THE NMR SET
5550
DETERMINE DISTORTION MEASURE FOR EACH REPRESENTATIVE VALUE
5560
GENERATE ESTIMATED LOCATION FOR MOBILE DEVICE

FIG. 55

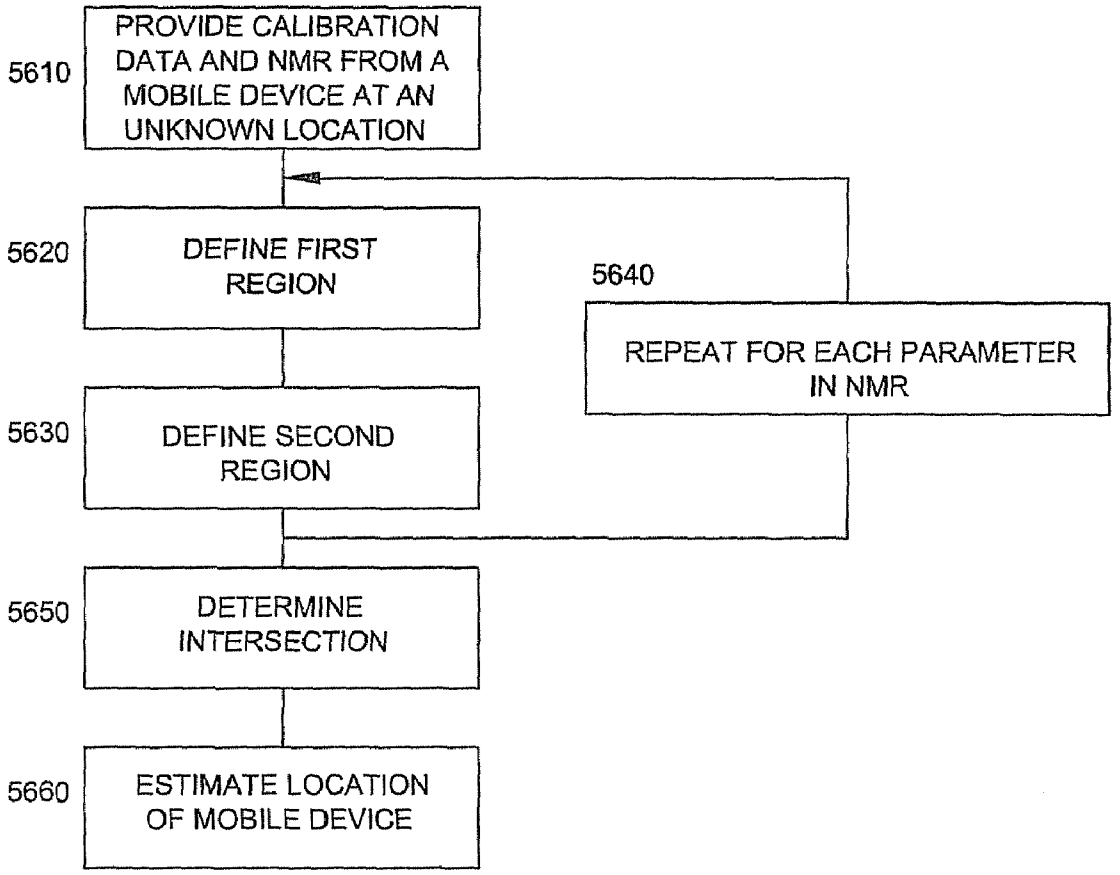

5610
PROVIDE CALIBRATION DATA AND NMR FROM A MOBILE DEVICE AT AN UNKNOWN LOCATION
5620
DEFINE FIRST REGION
5640
REPEAT FOR EACH PARAMETER IN NMR
5630
DEFINE SECOND REGION
5650
DETERMINE INTERSECTION
5660
ESTIMATE LOCATION OF MOBILE DEVICE

FIG. 56

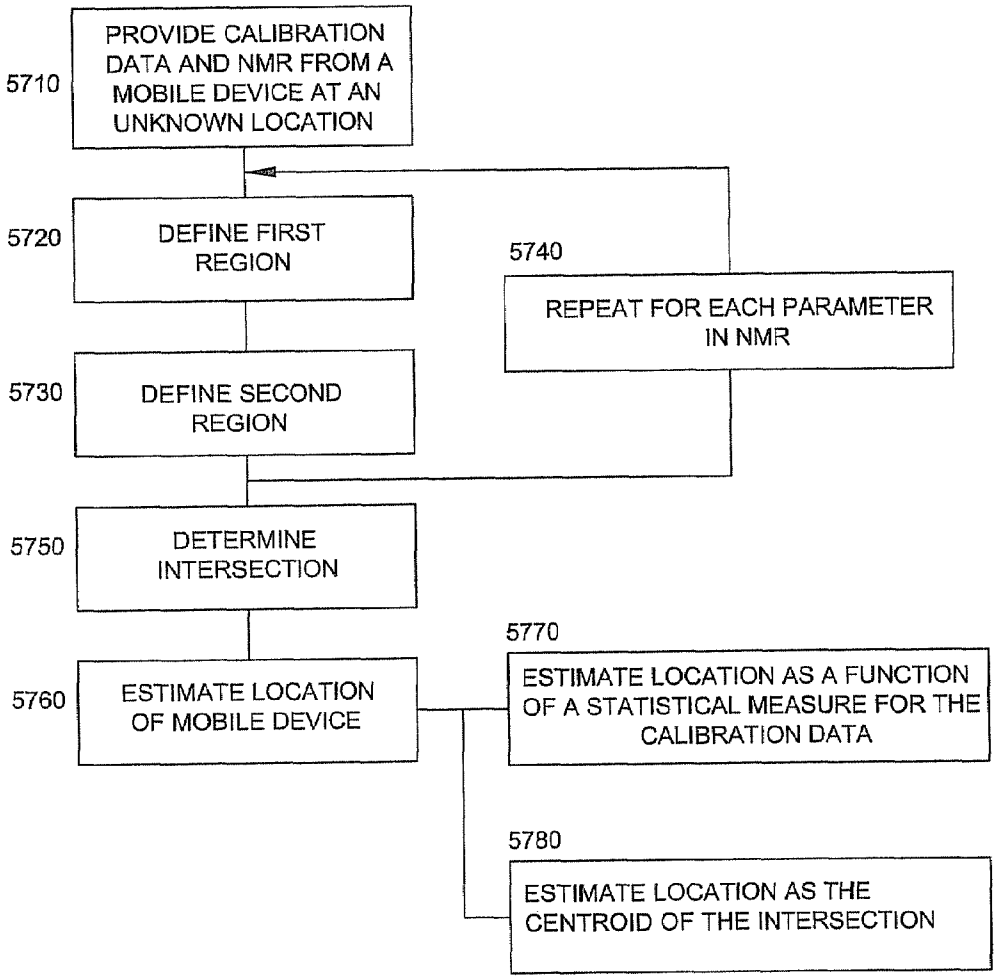

5710
PROVIDE CALIBRATION DATA AND NMR FROM A MOBILE DEVICE AT AN UNKNOWN LOCATION
5720
DEFINE FIRST REGION
5740
REPEAT FOR EACH PARAMETER IN NMR
5730
DEFINE SECOND REGION
5750
DETERMINE INTERSECTION
5770
5760
ESTIMATE LOCATION OF MOBILE DEVICE
ESTIMATE LOCATION AS A FUNCTION OF A STATISTICAL MEASURE FOR THE CALIBRATION DATA
5780
ESTIMATE LOCATION AS THE CENTROID OF THE INTERSECTION

FIG. 57

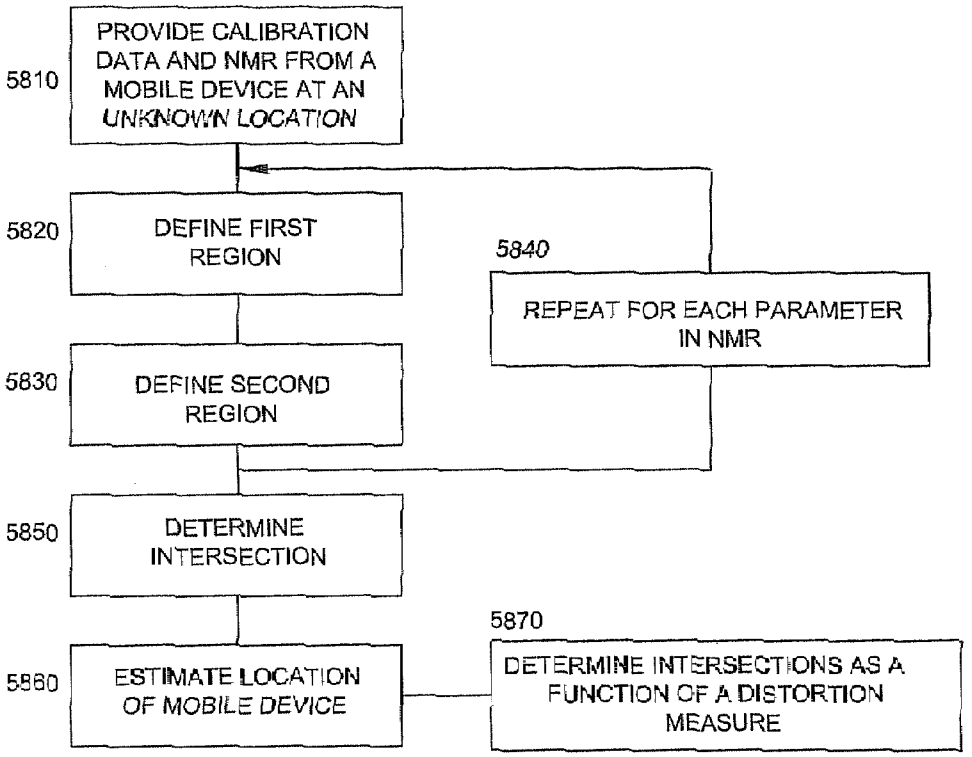

5810
PROVIDE CALIBRATION DATA AND NMR FROM A MOBILE DEVICE AT AN UNKNOWN LOCATION
5820
DEFINE FIRST REGION
5840
REPEAT FOR EACH PARAMETER IN NMR
5830
DEFINE SECOND REGION
5850
DETERMINE INTERSECTION
5870
5860
ESTIMATE LOCATION OF MOBILE DEVICE
DETERMINE INTERSECTIONS AS A FUNCTION OF A DISTORTION MEASURE

FIG. 58

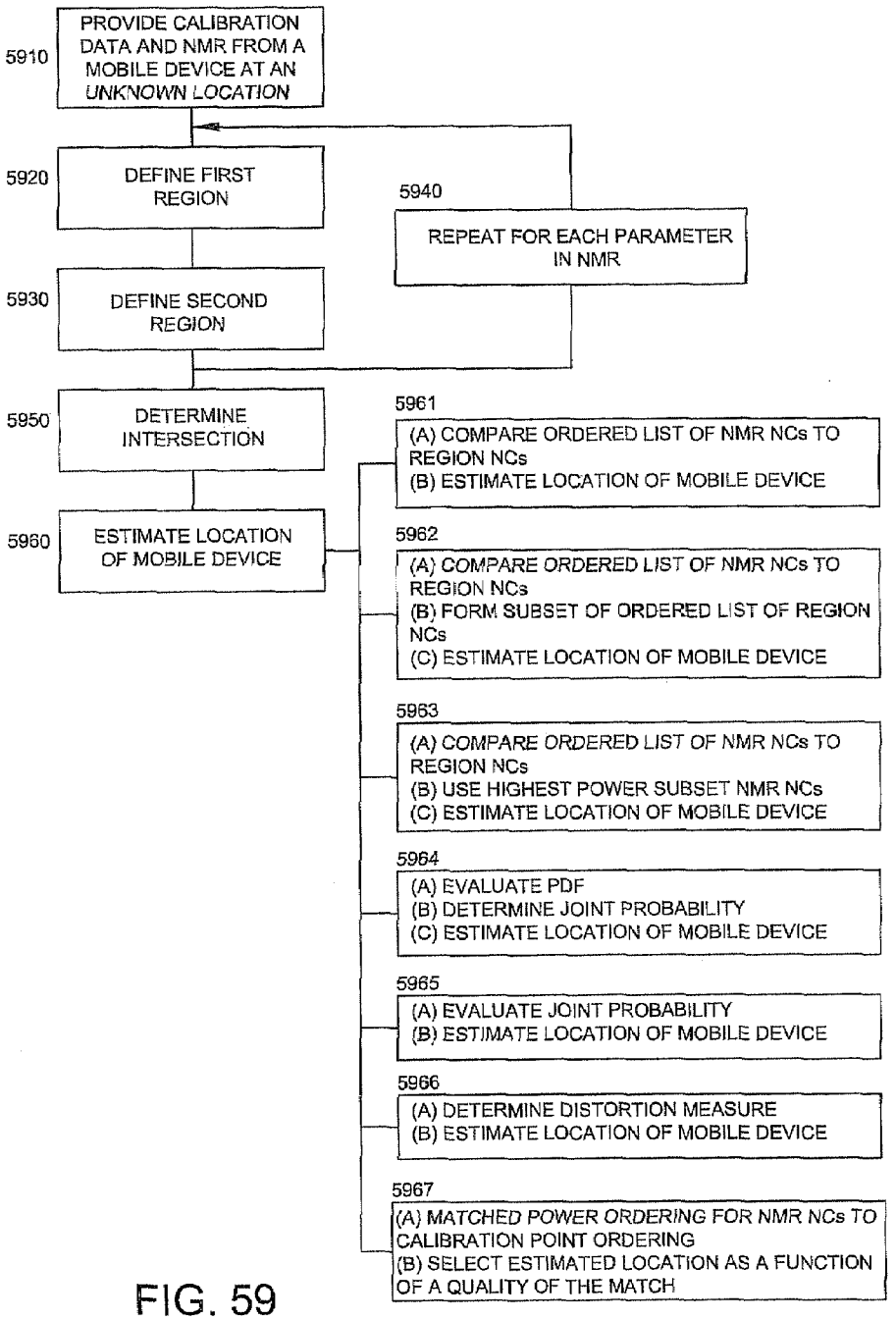

5910
PROVIDE CALIBRATION DATA AND NMR FROM A MOBILE DEVICE AT AN UNKNOWN LOCATION
5920
DEFINE FIRST REGION
5940
REPEAT FOR EACH PARAMETER IN NMR
5930
DEFINE SECOND REGION
5950
DETERMINE INTERSECTION
5960
ESTIMATE LOCATION OF MOBILE DEVICE
5961
(A) COMPARE ORDERED LIST OF NMR NCs TO REGION NCs
(B) ESTIMATE LOCATION OF MOBILE DEVICE
5962
(A) COMPARE ORDERED LIST OF NMR NCs TO REGION NCs
(B) FORM SUBSET OF ORDERED LIST OF REGION NCs
(C) ESTIMATE LOCATION OF MOBILE DEVICE
5963
(A) COMPARE ORDERED LIST OF NMR NCs TO REGION NCs
(B) USE HIGHEST POWER SUBSET NMR NCs
(C) ESTIMATE LOCATION OF MOBILE DEVICE
5964
(A) EVALUATE PDF
(B) DETERMINE JOINT PROBABILITY
(C) ESTIMATE LOCATION OF MOBILE DEVICE
5965
(A) EVALUATE JOINT PROBABILITY
(B) ESTIMATE LOCATION OF MOBILE DEVICE
5966
(A) DETERMINE DISTORTION MEASURE
(B) ESTIMATE LOCATION OF MOBILE DEVICE
5967
(A) MATCHED POWER ORDERING FOR NMR NCs TO CALIBRATION POINT ORDERING
(B) SELECT ESTIMATED LOCATION AS A FUNCTION OF A QUALITY OF THE MATCH

FIG. 59

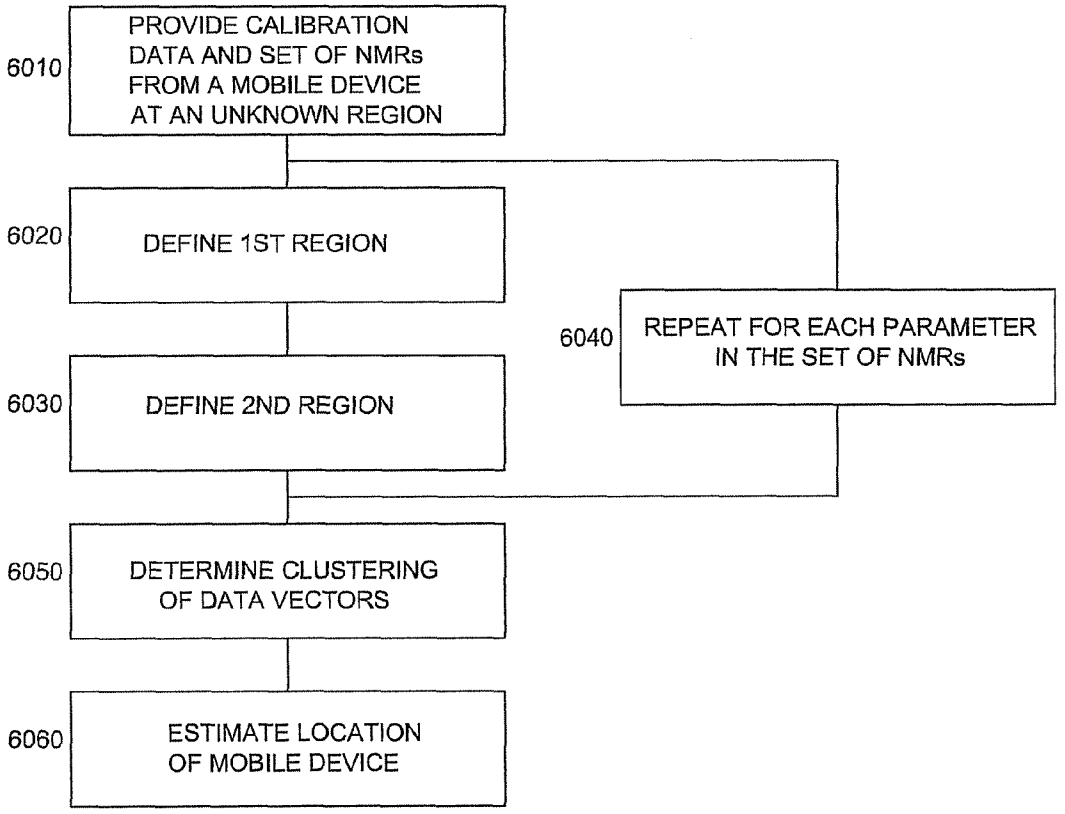

6010
PROVIDE CALIBRATION DATA AND SET OF NMRs FROM A MOBILE DEVICE AT AN UNKNOWN REGION
6020
DEFINE 1ST REGION
6040
REPEAT FOR EACH PARAMETER IN THE SET OF NMRs
6030
DEFINE 2ND REGION
6050
DETERMINE CLUSTERING OF DATA VECTORS
6060
ESTIMATE LOCATION OF MOBILE DEVICE

FIG. 60

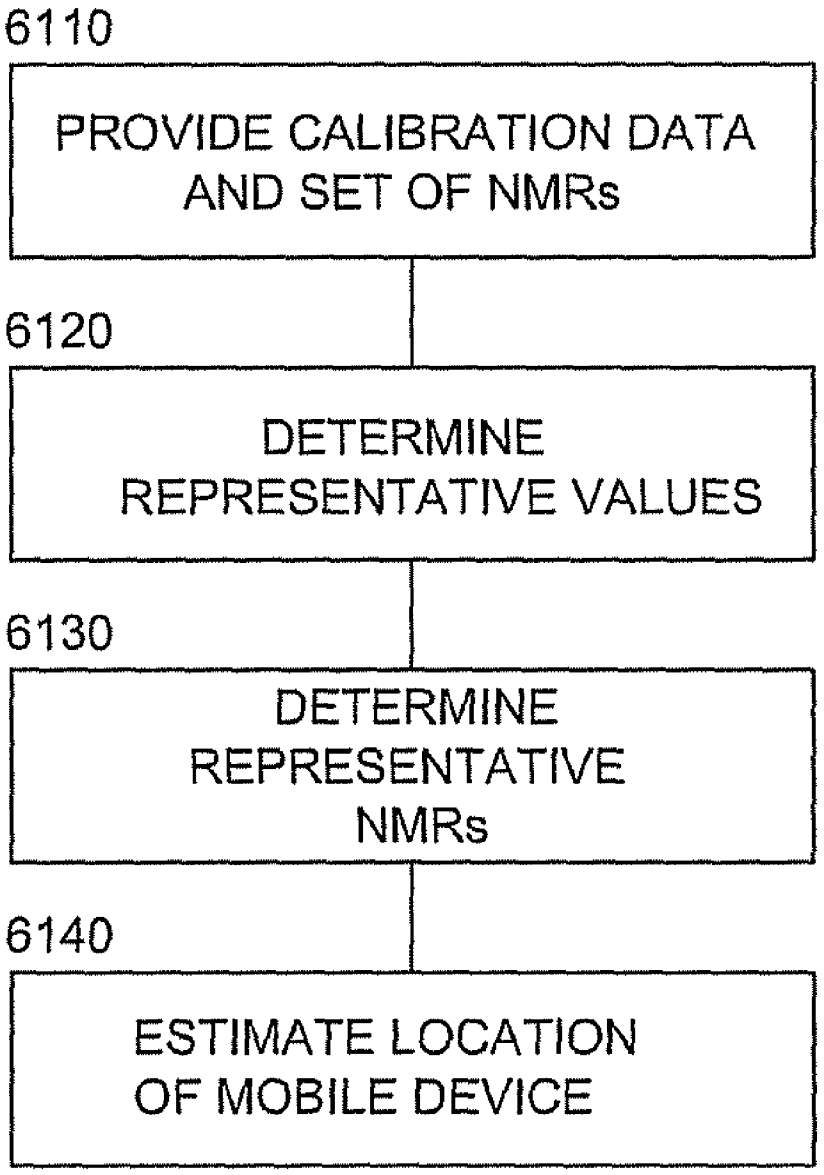

6110
PROVIDE CALIBRATION DATA AND SET OF NMRs
6120
DETERMINE REPRESENTATIVE VALUES
6130
DETERMINE REPRESENTATIVE NMRs
6140
ESTIMATE LOCATION OF MOBILE DEVICE

FIG. 61

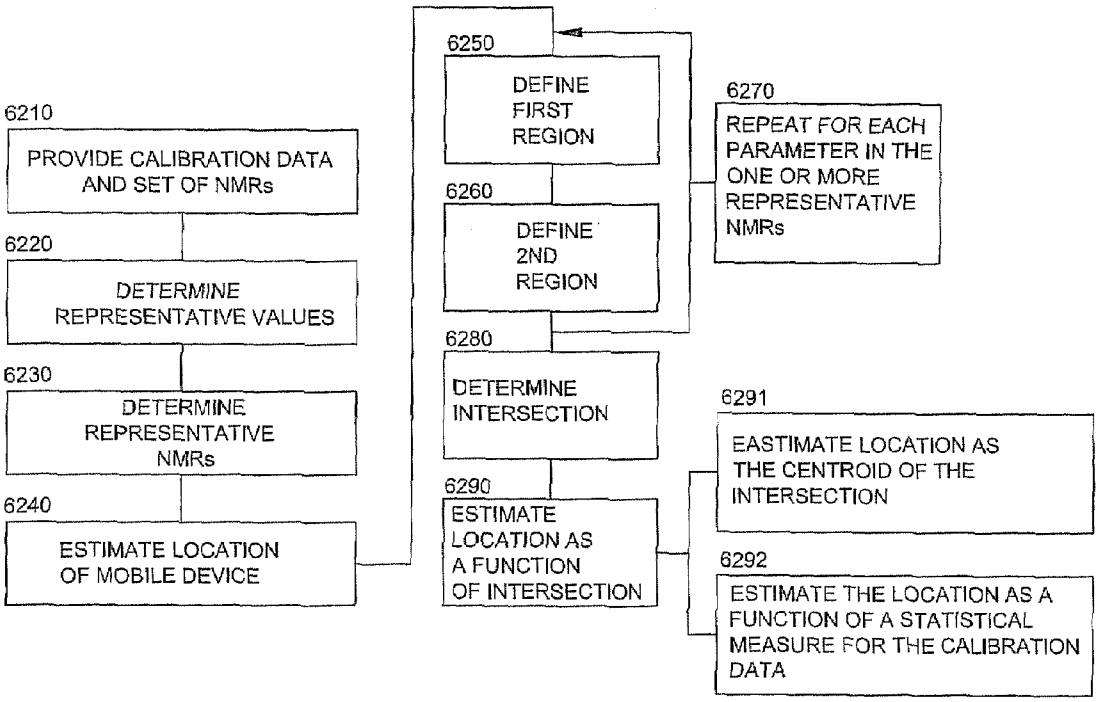

6210
PROVIDE CALIBRATION DATA AND SET OF NMRs
6220
DETERMINE REPRESENTATIVE VALUES
6230
DETERMINE REPRESENTATIVE NMRs
6240
ESTIMATE LOCATION OF MOBILE DEVICE
6250
DEFINE FIRST REGION
6260
DEFINE 2ND REGION
6270
REPEAT FOR EACH PARAMETER IN THE ONE OR MORE REPRESENTATIVE NMRs
6280
DETERMINE INTERSECTION
6290
ESTIMATE LOCATION AS A FUNCTION OF INTERSECTION
6291
EASTIMATE LOCATION AS THE CENTROID OF THE INTERSECTION
6292
ESTIMATE THE LOCATION AS A FUNCTION OF A STATISTICAL MEASURE FOR THE CALIBRATION DATA

FIG. 62

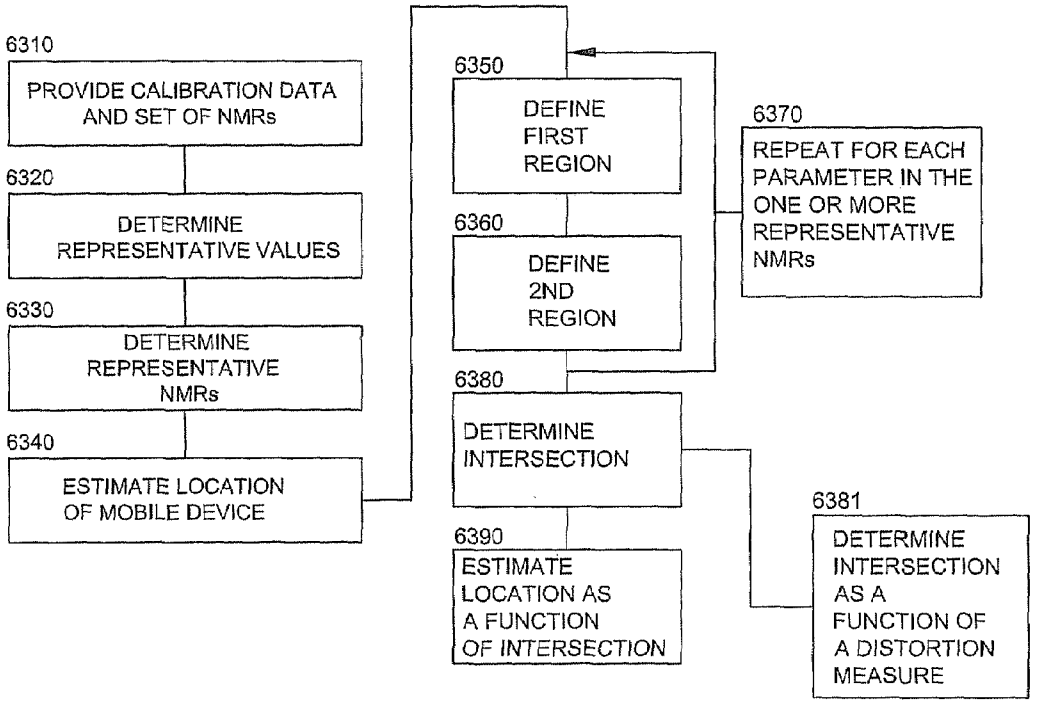

6310
PROVIDE CALIBRATION DATA AND SET OF NMRs
6320
DETERMINE REPRESENTATIVE VALUES
6330
DETERMINE REPRESENTATIVE NMRs
6340
ESTIMATE LOCATION OF MOBILE DEVICE
6350
DEFINE FIRST REGION
6360
DEFINE 2ND REGION
6370
REPEAT FOR EACH PARAMETER IN THE ONE OR MORE REPRESENTATIVE NMRs
6380
DETERMINE INTERSECTION
6381
DETERMINE INTERSECTION AS A FUNCTION OF A DISTORTION MEASURE
6390
ESTIMATE LOCATION AS A FUNCTION OF INTERSECTION

FIG. 63

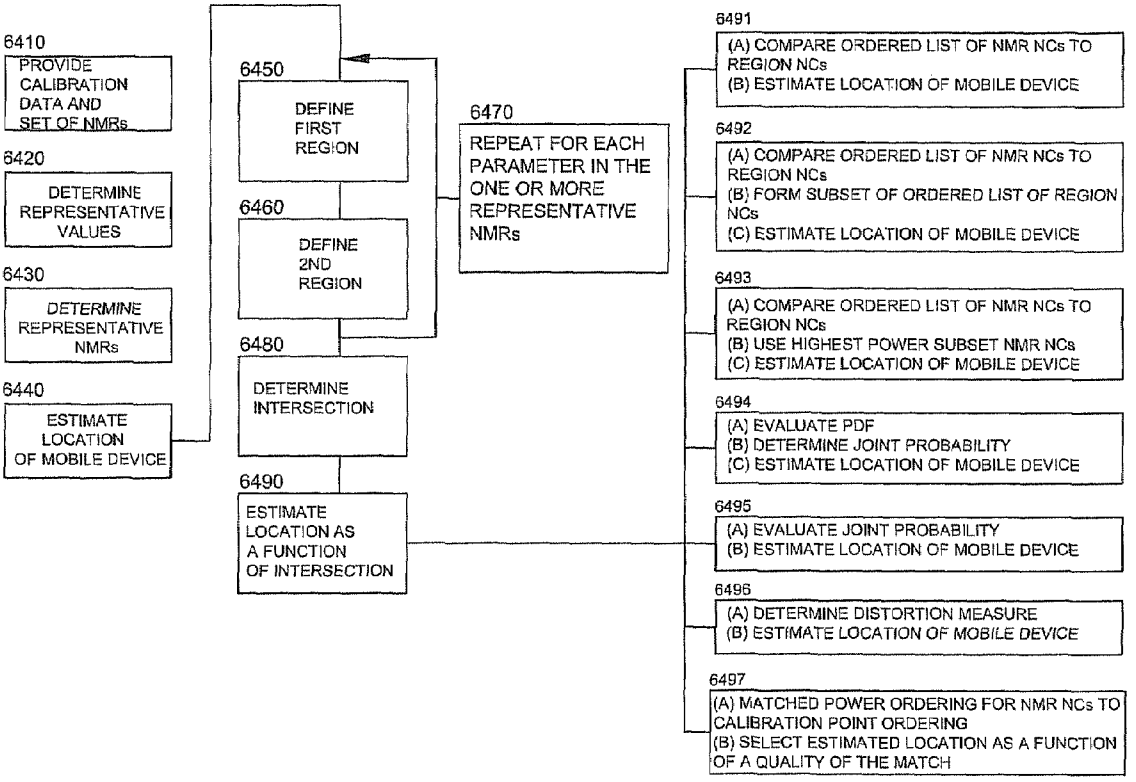

6410
PROVIDE CALIBRATION DATA AND SET OF NMRs
6420
DETERMINE REPRESENTATIVE VALUES
6430
DETERMINE REPRESENTATIVE NMRs
6440
ESTIMATE LOCATION OF MOBILE DEVICE
6450
DEFINE FIRST REGION
6460
DEFINE 2ND REGION
6470
REPEAT FOR EACH PARAMETER IN THE ONE OR MORE REPRESENTATIVE NMRs
6480
DETERMINE INTERSECTION
6490
ESTIMATE LOCATION AS A FUNCTION OF INTERSECTION
6491
(A) COMPARE ORDERED LIST OF NMR NCs TO REGION NCs
(B) ESTIMATE LOCATION OF MOBILE DEVICE
6492
(A) COMPARE ORDERED LIST OF NMR NCs TO REGION NCs
(B) FORM SUBSET OF ORDERED LIST OF REGION NCs
(C) ESTIMATE LOCATION OF MOBILE DEVICE
6493
(A) COMPARE ORDERED LIST OF NMR NCs TO REGION NCs
(B) USE HIGHEST POWER SUBSET NMR NCs
(C) ESTIMATE LOCATION OF MOBILE DEVICE
6494
(A) EVALUATE PDF
(B) DETERMINE JOINT PROBABILITY
(C) ESTIMATE LOCATION OF MOBILE DEVICE
6495
(A) EVALUATE JOINT PROBABILITY
(B) ESTIMATE LOCATION OF MOBILE DEVICE
6496
(A) DETERMINE DISTORTION MEASURE
(B) ESTIMATE LOCATION OF MOBILE DEVICE
6497
(A) MATCHED POWER ORDERING FOR NMR NCs TO CALIBRATION POINT ORDERING
(B) SELECT ESTIMATED LOCATION AS A FUNCTION OF A QUALITY OF THE MATCH

FIG. 64

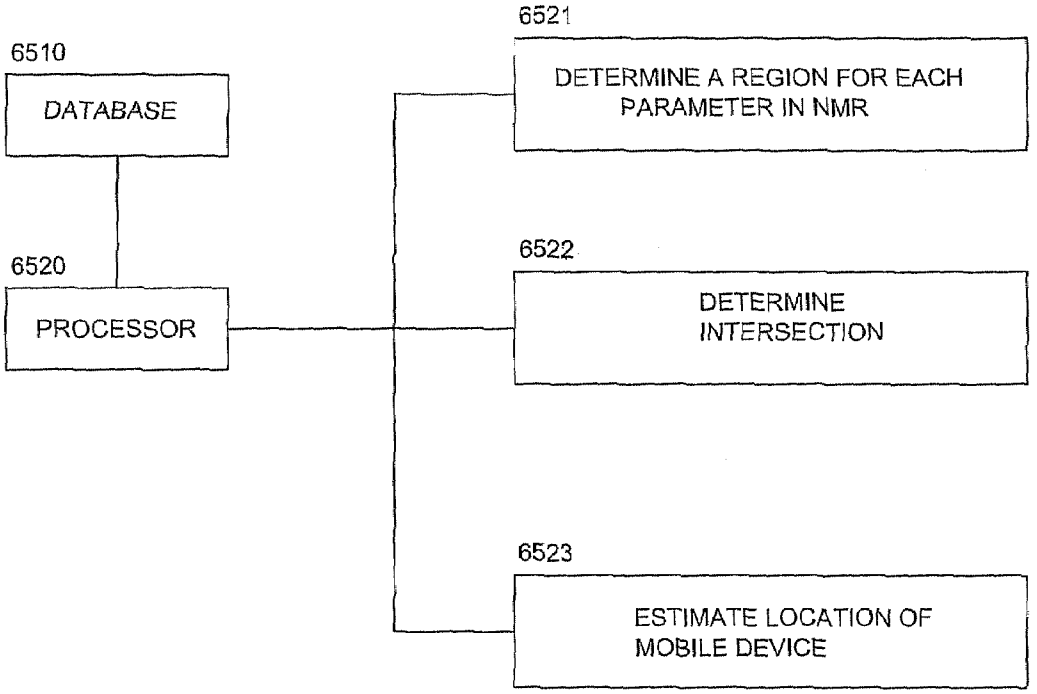

6510
DATABASE
6520
PROCESSOR
6521
DETERMINE A REGION FOR EACH PARAMETER IN NMR
6522
DETERMINE INTERSECTION
6523
ESTIMATE LOCATION OF MOBILE DEVICE

FIG. 65

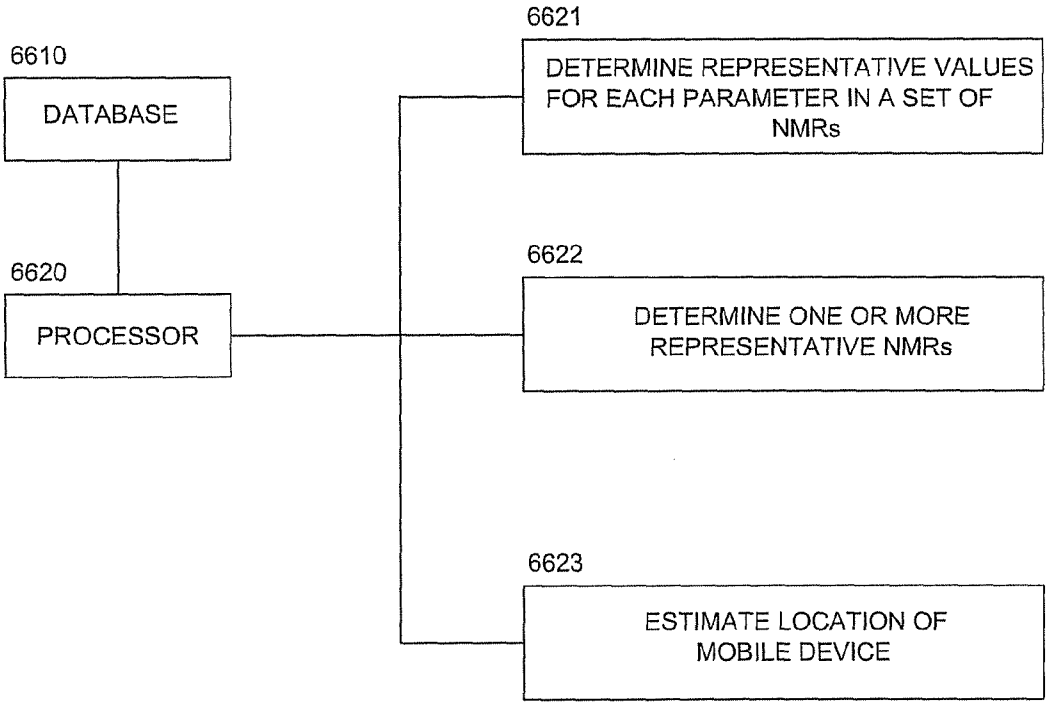

6610
DATABASE
6620
PROCESSOR
6621
DETERMINE REPRESENTATIVE VALUES FOR EACH PARAMETER IN A SET OF NMRs
6622
DETERMINE ONE OR MORE REPRESENTATIVE NMRs
6623
ESTIMATE LOCATION OF MOBILE DEVICE

FIG. 66

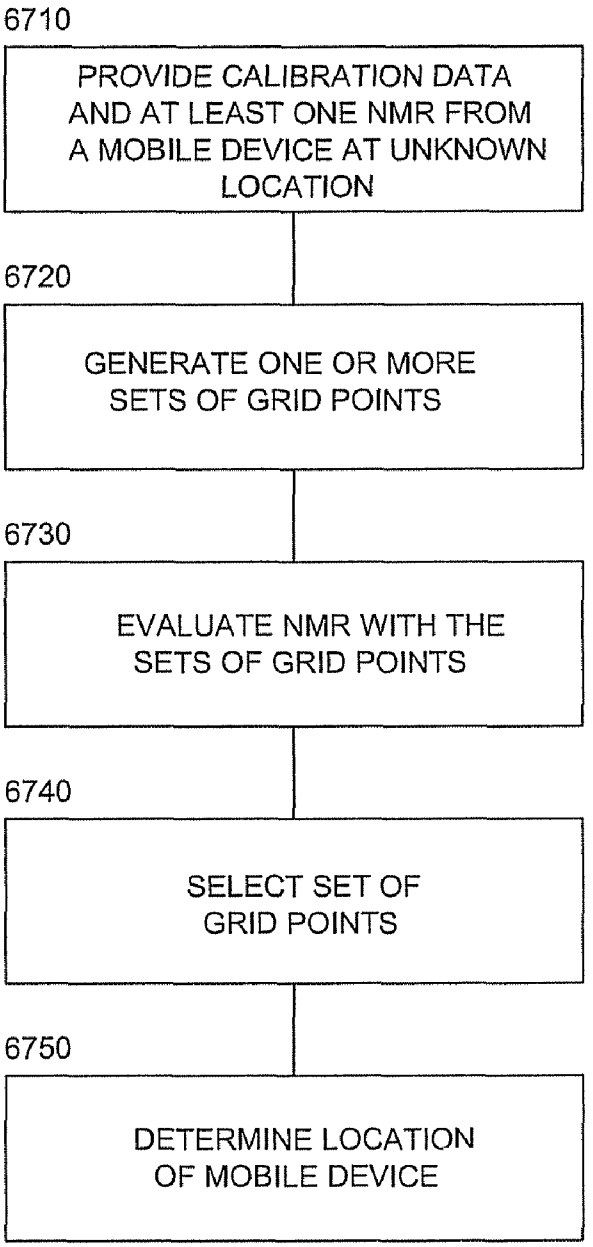

6710
PROVIDE CALIBRATION DATA AND AT LEAST ONE NMR FROM A MOBILE DEVICE AT UNKNOWN LOCATION
6720
GENERATE ONE OR MORE SETS OF GRID POINTS
6730
EVALUATE NMR WITH THE SETS OF GRID POINTS
6740
SELECT SET OF GRID POINTS
6750
DETERMINE LOCATION OF MOBILE DEVICE

FIG. 67

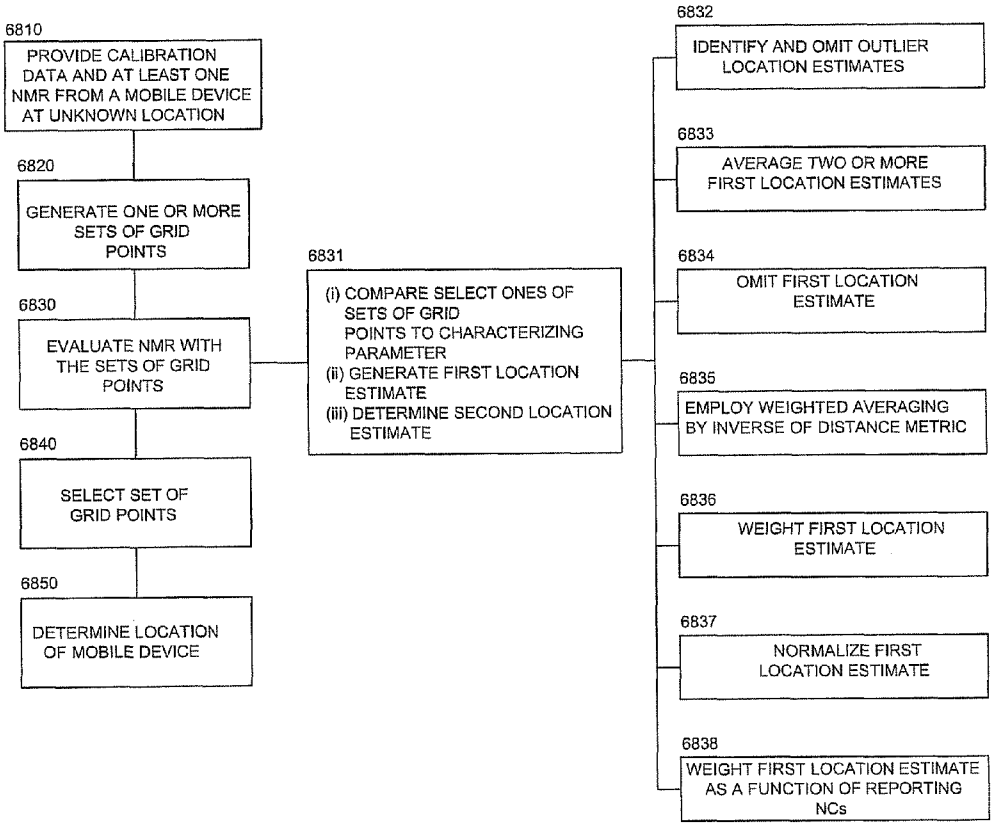

6810
PROVIDE CALIBRATION DATA AND AT LEAST ONE NMR FROM A MOBILE DEVICE AT UNKNOWN LOCATION
6820
GENERATE ONE OR MORE SETS OF GRID POINTS
6830
EVALUATE NMR WITH THE SETS OF GRID POINTS
6840
SELECT SET OF GRID POINTS
6850
DETERMINE LOCATION OF MOBILE DEVICE
6831
(i) COMPARE SELECT ONES OF SETS OF GRID POINTS TO CHARACTERIZING PARAMETER
(ii) GENERATE FIRST LOCATION ESTIMATE
(iii) DETERMINE SECOND LOCATION ESTIMATE
6832
IDENTIFY AND OMIT OUTLIER LOCATION ESTIMATES
6833
AVERAGE TWO OR MORE FIRST LOCATION ESTIMATES
6834
OMIT FIRST LOCATION ESTIMATE
6835
EMPLOY WEIGHTED AVERAGING BY INVERSE OF DISTANCE METRIC
6836
WEIGHT FIRST LOCATION ESTIMATE
6837
NORMALIZE FIRST LOCATION ESTIMATE
6838
WEIGHT FIRST LOCATION ESTIMATE AS A FUNCTION OF REPORTING NCs

FIG. 68

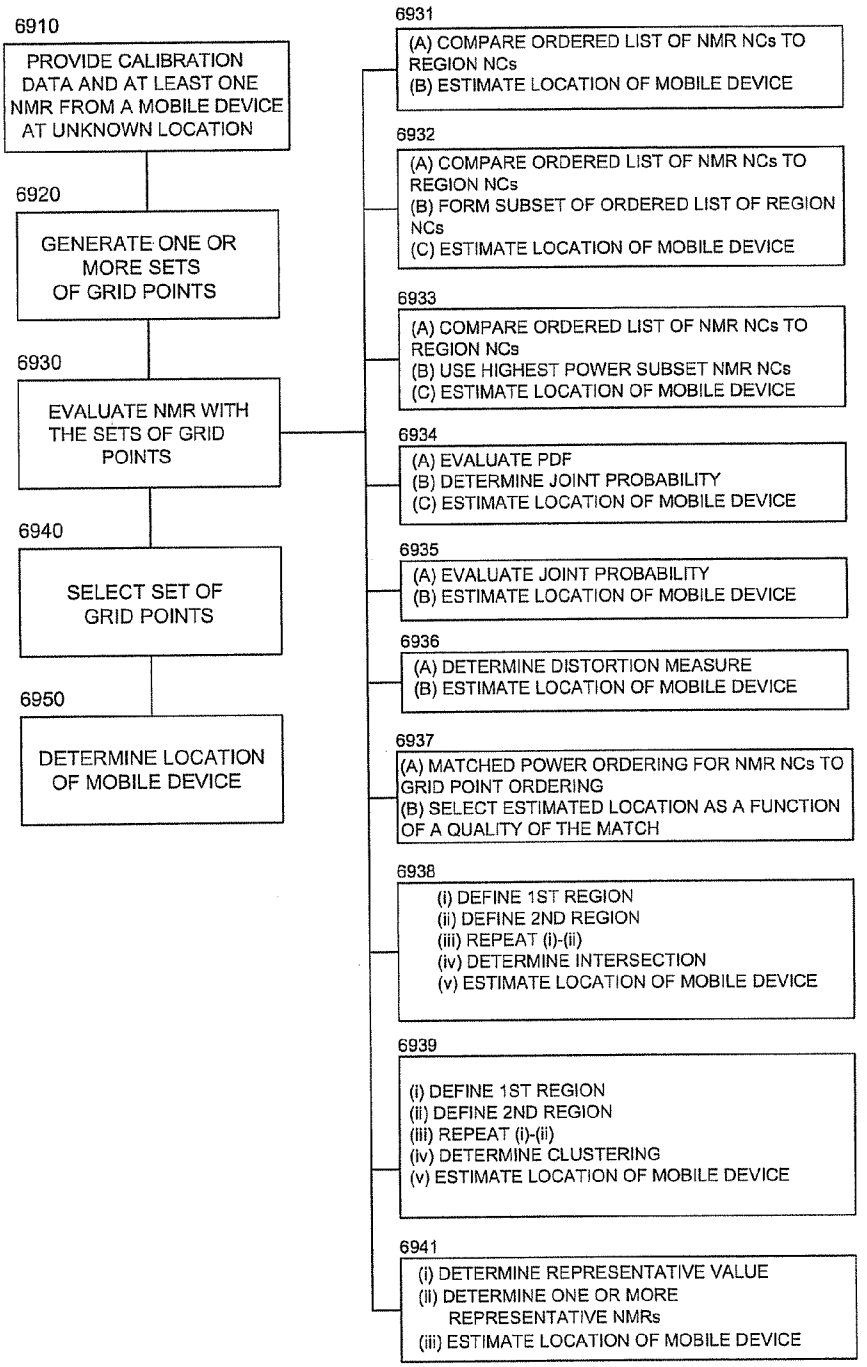

6910
PROVIDE CALIBRATION DATA AND AT LEAST ONE NMR FROM A MOBILE DEVICE AT UNKNOWN LOCATION
6920
GENERATE ONE OR MORE SETS OF GRID POINTS
6930
EVALUATE NMR WITH THE SETS OF GRID POINTS
6940
SELECT SET OF GRID POINTS
6950
DETERMINE LOCATION OF MOBILE DEVICE
6931
(A) COMPARE ORDERED LIST OF NMR NCs TO REGION NCs
(B) ESTIMATE LOCATION OF MOBILE DEVICE
6932
(A) COMPARE ORDERED LIST OF NMR NCs TO REGION NCs
(B) FORM SUBSET OF ORDERED LIST OF REGION NCs
(C) ESTIMATE LOCATION OF MOBILE DEVICE
6933
(A) COMPARE ORDERED LIST OF NMR NCs TO REGION NCs
(B) USE HIGHEST POWER SUBSET NMR NCs
(C) ESTIMATE LOCATION OF MOBILE DEVICE
6934
(A) EVALUATE PDF
(B) DETERMINE JOINT PROBABILITY
(C) ESTIMATE LOCATION OF MOBILE DEVICE
6935
(A) EVALUATE JOINT PROBABILITY
(B) ESTIMATE LOCATION OF MOBILE DEVICE
6936
(A) DETERMINE DISTORTION MEASURE
(B) ESTIMATE LOCATION OF MOBILE DEVICE
6937
(A) MATCHED POWER ORDERING FOR NMR NCs TO GRID POINT ORDERING
(B) SELECT ESTIMATED LOCATION AS A FUNCTION OF A QUALITY OF THE MATCH
6938
(i) DEFINE 1ST REGION
(ii) DEFINE 2ND REGION
(iii) REPEAT (i)-(ii)
(iv) DETERMINE INTERSECTION
(v) ESTIMATE LOCATION OF MOBILE DEVICE
6939
(i) DEFINE 1ST REGION
(ii) DEFINE 2ND REGION
(iii) REPEAT (i)-(ii)
(iv) DETERMINE CLUSTERING
(v) ESTIMATE LOCATION OF MOBILE DEVICE
6941
(i) DETERMINE REPRESENTATIVE VALUE
(ii) DETERMINE ONE OR MORE REPRESENTATIVE NMRs
(iii) ESTIMATE LOCATION OF MOBILE DEVICE

FIG. 69

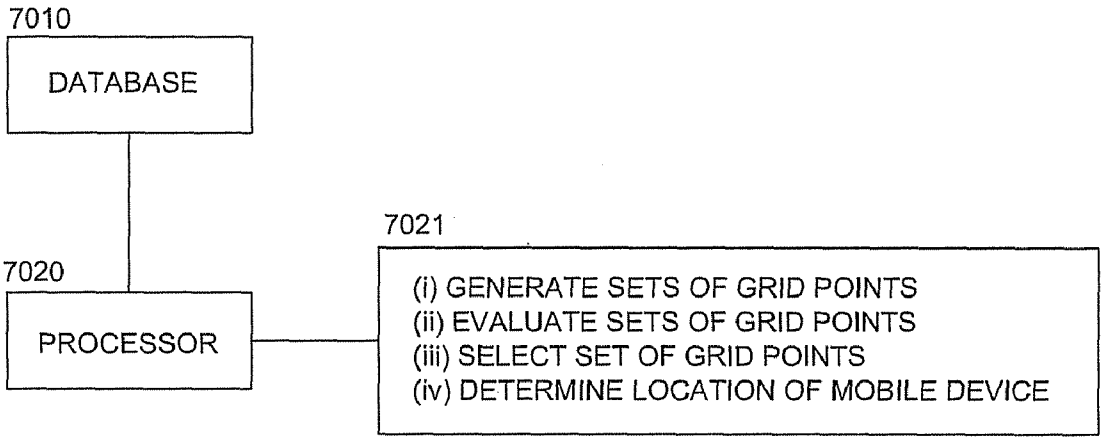

7010
DATABASE
7020
PROCESSOR
7021
(i) GENERATE SETS OF GRID POINTS
(ii) EVALUATE SETS OF GRID POINTS
(iii) SELECT SET OF GRID POINTS
(iv) DETERMINE LOCATION OF MOBILE DEVICE

FIG. 70

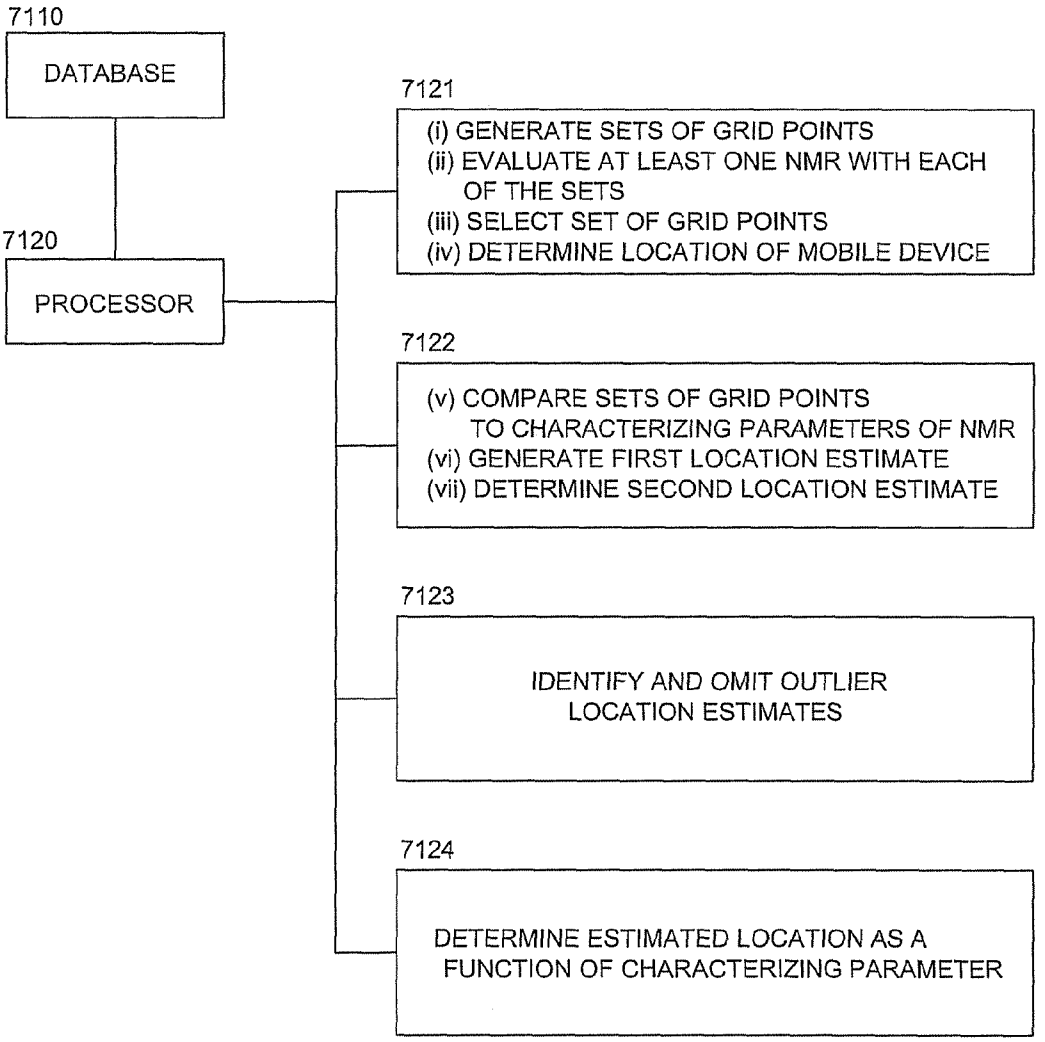

7110
DATABASE
7120
PROCESSOR
7121
(i) GENERATE SETS OF GRID POINTS
(ii) EVALUATE AT LEAST ONE NMR WITH EACH OF THE SETS
(iii) SELECT SET OF GRID POINTS
(iv) DETERMINE LOCATION OF MOBILE DEVICE
7122
(v) COMPARE SETS OF GRID POINTS TO CHARACTERIZING PARAMETERS OF NMR
(vi) GENERATE FIRST LOCATION ESTIMATE
(vii) DETERMINE SECOND LOCATION ESTIMATE
7123
IDENTIFY AND OMIT OUTLIER LOCATION ESTIMATES
7124
DETERMINE ESTIMATED LOCATION AS A FUNCTION OF CHARACTERIZING PARAMETER

FIG. 71

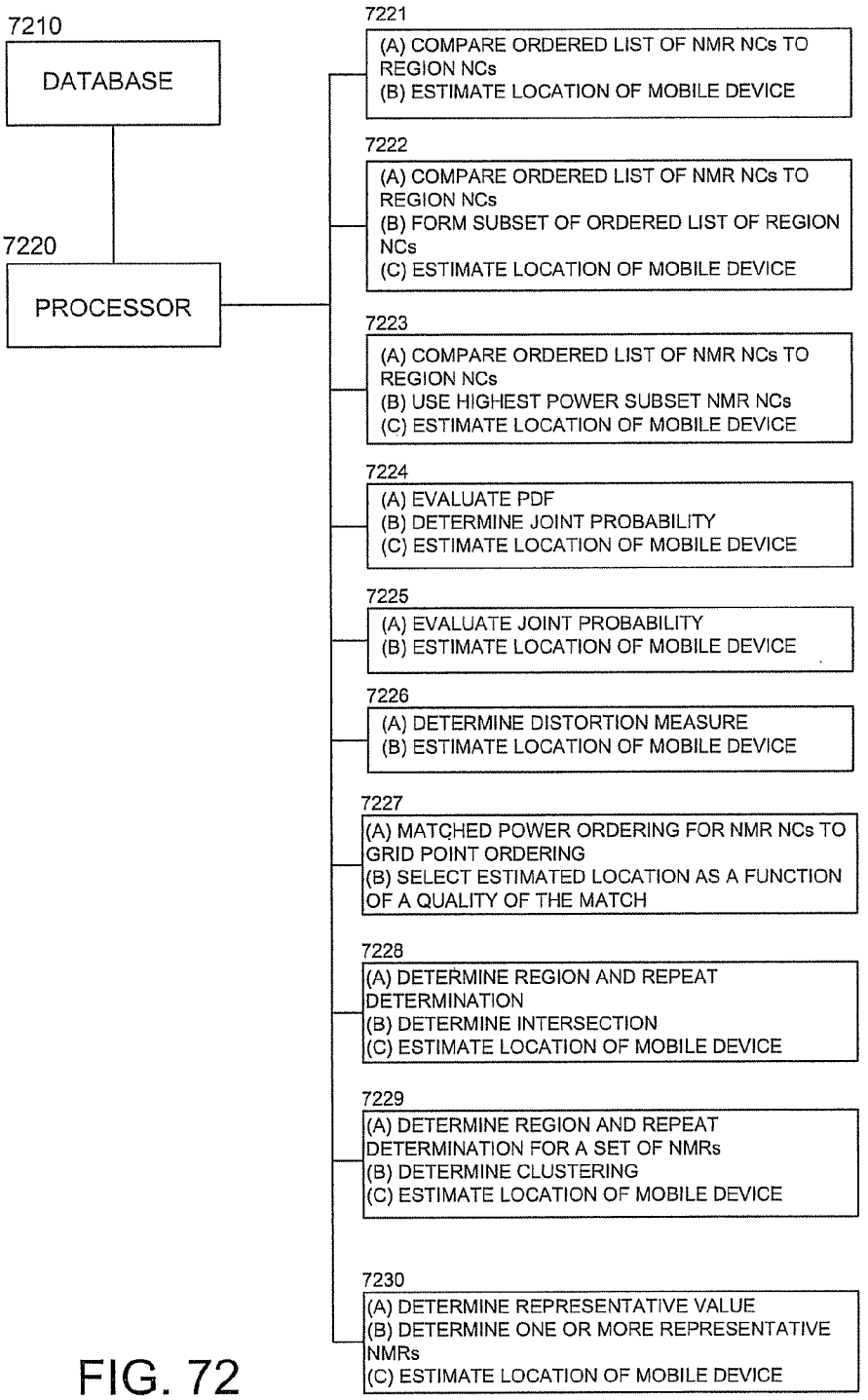

7210
DATABASE
7220
PROCESSOR
7221
(A) COMPARE ORDERED LIST OF NMR NCs TO REGION NCs
(B) ESTIMATE LOCATION OF MOBILE DEVICE
7222
(A) COMPARE ORDERED LIST OF NMR NCs TO REGION NCs
(B) FORM SUBSET OF ORDERED LIST OF REGION NCs
(C) ESTIMATE LOCATION OF MOBILE DEVICE
7223
(A) COMPARE ORDERED LIST OF NMR NCs TO REGION NCs
(B) USE HIGHEST POWER SUBSET NMR NCs
(C) ESTIMATE LOCATION OF MOBILE DEVICE
7224
(A) EVALUATE PDF
(B) DETERMINE JOINT PROBABILITY
(C) ESTIMATE LOCATION OF MOBILE DEVICE
7225
(A) EVALUATE JOINT PROBABILITY
(B) ESTIMATE LOCATION OF MOBILE DEVICE
7226
(A) DETERMINE DISTORTION MEASURE
(B) ESTIMATE LOCATION OF MOBILE DEVICE
7227
(A) MATCHED POWER ORDERING FOR NMR NCs TO GRID POINT ORDERING
(B) SELECT ESTIMATED LOCATION AS A FUNCTION OF A QUALITY OF THE MATCH
7228
(A) DETERMINE REGION AND REPEAT DETERMINATION
(B) DETERMINE INTERSECTION
(C) ESTIMATE LOCATION OF MOBILE DEVICE
7229
(A) DETERMINE REGION AND REPEAT DETERMINATION FOR A SET OF NMRs
(B) DETERMINE CLUSTERING
(C) ESTIMATE LOCATION OF MOBILE DEVICE
7230
(A) DETERMINE REPRESENTATIVE VALUE
(B) DETERMINE ONE OR MORE REPRESENTATIVE NMRs
(C) ESTIMATE LOCATION OF MOBILE DEVICE

FIG. 72

SYSTEM AND METHOD FOR GENERATING A LOCATION ESTIMATE USING UNIFORM AND NON-UNIFORM GRID POINTS

CROSS REFERENCE TO RELATED APPLICATIONS

The present application claims priority benefit to and hereby incorporates by reference in its entirety co-pending U.S. Provisional Patent Application Ser. No. 60/899,379 filed on 5 Feb. 2007.

BACKGROUND

The present subject matter is directed generally towards a system and method for estimating the location of a wireless mobile device that is in communication with a wireless communications network. More specifically, the present subject matter relates to the problem of estimating the location of a wireless mobile device using information from one or more Network Measurement Reports ("NMRs") which may be generated by a wireless communications network or the mobile device.

As is well known in the art, the use of wireless communication devices such as telephones, pagers, personal digital assistants, laptop computers, anti-theft devices, etc., hereinafter referred to collectively as "mobile devices", has become prevalent in today's society. Along with the proliferation of these mobile devices is the safety concern associated with the need to locate the mobile device, for example in an emergency situation. For example, the Federal Communication Commission ("FCC") has issued a geolocation mandate for providers of wireless telephone communication services that puts in place a schedule and an accuracy standard under which the providers of wireless communications must implement geolocation technology for wireless telephones when used to make a 911 emergency telephone call (FCC 94-102 E911). In addition to E911 emergency related issues, there has been increased interest in technology which can determine the geographic position, or "geolocate" a mobile device. For example, wireless telecommunications providers are developing location-enabled services for their subscribers including roadside assistance, turn-by-turn driving directions, concierge services, location-specific billing rates and location-specific advertising.

Currently in the art, there are a number of different ways to geolocate a mobile device. For example, providers of wireless communication services have installed mobile device location capabilities into their networks. In operation, these network overlay location systems take measurements on radio frequency ("RF") transmissions from mobile devices at base station locations surrounding the mobile device and estimate the location of the mobile device with respect to the base stations. Because the geographic location of the base stations is known, the determination of the location of the mobile device with respect to the base station permits the geographic location of the mobile device to be determined. The RF measurements of the transmitted signal at the base stations can include the time of arrival, the angle of arrival, the signal power, or the unique/repeatable radio propagation path (radio fingerprinting) derivable features. In addition, the geolocation systems can also use collateral information, e.g., information other than that derived for the RF measurement to assist in the geolocation of the mobile device, i.e., location of roads, dead-reckoning, topography, map matching, etc.

In a network-based geolocation system, the mobile device to be located is typically identified and radio channel assignments determined by (a) monitoring the control information transmitted on radio channel for telephone calls being placed by the mobile device or on a wireline interface to detect calls of interest, i.e., 911, (b) a location request provided by a non-mobile device source, i.e., an enhanced services provider. Once a mobile device to be located has been identified and radio channel assignments determined, the location determining system is first tasked to determine the geolocation of the mobile device and then directed to report the determined position to the requesting entity or enhanced services provider.

The monitoring of the RF transmissions from the mobile device or wireline interfaces to identify calls of interest is known as "tipping", and generally involves recognizing a call of interest being made from a mobile device and collecting the call setup information. Once the mobile device is identified and the call setup information is collected, the location determining system can be tasked to geolocate the mobile device.

While the above-described systems are useful in certain situations, there is a need to streamline the process in order to efficiently and effectively handle the vast amount of data being sent between the wireless communications network and the large number of mobile devices for which locations are to be determined. In this regard, the present subject matter overcomes the limitations of the prior art by estimating the location of a wireless mobile device using, at least in part, one or more pre-existing Network Measurement Reports ("NMRs") which include calibration data for a number of locations within a geographic region. The calibration data for these locations must be gathered and analyzed so that particular points (e.g., "grid points") within the geographic region can be determined and associated with a particular set or sets of calibration data from, for example, one or more NMRs. Then, the received signal level measurements reported by the mobile device to be geolocated may be compared with the data associated with the various grid points to estimate the location of the mobile device. The performance of a grid-based pattern matching system such as that disclosed herein is typically dependent on stored received signal level measurements that accurately reflect the levels that are likely to be reported by the mobile device to be located. These grid points do not necessarily have to be part of a uniform grid and usually will not be uniformly distributed throughout the geographic region. These non-uniform grid points ("NUGs"), once determined, can be assigned geographic coordinates so that the NUGs may be used in determining the location of a mobile device exhibiting certain attributes as discussed in more detail below.

Accordingly, an embodiment of the present subject matter provides a method for assigning geographical coordinates to a grid point located in a geographic region for the location of a mobile device where the method provides calibration data for each of one or more calibration points in the geographic region and where for each of the calibration points the associated calibration data is evaluated and based on that evaluation a determination is made as to whether at least one grid point should be defined, and if so, geographical coordinates are assigned to the grid point.

An additional embodiment of the present subject matter further includes in the above method a determination of geographical coordinates for each of a plurality of nodes of a uniform grid spanning the geographic region and for each of the grid points determining a closest node from the plurality of nodes and assigning characteristic data associated with the grid point to the closest node.

A further embodiment includes a method of assigning geographical coordinates to a grid point located in a geographic region for the location of a mobile device where calibration data for each of one or more calibration points in the geographic region are provided, and where for the calibration data associated with each of the calibration points the calibration data is evaluated, a determination is made based on the evaluation as to whether at least one grid point should be defined, and geographical coordinates are assigned to the grid point.

In another embodiment of the present subject matter, a system for assigning geographical coordinates to a grid point located in a geographic region is presented where the system includes a database and a processor for receiving calibration data for each of one or more calibration points in the geographic region and for each of the calibration points the processor is programmed to evaluate the associated calibration data, determine if at least one grid point should be defined based on the evaluation, assign geographical coordinates to the at least one grid point, and populate the database with the geographical coordinates.

A further embodiment of the present subject matter includes in the above system circuitry for determining geographical coordinates for each of a plurality of nodes of a uniform grid spanning the geographic region, and circuitry for determining, for each of the at least one grid point, a closest node from the plurality of nodes and assigning characteristic data associated with the grid point to the closest node.

Yet another embodiment of the present subject matter provides a method of locating a mobile device. The method comprises the steps of providing a plurality of grid points in a geographic region, providing a plurality of network measurement reports for a mobile device in the geographic region, and comparing ones of the plurality of grid points to at least one parameter of ones of the plurality of network measurement reports. The method further includes generating a first location estimate of the mobile device for each of the ones of said plurality of network measurement reports, and determining a second location estimate of the mobile device as a function of at least one of the generated first location estimates. An additional embodiment includes the step of identifying and omitting outlier first location estimates by determining a Mahalanobis distance from each first location estimate to the second location estimate, determining a distance threshold from a median of the Mahalanobis distances multiplied by a predetermined factor, and determining a third location estimate by averaging two or more of said first location estimates. Another embodiment may also interpolate between ones of the plurality of grid points when more than one grid point corresponds to the at least one parameter of the plurality of network measurement reports. An additional embodiment may provide a default location for the second location estimate if a second location estimate cannot be determined as a function of at least one of the generated first location estimates.

An additional embodiment of the present subject matter provides a method of improving a location estimate of a mobile device. The method comprises the steps of providing a plurality of grid points in a geographic region, providing a set of network measurement reports for a mobile device in the geographic region, the set of network measurement reports including one or more subsets of network measurement reports, and comparing ones of the plurality of grid points to at least one parameter of a subset of the network measurement reports. The method further includes generating a first location estimate of the mobile device for each subset of network measurement reports, determining a second location estimate of the mobile device as a function of at least one of the generated first location estimates, and indicating an attribute of the second location estimate as a function of a parameter of a subset of the network measurement reports.

Another embodiment of the present subject matter provides a method of locating a mobile device in a geographic region. The method comprises the steps of providing a plurality of grid points in a geographic region, each of the grid points including at least one characterizing parameter and each of the grid points located on a grid defined over the geographic region and providing a plurality of network measurement reports for a mobile device in the geographic region. The method also comprises determining an estimated location for the mobile device from one network measurement report as a function of the at least one parameter.

An additional embodiment of the present subject matter provides a method of locating a mobile device in a geographic region. The method comprises the steps of providing a plurality of grid points in a geographic region, each of the grid points including at least one characterizing parameter and each of the grid points located on a grid defined over the geographic region and providing a plurality of network measurement reports for a mobile device in the geographic region. The method also comprises determining an estimated location for the mobile device from a set of said plurality of network measurement reports as a function of the parameter.

Yet another embodiment of the present subject matter provides another method of estimating the location of a mobile device in a geographic region. The method comprises the steps of providing calibration data for each of one or more calibration points in a geographic region where the calibration data includes at least one characterizing parameter. A candidate network measurement report or set of network measurement reports may be received from a mobile device at an unknown location, where the network measurement report also includes at least one characterizing parameter. The method further comprises defining a first region as a function of a first characterizing parameter and a predetermined range of said first parameter. A second region may be defined as a function of another characterizing parameter and a predetermined range of another parameter. These steps may be repeated for each characterizing parameter in the calibration data and an intersection of each defined region determined. The location of a mobile device may then be estimated in the geographic region as a function of the intersection.

In a further embodiment of the present subject matter, a method of estimating the location of a mobile device in a geographic region is provided. The method may comprise the steps of providing one or more sets of calibration data for a plurality of calibration points in a geographic region where the calibration data includes at least one characterizing parameter and for each of select ones of the calibration points the calibration data includes plural data vectors. The method may also include receiving a candidate network measurement report or set of network measurement reports from a mobile device at an unknown location, where the network measurement report also includes at least one characterizing parameter. The method also includes defining a first region as a function of a first characterizing parameter and a predetermined range of the first parameter for a select one set of calibration data, and for the set of calibration data, defining a second region as a function of another characterizing parameter and a predetermined range of the another parameter. These steps may be repeated for each characterizing parameter in the set of calibration data and a clustering of the plural

data vectors may be determined. The location of a mobile device may be estimated in the geographic region as a function of the clustering.

Another embodiment of the present subject matter provides a method of estimating the location of a mobile device in a geographic region comprising providing calibration data for each of one or more calibration points in a geographic region where the calibration data includes at least one characterizing parameter and receiving a set of network measurement reports from a mobile device at an unknown location where at least one of the network measurement reports in the set also includes at least one characterizing parameter. The method may also comprise determining a representative value for each available characterizing parameter in the set as a function of a variation of the available characterizing parameter in each network measurement report in the set and determining one or more representative network measurement reports as a function of the representative value. The method may then estimate the location of a mobile device in the geographic region as a function of the one or more representative network measurement reports.

One embodiment of the present subject matter provides a system for estimating the location of a mobile device in a geographic region comprising a database and a processor for receiving calibration data for each of one or more calibration points in a geographic region, the calibration data having at least one characterizing parameter and receiving a candidate network measurement report or set of network measurement reports from a mobile device at an unknown location, where the network measurement report also includes at least one characterizing parameter. The processor may be programmed to determine a first region as a function of a first characterizing parameter and a predetermined range of the first parameter and repeat the determination for each characterizing parameters in the calibration data. The processor may be further programmed to determine an intersection for each defined region, and estimate the location of a mobile device in the geographic region as a function of the intersection.

Another embodiment of the present subject matter provides a system for estimating the location of a mobile device in a geographic region comprising a database and a processor for receiving calibration data for each of one or more calibration points in a geographic region where the calibration data may include at least one characterizing parameter. The processor may also receive a set of network measurement reports from a mobile device at an unknown location, at least one of the network measurement reports in the set may also include at least one characterizing parameter. The processor may be programmed to determine a representative value for each available characterizing parameter in the set as a function of a variation of the available characterizing parameter in each network measurement report in the set, determine one or more representative network measurement reports as a function of the representative value, and estimate the location of a mobile device in the geographic region as a function of the one or more representative network measurement reports.

One embodiment of the present subject matter provides a method of determining the location of a mobile device in a geographic region. The method may comprise providing calibration data for each of one or more calibration points in a geographic region where the calibration data includes one or more characterizing parameters and generating one or more sets of grid points for the calibration data. At least one network measurement report may be received from a mobile device at an unknown location and the network measurement report may be evaluated with each of the sets of grid points as a function of select ones of the characterizing parameters. A set of grid points may be selected as a function of a predetermined criteria, and the location of a mobile device in the geographic region may be determined as a function of the selected set of grid points. Additionally, the final estimated location may also be determined as a function of the estimated locations determined within each of the individual sets of grid points.

Another embodiment of the present subject matter includes a system for determining the location of a mobile device in a geographic region. The system comprises a database and a processor for receiving calibration data for each of one or more calibration points in a geographic region and receiving at least one network measurement report from a mobile device at an unknown location in the geographic region where the calibration data and network measurement report include at least one characterizing parameter. The processor may be programmed to generate one or more sets of grid points for the calibration data and evaluate the at least one network measurement report with each of the sets of grid points as a function of select ones of the characterizing parameters. The processor may further be programmed to select a set of grid points as a function of a predetermined criteria, and determine the location of a mobile device in the geographic region as a function of the selected set. Additionally, the final estimated location may also be determined as a function of the estimated locations determined within each of the individual sets of grid points.

These embodiments and many other objects and advantages thereof will be readily apparent to one skilled in the art to which the invention pertains from a perusal of the claims, the appended drawings, and the following detailed description of the embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a flow chart for a method for assigning geographical coordinates according to an embodiment of the present subject matter.

FIG. **2** is a flow chart for a method for assigning geographical coordinates including a calibration point according to an embodiment of the present subject matter.

FIG. **3** is a flow chart for a method for assigning geographical coordinates including calibration data according to an embodiment of the present subject matter.

FIG. **4** is a flow chart for a method for assigning geographical coordinates including clustering of data according to an embodiment of the present subject matter.

FIG. **5** is a flow chart for a method for assigning geographical coordinates including clustering of data vectors according to an embodiment of the present subject matter.

FIG. **6** is a flow chart for a method for assigning geographical coordinates including clustering according to an embodiment of the present subject matter.

FIG. **7** is a flow chart for a method for assigning geographical coordinates including determining outliers according to an embodiment of the present subject matter.

FIG. **8** is a flow chart for a method for assigning geographical coordinates including clustering of data vectors at the same calibration point according to an embodiment of the present subject matter.

FIG. **9** is a flow chart for a method for assigning geographical coordinates including clustering of data vectors at the same calibration point according to an embodiment of the present subject matter.

FIG. **10** is a flow chart for a method for assigning geographical coordinates to a grid point according to an embodiment of the present subject matter.

FIG. **11** is a flow chart for a method for assigning geographical coordinates including assigning geographical coordinates to a grid point where only one calibration point is in a geographic region according to an embodiment of the present subject matter.

FIG. **12** is a flow chart for a method for assigning geographical coordinates including assigning geographical coordinates to a grid point where there are plural calibration points in a geographic region according to an embodiment of the present subject matter.

FIG. **13** is a flow chart for a method for assigning geographical coordinates including calibration data information according to an embodiment of the present subject matter.

FIG. **14** is a flow chart for a method for assigning geographical coordinates including evaluating calibration data according to an embodiment of the present subject matter.

FIG. **15** is a flow chart for a method for assigning geographical coordinates including populating a database with the geographical coordinates according to an embodiment of the present subject matter.

FIG. **16** is a flow chart for a method for assigning geographical coordinates including database information according to an embodiment of the present subject matter.

FIG. **17** is a flow chart for a method for assigning geographical coordinates including determining geographical coordinates for nodes of a uniform grid according to an embodiment of the present subject matter.

FIG. **18** is a flow chart for a method for assigning geographical coordinates including characteristic data to nodes of uniform grid according to an embodiment of the present subject matter.

FIG. **19** is a flow chart for a method for assigning geographical coordinates for calibration data for each of one or more calibration points in a geographic region according to an embodiment of the present subject matter.

FIG. **20** is a block diagram for a system for assigning geographical coordinates according to an embodiment of the present subject matter.

FIG. **21** is a block diagram for a system for assigning geographical coordinates including a determination of clustering of plural data vectors according to an embodiment of the present subject matter.

FIG. **22** is a block diagram for a system for assigning geographical coordinates including comparing clusters of data vectors from different calibration points according to an embodiment of the present subject matter.

FIG. **23** is a block diagram for a system for assigning geographical coordinates including comparing clusters of data vectors from the same calibration point according to an embodiment of the present subject matter.

FIG. **24** is a block diagram for a system for assigning geographical coordinates including calibration data according to an embodiment of the present subject matter.

FIG. **25** is a block diagram for a system for assigning geographical coordinates including evaluating calibration data according to an embodiment of the present subject matter.

FIG. **26** is a block diagram for a system for assigning geographical coordinates including information for populating a database according to an embodiment of the present subject matter.

FIG. **27** is a block diagram for a system for assigning geographical coordinates including circuitry for determining geographical coordinates for nodes of a uniform grid according to an embodiment of the present subject matter.

FIG. **28** is a block diagram for a system for assigning geographical coordinates including characteristic data according to an embodiment of the present subject matter.

FIG. **29** is a flow chart for a method for locating a mobile device according to one embodiment of the present subject matter.

FIG. **30** is a flow chart for a method for locating a mobile device according to one embodiment of the present subject matter including identifying and omitting outlier first location estimates.

FIG. **31** is a flow chart for a method for locating a mobile device according to another embodiment of the present subject matter.

FIG. **32** is a flow chart for a method for locating a mobile device according to one embodiment of the present subject matter including omitting a first location estimate.

FIG. **33** is a flow chart for a method for locating a mobile device according to one embodiment of the present subject matter including interpolating between grid points.

FIG. **34** is a flow chart for a method for locating a mobile device according to another embodiment of the present subject matter including interpolating between grid points and/or assigning weights to selected grid points.

FIG. **35** is a flow chart for a method for locating a mobile device according to another embodiment of the present subject matter including providing a default location.

FIG. **36** is a flow chart for a method of improving a location estimate of a mobile device.

FIG. **37** is a flow chart for a method of improving a location estimate of a mobile device according to another embodiment of the present subject matter.

FIG. **38** is a flow chart for a method of improving a location estimate of a mobile device according to another embodiment of the present subject matter including omitting a first location estimate.

FIG. **39** is a flow chart for a method for locating a mobile device according to one embodiment of the present subject matter including identifying and omitting outlier first location estimates.

FIG. **40** is a flow chart for a method of improving a location estimate of a mobile device according to a further embodiment of the present subject matter.

FIG. **41** is a flow chart for a method of improving a location estimate of a mobile device according to a further embodiment of the present subject matter including providing a default location.

FIGS. **42-55** are flow charts for methods of locating a mobile device in a geographic region according embodiments of the present subject matter.

FIGS. **56-64** are flow charts for methods of estimating the location of a mobile device in a geographic region according to embodiments of the present subject matter.

FIGS. **65-66** are diagrams for systems for estimating the location of a mobile device in a geographic region according to embodiments of the present subject matter.

FIGS. **67-69** are flow charts for methods of determining the location of a mobile device in a geographic region according to embodiments of the present subject matter.

FIGS. **70-72** are diagrams for systems for determining the location of a mobile device in a geographic region according to embodiments of the present subject matter.

DETAILED DESCRIPTION

With reference to the Figures where generally like elements have been given like numerical designations to facilitate an understanding of the present subject matter, the vari-

ous embodiments of a system and method for generating a location estimate using uniform and non-uniform grid points are herein described.

The following description of the present subject matter is provided as an enabling teaching of the present subject matter and its best, currently-known embodiment. Those skilled in the art will recognize that many changes can be made to the embodiments described herein while still obtaining the beneficial results of the present subject matter. It will also be apparent that some of the desired benefits of the present subject matter can be obtained by selecting some of the features of the present subject matter without utilizing other features. Accordingly, those who work in the art will recognize that many modifications and adaptations of the present subject matter are possible and may even be desirable in certain circumstances and are part of the present subject matter. Thus, the following description is provided as illustrative of the principles of the present subject matter and not in limitation thereof. While the following exemplary discussion of embodiments of the present subject matter may be directed primarily towards calibration data, it is to be understood that the discussion is not intended to limit the scope of the present subject matter in any way and that the principles presented are equally applicable to other types of data, e.g., signal strength, GPS, NMR, Cell-ID, TDOA, RTT, TA, AOA, etc., capable of being delivered by components in a communications network such as a base station, location measurement unit, other mobile devices, etc. In addition, the use of various combinations of all of these sources, as in a hybrid location scheme, is within the scope of the subject matter disclosed herein.

The present subject matter is directed generally to the problem of estimating the location of a wireless mobile device using calibration data contained in one or more Network Measurement Reports ("NMRs"). The calibration data for various points must be gathered and analyzed so that particular points (e.g., "grid points") within the geographic region can be determined and associated with a particular set or sets of calibration data from, for example, one or more NMRs. In order to do so geographic coordinates may be assigned to grid points located in a geographic region. The grid points may be non-uniformly spaced throughout the geographic region and hence may be referred to as non-uniform grid points ("NUGs"). The location of a wireless mobile device may be estimated by comparing data reported by the mobile device to be geolocated with the data (and more particularly the characteristics derived from this data) associated with the various grid points to thereby estimate the location of the mobile.

The system and/or method of the present subject matter may apply to the situation where calibration data is available over discrete points in a 2-dimensional region "R" (3-D region is also contemplated such as within large multi-level structures). The calibration data may be contained within a Network Measurement Report ("NMR") as is known in the art or the calibration data may be obtained using other known methods. The calibration data may be obtained at each of several calibration points, which may be discrete points within region R each having geographical coordinates (e.g., latitude and longitude) associated therewith. The calibration data may include, but is not limited to, the following: (a) signal strengths observed for signals transmitted by a set of transmitters of known location within or in proximity to the region R; (b) signal strength of a transmitter located at the calibration point as measured by a set of receivers of known location within or in proximity to the region R; (c) round trip time for a signal between the calibration point and an external known point; (d) time difference of arrival at the calibration point with respect pairs of external points located within or in proximity to region R as measured by either a receiver at the calibration point or the external points; (e) the serving cell or sector for a mobile wireless device operating at that calibration point; (f) the network state at the time of collection—a finite number of such states may be required to distinguish between network conditions that vary diurnally, weekly or in some other manner; and (g) combinations of the above.

As a non-limiting example, the case in (a) may apply to the Integrated Digital Enhanced Network ("IDEN") specification, (c) may apply to the Global System for Mobile communications ("GSM") specification as in the Timing Advance ("TA") parameter or the Round Trip Time ("RTT") parameter in the Universal Mobile Telecommunications System ("UMTS") specification, (d) may apply to the UMTS specification, while the external receivers may be the base stations. In general, the calibration data may be any of those measurements made by a mobile wireless device located at the calibration point or any measurement made on the transmissions or characteristics of the mobile wireless device at a set of external transmitter/receivers in the region R or in proximity thereto.

The calibration data may consist of many such sets (i.e., vectors) obtained at one or more calibration points. At each calibration point, the data gathering may have resulted in either a single data vector or multiple data vectors, so that there are potentially multiple sets of data and/or data vectors associated with each calibration point.

A NUG generator or a method to produce NUGs may begin the NUG generation operation using, for example, one of more of the following: (a) a fixed uniform grid ("UG") defined over the region R with the calibration point data being assigned to the fixed grid points by some rule (e.g., allocated by closest fixed grid point, a centroid of a set of fixed grid points, etc.); (b) random grid points to define the start of each NUG; (c) combinations of (a) and (b) depending on the characteristics of the calibration data; or (d) some other useful method.

In any of these cases, the NUG generator may evaluate the data vectors at a particular (candidate) calibration point, or at a fixed grid point to which the data vector(s) is/are assigned. This calibration point or grid point may serve as the root of a first NUG. The root of the NUG may be the calibration data vector that initiates the creation of that NUG. The vectors may be examined using, for example, increasingly stringent tests of statistical sufficiency. In particular, a determination may be made as to whether the data vectors exhibit clustering. If the data exhibits tight clustering, the data for the next candidate calibration point may be aggregated to the former calibration point and the clustering property may be re-evaluated. For example, if the second calibration point also has a cluster but this cluster is sufficiently different than the cluster of the first calibration point, a determination may be made that the data for the two considered calibration points should be allocated to the roots of separate NUGs. If the aggregate cluster (i.e., a cluster including data from both the first and second calibration points) is statistically very similar to either of the first or second clusters (taken independently), then the data for the two calibration points may be allocated to the same NUG. All adjacent calibration data points may be similarly evaluated with respect to the first considered calibration point. Thus one or more of the adjacent calibration points may either wind up having all their data accumulated into a single NUG or, at the other extreme, each such calibration point may become the root of a separate NUG.

The primary test made to determine the allocation may be one of a variety of clustering tests, such as, for example, the

K-means algorithm. Statistical similarity may be determined by, for example, the probability density function ("pdf") of the data parameters (e.g., neighboring cell signal levels, timing information, etc.), the mean and variance of the data parameters, the serving cell/sector, or other functions of the calibration data.

Those measurements or parameter values that do not cluster may be referred to as outliers. The performance of a grid-based pattern matching system such as that disclosed herein is typically dependent on stored received signal level measurements that accurately reflect the levels that are likely to be reported by the mobile device to be located. If the drive test data, for example, used to create the RF signal level grid contains outlier measurements, the statistically consistent value of the signal level will be distorted. Therefore, the present subject matter also describes a system and method used to identify and eliminate outlier signal level measurements and timing advance values (or in general, any parameter within the NMR) during NUG or grid creation so as to improve the estimate of the mean parameter value.

As a non-limiting example, in a very simple consideration of clustering one could consider the mean value of a parameter. In this scenario, neighbor cell control channel signal level measurement outliers could be eliminated as follows: At each grid point, the average received signal level of a particular control channel signal may be computed from all of the measurements of that signal assigned to the grid point. The deviation of each individual measurement from the mean may be computed. Measurements that deviate by more than a configurable predetermined threshold from the mean may be omitted. The average may then be recomputed without the omitted outliers. In a scenario where there are very few measurements, typically less than five or so, the original mean value will be greatly influenced by any outlier measurements and thus may falsely identify too many of the measurements as outliers, or fail to detect outliers at all. For this reason, another parameter is used to only perform the outlier check if there are at least a minimum number of measurements.

In a more general case, a cluster may be a region in N-dimensional NMR vector space where there is a sufficient number of such vectors with a mutual variation such that the mutual variation could be ascribed purely to noise in the measurement. Thus, for example, if within a few feet of the original measurement, if a particular parameter is blocked (say by a large structure such as a building) that parameter would fall out of the original cluster. If sufficient such blocked locations have data falling near the original cluster, one may obtain a secondary cluster where the difference between the first and second clusters is the large variation in this particular parameter.

In addition, if any of the examined sets of data associated with a calibration point exhibit more than one cluster, it may be necessary to define one or more co-located NUGs. Thus, if there are, for example, three well defined clusters associated with a particular calibration point, these clusters could form the roots of three co-located NUGs. The data in these NUGs may grow depending on whether similar clusters can also be found in adjacent (or close) calibration points in which case the similar clusters may be aggregated to the original NUGs or, if the adjacent clusters are not similar, the adjacent clusters (or cluster) may form separate root NUGs (or NUG).

Further, if the quantity of data associated with a particular calibration point is insufficient to sensibly test for statistical similarity or clustering, data from adjacent calibration grid points may be accumulated first and the statistical or clustering test performed thereafter. Thus, based on the results of the clustering test using the accumulated data the determination of how one should separate out the data into NUGs may be made.

The technique may be repeated until all calibration grid points in the region R are exhausted. At the end of this process one has divided the region into a collection of NUGs, where multiple co-located NUGs may exist. The NUGs may fully cover the region R and each NUG may have statistically similar data accumulated into itself. The geometrical shape (i.e., the shape defined by the union of locations of calibration points assigned to the NUG) and the amount of data accumulated into such NUGs is seen to be variable since these are determined by the statistical similarity of the data allocated to a NUG.

Additionally, we may also consider the method of generating NUGs based not on statistical consistency of calibration data, but on other conditions such as (a) a minimum number of unique neighbors observed in data accumulated from allocated calibration grid points; (b) a minimum number of data vectors (NMRs); (c) a maximum and/or minimum NUG radius; (d) a specific set of neighboring cells; (e) a specific set of neighboring cells with power ordering; or (f) any combination of the above. Additionally, the method of using statistical consistency or similarity or data clustering combined with any of these other conditions may be employed.

For each so obtained NUG, a variety of parameters and functions may be generated and stored to describe that NUG. These are termed the NUG characteristics. The NUG characteristics are a representation in that attempt to capture the nature and variability of the data associated with that NUG in a compact and representative form. These characteristics may include, but are not limited to, the following: (a) an ordered list of neighboring cells; (b) functions defined on the absolute neighboring cell power levels (e.g., mean, median, k^{th} moment, cluster-mean, etc.); (c) functions defined on the relative neighboring cell power differences (e.g., mean, median, k^{th} moment, cluster-mean, etc.); (d) serving cell/sector; (e) timing advance parameter (or equivalent); (f) individual pdf (probability density function or probability distribution function) of each neighboring cell power level; (g) joint pdf of neighboring cell power levels; (h) mean and variance of neighboring cell power levels; (i) mobile device orientation (e.g., indoors, outdoors, direction mobile device is facing (e.g., North, South, etc.), tilted upwards, azimuth, elevation, etc.); (j) a compact and/or efficient representation that enables retrieval of the calibration data NMR vectors assigned to this NUG; (k) the network state as indicated in the calibration data; (l) a confidence measure indicative of the reliability of the calibration data feeding this NUG; and (m) any combinations of the above.

If a pdf is determined for a NUG, that pdf may be generated using either the Parzen technique or the method of Gaussian mixtures or some variant thereof. In addition when a need to specify the variance or covariance exists, that parameter may be set to a value dependent on the observed variance for a particular neighboring cell power level or the observed covariance matrix for a set of neighboring cell power levels.

The location ascribed to the NUG may be, for example, any internal point within the NUG. If the NUG contains only a single calibration point, the location of the NUG may be set as the location of the calibration point. If the NUG encompasses several calibration points, the location of any one of the calibration points or the centroid of such calibration points or some other similar measure may be used to define the NUG location. Also, in the case of multiple co-located NUGs, all such NUGs may have their assigned location set to the same value.

With reference now to FIG. **1**, a flow chart is depicted for a method for assigning geographical coordinates according to an embodiment of the present subject matter. At block **101**, calibration data may be provided for each of one or more calibration points in a geographic region. At block **102**, for each of the calibration points calibration data associated with the calibration point is evaluated and a determination is made as to whether a grid point, such as a NUG, should be defined. If it is determined that a grid point is to be defined, geographical coordinates are assigned to the grid point so that the grid point may be useful in estimating the location of a mobile device.

FIG. **2** is a flow chart for a method for assigning geographical coordinates including a calibration point according to an embodiment of the present subject matter. Blocks **201** and **202** are similar to blocks **101** and **102**, respectively. At block **213**, the calibration point may be located on a predetermined fixed uniform grid defined over the geographic region or the calibration point may be randomly located within the geographic region.

FIG. **3** is a flow chart for a method for assigning geographical coordinates including calibration data according to an embodiment of the present subject matter. Blocks **301** and **302** are similar to blocks **101** and **102**, respectively. At block **313**, the calibration data associated with one or more calibration points may be comprised of information from a NMR, or the calibration data for a particular calibration point may be obtained from one or more mobile devices located at or in close proximity to the calibration point, or the calibration data for a particular calibration point may be obtained from a signal transmitted from a mobile device (or devices) located at or in close proximity to the calibration point where the signal is received by a receiver in or in proximity to the geographic region.

FIG. **4** is a flow chart for a method for assigning geographical coordinates including clustering of data according to an embodiment of the present subject matter. Blocks **401** and **402** are similar to blocks **101** and **102**, respectively. At block **413**, for one or more of the calibration points the calibration data may include multiple data vectors and, at block **414**, the evaluation of the data vectors may include a determination of clustering of the multiple data vectors as described above.

Considering now the flow chart depicted in FIG. **5**, the flow chart indicates a method for assigning geographical coordinates including clustering of data vectors according to an embodiment of the present subject matter. Blocks **501** and **502** are similar to blocks **101** and **102**, respectively. At block **503**, the determination of whether at least one grid point should be defined based on the evaluation of the calibration data associated with a calibration point includes a comparison of a first cluster of data vectors from a first calibration point to a second cluster of data vectors where the second cluster of data vectors includes the first cluster of data vectors as well as data vectors from a second calibration point. At block **504**, if the comparison in block **503** results in the difference between the first and second cluster of data vectors being within a predetermined tolerance value, then the data vectors from the first and second calibration points are assigned to the same grid point. However, if the comparison is not within tolerance, then the data vectors from the first calibration point are assigned to a first grid point and the data vectors from the second calibration point are assigned to a second grid point.

The flow chart shown in FIG. **6** illustrates another method for assigning geographical coordinates including clustering according to an embodiment of the present subject matter. Here, blocks **601**, **602**, **603**, and **604** are similar to blocks **501**, **502**, **503**, and **504**, respectively. At block **615** the evaluation of calibration data for one or more calibration points may include determining the clustering of plural data vectors using a K-means analysis. At block **616** the comparing of clusters of data vectors may include determining a probability density function of an aspect of the data vectors.

FIG. **7** is a flow chart for a method for assigning geographical coordinates including determining outliers according to an embodiment of the present subject matter. Blocks **701**, **702**, **713**, and **714** are similar to blocks **401**, **402**, **413**, and **414**, respectively. At block **703**, a determination of outlier data vectors may be made and the outlier data vectors may be eliminated from the determination of data vector clustering.

Regarding FIG. **8**, a flow chart is represented for a method for assigning geographical coordinates including clustering of data vectors at the same calibration point according to an embodiment of the present subject matter. Blocks **801** and **802** are similar to blocks **101** and **102**, respectively. At block **803**, the determination if at least one grid point should be defined based on the evaluation of calibration data may include a comparison of a first cluster of data vectors associated with a first calibration point to a second cluster of data vectors associated with the first calibration point. If the result of the comparison is within a predetermined tolerance, then the data vectors from the first and second clusters may be assigned to the same grid point; otherwise, the data vectors from the first cluster may be assigned to a first grid point while the data vectors from the second cluster may be assigned to a second grid point.

FIG. **9** is a flow chart illustrating another method for assigning geographical coordinates including clustering of data vectors at the same calibration point according to an embodiment of the present subject matter. Here, blocks **901**, **902**, **903**, and **904** are similar to blocks **801**, **802**, **803**, and **804**, respectively. At block **915** the geographical coordinates assigned to the first and second grid points may be identical.

Directing attention now towards FIG. **10**, a flow chart is presented for a method for assigning geographical coordinates to a grid point according to an embodiment of the present subject matter. Blocks **1001** and **1002** are similar to blocks **101** and **102**, respectively. At block **1013**, the geographical coordinates assigned to a first grid point may be different than the geographical coordinates assigned to a second grid point or the geographical coordinates assigned to a first grid point may be the same as the geographical coordinates assigned to a second grid point.

FIG. **11** is a flow chart for a method for assigning geographical coordinates including assigning geographical coordinates to a grid point where only one calibration point is in a geographic region according to an embodiment of the present subject matter. Blocks **1101** and **1102** are similar to blocks **101** and **102**, respectively. At block **1113**, if there is only one calibration point within the geographic region, then the geographical coordinates assigned to a grid point may result in the grid point being located within a predetermined radius of the one calibration point. Or, the geographical coordinates assigned to a grid point may be identical to the geographical coordinates of the calibration point.

Moving now to FIG. **12**, a flow chart is shown for a method for assigning geographical coordinates including assigning geographical coordinates to a grid point where there are plural calibration points in a geographic region according to an embodiment of the present subject matter. Blocks **1201** and **1202** are similar to blocks **101** and **102**, respectively. At block **1213**, where there are multiple calibration points in the geographic region, the geographical coordinates assigned to a grid point may result in the grid point being located within a

predetermined radius of a centroid of a polygon formed by connecting the multiple calibration points.

FIG. **13** is a flow chart for a method for assigning geographical coordinates including calibration data information according to an embodiment of the present subject matter. Blocks **1301** and **1302** are similar to blocks **101** and **102**, respectively. At block **1313**, the calibration data may include one or more of the following: signal strength for a signal transmitted by a transmitter having a known location as received by a receiver at a calibration point; signal strength of a signal transmitted by a transmitter located at a calibration point as received by a receiver at a known location; round trip time for a signal traveling between a calibration point and a known location; timing advance of a signal received by a mobile device at a calibration point; time difference of arrival of plural signals at a calibration point with respect to a pair of known locations as measured by a receiver at a calibration point or at the known locations; the identification of a serving cell or serving sector of a mobile device located at a calibration point; a state of a wireless network serving a mobile device, and combinations thereof.

FIG. **14** is a flow chart for a method for assigning geographical coordinates including evaluating calibration data according to an embodiment of the present subject matter. Blocks **1401** and **1402** are similar to blocks **101** and **102**, respectively. At block **1413**, the evaluating of the calibration data associated with a calibration point may include an evaluation such as: a minimum number of unique neighboring calibration points as determined by calibration data of the neighboring calibration points; a minimum number of data vectors or network measurement reports; a predetermined maximum or minimum radius from a calibration point; a predetermined set of cells neighboring a cell serving a mobile device; and combinations thereof.

FIG. **15** is a flow chart for a method for assigning geographical coordinates including populating a database with the geographical coordinates according to an embodiment of the present subject matter. Blocks **1501** and **1502** are similar to blocks **101** and **102**, respectively. At block **1503**, a database may be populated with the geographical coordinates assigned to the grid points.

FIG. **16** is a flow chart for a method for assigning geographical coordinates including database information according to an embodiment of the present subject matter. Blocks **1601**, **1602**, and **1603** are similar to blocks **1501**, **1502**, and **1503**, respectively. At block **1604**, the database may be populated with information such as: a list of cells neighboring a cell serving a mobile device; a quantity that is a function of a power level of one or more cells neighboring a cell serving a mobile device; an identity of a cell or a sector serving a mobile device; a timing advance parameter; a geographical orientation of a mobile device; a location of a mobile device; network measurement report data vectors; a state of a network serving a mobile device; a confidence measure indicative of a reliability of the calibration data; and combinations thereof.

Directing attention now to FIG. **17**, a flow chart is presented for a method for assigning geographical coordinates including determining geographical coordinates for nodes of a uniform grid according to an embodiment of the present subject matter. Blocks **1701** and **1702** are similar to blocks **101** and **102**, respectively. At block **1703**, geographical coordinates may be determined for the nodes of a uniform grid spanning the geographic region. At block **1704**, for each of the grid points, a determination of the closest node of the uniform grid is made and the characteristic data associated with the grid point may be assigned to the closest node.

Further, FIG. **18** is a flow chart for a method for assigning geographical coordinates including characteristic data to nodes of uniform grid according to an embodiment of the present subject matter. Here, blocks **1801**, **1802**, **1803**, and **1804** are similar to blocks **1701**, **1702**, **1703**, and **1704**, respectively. At block **1805**, the characteristic data may include a list of cells neighboring a cell serving a mobile device; a quantity that is a function of a power level of one or more cells neighboring a cell serving a mobile device; an identity of a cell or a sector serving a mobile device; a timing advance parameter; a geographical orientation of a mobile device; a location of a mobile device; network measurement report data vectors; a state of a network serving a mobile device; a confidence measure indicative of a reliability of the calibration data; and combinations thereof.

With reference to FIG. **19**, a flow chart is illustrated for a method for assigning geographical coordinates for calibration data for each of one or more calibration points in a geographic region according to an embodiment of the present subject matter. At block **1901**, calibration data may be provided for each of one or more calibration points in a geographic region. At block **1902**, for the calibration data for each of the calibration points in the geographic region, the calibration data is evaluated and a determination is made as to whether a grid point should be defined based on the evaluation. If it is determined that a grid point is to be defined, geographical coordinates are assigned to the grid point so that the grid point may be useful in estimating the location of a mobile device.

With attention now directed to FIG. **20**, a block diagram is presented that represents a system for assigning geographical coordinates according to an embodiment of the present subject matter. A database **2001** is operatively connected to a processor **2002**. The processor **2002** is capable of receiving calibration data for each of one or more calibration points in a geographic region. The processor **2002** may be programmed, as shown in block **2003**, to evaluate the calibration data associated with the calibration points, determine if at least one grid point should be defined based on the evaluation, assign geographical coordinates to the one or more grid points, and populate the database **2001** with the geographical coordinates.

FIG. **21** is a block diagram for a system for assigning geographical coordinates including a determination of clustering of plural data vectors according to an embodiment of the present subject matter. The database **2101**, the processor **2102**, and block **2103** are similar to the database **2001**, the processor **2002**, and block **2003**, as described above, respectfully. At block **2114**, for each of select ones of the calibration points, the calibration data may include multiple data vectors and the evaluating of the calibration data may include a determination of clustering of the multiple data vectors.

FIG. **22** is a block diagram for a system for assigning geographical coordinates including comparing clusters of data vectors from different calibration points according to an embodiment of the present subject matter. The database **2201**, the processor **2202**, block **2203**, and block **2214** are similar to the database **2101**, the processor **2102**, block **2103**, and block **2114**, as described above, respectfully. At block **2215**, the determination if at least one grid point should be defined based on the evaluation may include comparing a first cluster of data vectors from a first one of the select calibration points to a second cluster of data vectors, where the second cluster of data vectors may include the first cluster of data vectors and data vectors from a second one of the select calibration points. At block **2216**, if the result of the comparison is within a predetermined tolerance, then the data vectors from the first

and second calibration points may be assigned to the same grid point; otherwise, the data vectors from the first calibration point may be assigned to a first grid point and the data vectors from the second calibration point may be assigned to a second grid point.

FIG. **23** is a block diagram for a system for assigning geographical coordinates including comparing clusters of data vectors from the same calibration point according to an embodiment of the present subject matter. The database **2301**, the processor **2302**, block **2303**, and block **2314** are similar to the database **2101**, the processor **2102**, block **2103**, and block **2114**, as described above, respectfully. At block **2315**, the determination if at least one grid point should be defined based on the evaluation may include comparing a first cluster of data vectors from a first one of the select calibration points to a second cluster of data vectors from the first one of the select calibration points. At block **2316**, if the result of the comparison is within a predetermined tolerance, then the data vectors from the first and second calibration points may be assigned to the same grid point; otherwise, the data vectors from the first cluster may be assigned to a first grid point and the data vectors from the second cluster may be assigned to a second grid point.

Looking now at FIG. **24**, a block diagram is presented representing a system for assigning geographical coordinates including calibration data according to an embodiment of the present subject matter. The database **2401**, the processor **2402**, and block **2403** are similar to the database **2001**, the processor **2002**, and block **2003**, as described above, respectfully. At block **2414**, the calibration data may include: signal strength for a signal transmitted by a transmitter having a known location as received by a receiver at a calibration point; signal strength of a signal transmitted by a transmitter located at a calibration point as received by a receiver at a known location; round trip time for a signal traveling between a calibration point and a known location; timing advance of a signal received by a mobile device at a calibration point; time difference of arrival of multiple signals at a calibration point with respect to a pair of known locations as measured by a receiver at a calibration point or at the known locations; the identification of a serving cell or serving sector of a mobile device located at a calibration point; a state of a wireless network serving a mobile device, and combinations thereof.

FIG. **25** is a block diagram for a system for assigning geographical coordinates including evaluating calibration data according to an embodiment of the present subject matter. The database **2501**, the processor **2502**, and block **2503** are similar to the database **2001**, the processor **2002**, and block **2003**, as described above, respectfully. At block **2514**, the evaluation of the associated calibration data may include an evaluation such as: a minimum number of unique neighboring calibration points as determined by calibration data of the neighboring calibration points; a minimum number of data vectors or network measurement reports; a predetermined maximum or minimum radius from a calibration point; a predetermined set of cells neighboring a cell serving a mobile device; and combinations thereof.

FIG. **26** is a block diagram for a system for assigning geographical coordinates including information for populating a database according to an embodiment of the present subject matter. The database **2601** and the processor **2602** are similar to the database **2001** and the processor **2002**, as described above, respectfully. At block **2603**, the processor **2602** may be programmed to evaluate the calibration data associated with the calibration points, determine if at least one grid point should be defined based on the evaluation, assign geographical coordinates to the one or more grid points, populate the database **2601** with the geographical coordinates, and populate the database **2601** with information which may include: a list of cells neighboring a cell serving a mobile device; a quantity that is a function of a power level of one or more cells neighboring a cell serving a mobile device; an identity of a cell or a sector serving a mobile device; a timing advance parameter; a geographical orientation of a mobile device; a location of a mobile device; network measurement report data vectors; a state of a network serving a mobile device; a confidence measure indicative of a reliability of the calibration data; and combinations thereof.

FIG. **27** is a block diagram for a system for assigning geographical coordinates including circuitry for determining geographical coordinates for nodes of a uniform grid according to an embodiment of the present subject matter. The database **2701**, the processor **2702**, and block **2703** are similar to the database **2601**, the processor **2602**, and block **2603**, as described above, respectfully. The system may further comprise circuitry **2704** for determining geographical coordinates for each of a plurality of nodes of a uniform grid spanning the geographic region, and circuitry **2705** for determining, for each of the one or more grid points, a closest node from the plurality of nodes of the uniform grid and assigning characteristic data associated with each of the grid point to its closest node.

FIG. **28** is a block diagram for a system for assigning geographical coordinates including characteristic data according to an embodiment of the present subject matter. The database **2801**, the processor **2802**, block **2803**, circuitry **2804**, and circuitry **2805** are similar to the database **2701**, the processor **2702**, block **2703**, circuitry **2704**, and circuitry **2705**, as described above, respectfully. At block **2816**, the characteristic data may include: a list of cells neighboring a cell serving a mobile device; a quantity that is a function of a power level of one or more cells neighboring a cell serving a mobile device; an identity of a cell or a sector serving a mobile device; a timing advance parameter; a geographical orientation of a mobile device; a location of a mobile device; network measurement report data vectors; a state of a network serving a mobile device; a confidence measure indicative of a reliability of the calibration data; and combinations thereof.

In a typical signal strength pattern matching mobile location system the time allowed to produce a location may be such that multiple NMRs and sets and subsets thereof may be available. By way of a non-limiting example, in the GSM air standard, mobile measurements are reported at an approximate rate of approximately two per second. Generally, the time allowed to produce a location may be on the order of thirty seconds. It is therefore an aspect of embodiments of the present subject matter to improve location accuracy by combining individual locations from calibration data, e.g., multiple NMRs, to produce a final location estimate.

Grid-based signal strength pattern matching location systems typically determine a quantitative measure of how close each candidate grid point matches with mobile-reported measurement parameters. An estimate of a mobile device's location may then be given by a grid point having the closest match thereto or a location interpolated between several grid point locations. As multiple NMRs are generally available during the time allotted to report the estimated location of a mobile device, embodiments of the present subject matter may utilize each NMR to generate an independent location estimate. These independent or individual location estimates may then be averaged or another mathematical function employed thereon to produce a final estimated mobile location that may be statistically more accurate.

Many location systems may also "fall back" to a default location as a function of the serving cell when the system is unable to determine a grid point match location. In such an instance, a location status variable may be utilized to identify the default location as a fall back location. Such a fall back location is generally less accurate than a location estimate determined by a pattern matching location system; however, an exemplary location combiner may omit any fall back locations and average or combine location estimates determined by an exemplary pattern matching algorithm.

A correlation may exist between location accuracy and mismatch distance metrics, e.g., "cost" values. The correlation may be exploited by flagging individual location estimates as having a high cost or metric (e.g., using a location status variable), and the corresponding location estimates are likely to possess a large location error. Embodiments of the present subject matter may present a refinement to the location combiner by skipping or omitting individual locations exceeding a predetermined "cost" threshold. Thus, the resulting location accuracy may be significantly improved. In further embodiments, the correlation between mismatch distance metrics and location accuracy may be exploited by employing weighted averaging of the individual estimated locations, weighting by an inverse of the metrics, normalizing by a sum of the inverses, or any combination thereof. A further metric that may be utilized for weighting the contribution of individual location estimates to a final location estimate may be the number of reporting neighboring cells. By way of a non-limiting example, assuming five individual location estimates are combined and four of the five individual location estimates possessed six reporting neighboring cells and the fifth location estimate possessed four reporting neighboring cells, the fifth location estimate may then be de-weighted in the final location estimation.

Another embodiment of the present subject matter may identify and omit outlier individual location estimates to improve the final location estimation. For example, a Mahalanobis distance from each individual location estimate to the final location estimate may be determined. A dynamic distance threshold may be determined from the median of these distances multiplied by a configurable factor. An individual location estimate having a distance to the final location estimate exceeding the threshold may be identified as an outlier. The final location estimate may then be re-determined with the outlier locations omitted. In the event that weighted averaging is utilized in such a determination, the weights may be re-determined prior to the final location estimation.

It may also be noted that estimated locations derived utilizing subsets of available NMRs may often differ. For example, considering an NMR including a set of ordered (e.g., in descending magnitude) reporting neighboring cell (NC) power levels, with the NC having an order ABCDE. If the lowest power NC (NC=E) is omitted from the NMR, the locations determined using ABCD NCs may be different from ABCDE. Similarly, the location determined for ABCE NCs may differ from that for ABDE NCs.

An examination or evaluation of the location estimates derived from subsets of the NMRs may provide an indication regarding the quality of the final location estimate. By way of a non-limiting example, if the location estimates derived utilizing any possible method of mapping the NMR or sets thereof to a specific geographic location or grid point, whether using NUGs or uniform grid points, agree under combinations of subsets, the confidence in the location estimate may be high and thus represent a confidence measure on the location estimate. Further, the fraction of total location estimates within a predetermined distance of the final location estimate may also qualify as a confidence measure.

In one embodiment of the present subject matter, for each NMR, one may form a set of all subsets of a selected NMR. Therefore, in a non-limiting example of an ordered set of NCs given by ABC, a full set of subsets is {ABC, AB, AC, BC, A, B, C}. In each case, an estimated location may be derived utilizing any method of location. Each of the locations in this set of locations, L, may possess an associated probability or other measure derived from the particular location method, thus defining a set M. A variety of schemes may be defined and implemented upon the set L and the set of associated measures on L, given by M, such as, but not limited to: (a) computing the final estimated location by clustering the set L without any reference to the measures in M; (b) computing the final estimated location as the centroid of a region containing the tightest cluster in L having an aggregate measure higher than some pre-set value; (c) computing the final estimated location as the location of the NUG (e.g., centroid of the NUG) which occurs most often in L; (d) computing the final estimated location by clustering the subset of L obtained by dropping the least power member in the NMR successively (e.g., the subset {ABC, AB, A}); (e) computing the final estimated location as the subset of L obtained by successively dropping the least power member in the NMR and with weighting by the corresponding measure in M.

Considering that the individual marginal probabilities for each NMR component, characteristic or parameter over a set of candidate NUGs or uniform grid points (UG) have been determined, it may be assumed that for every subset in L, the measure set M provides the joint probability for the subsets of the NMR. Using the subset AB in the previous example, the marginal probability for A, B and C over all NUGs has been determined. To determine the joint probability of A and B, for example, the marginal probabilities for A and B may be multiplied over the NUGs (or other locations). This generates the measure set M, and having the set L and set M defined, any one or combination of the methods in (a)-(e) described in the previous paragraph may be applied thereto for an estimation of an exemplary confidence measure.

The same principles may be applied to multiple NMRs and each of their respective subsets where each subset of each NMR may be assigned its respective measure in a now larger set M. It follows that the methods in (a)-(e) described above are equally applicable. In the case of multiple NMRs, a representative NMR may be determined through a clustering algorithm applied to each parameter of the NMR viewed over the set of NMRs. The methods in (a)-(e) described above may then be applied to this representative NMR for an estimation of an exemplary confidence measure.

It is also an aspect of embodiments of the present subject matter to provide an estimate of the location error in a signal strength pattern matching location system. As discussed above, a confidence measure may be determined that provides an indication of the quality of the location estimate.

In one embodiment of the present subject matter, if the final estimated location is an average of the individual locations, the degree to which the individual locations are clustered around the final estimation may provide an indication of the location error. The error estimate may be determined as the average of the distances from each individual location to the final estimated location as a function of the following relationship:

$$\hat{e} \equiv \frac{\sum_{i=1}^{N} d_i}{N} \quad (1)$$

where N is the number of estimated locations and d_i is the Euclidean distance from the ith estimated location to the final estimated location.

The error estimate may also be determined as a function of the following relationship:

$$\hat{e} \equiv \frac{\sum_{i=1}^{N} w_i d_i}{\sum_{i=1}^{N} w_i} \quad (2)$$

where N is the number of estimated locations, d_i is the Euclidean distance from the ith estimated location to the final estimated location, and w_i is a series of weighting factors.

As discussed above, when subsets of available NMRs are considered, however, the estimated locations may also differ. Therefore, an exemplary confidence measure may also be defined upon an estimated location given by any function that increases as the number of subset locations agree with the final estimated location. A non-limiting example of such a function may be the fraction of total locations that agree with the final estimated location or the fraction of total locations that lie within a certain distance of the final estimated location. In a further embodiment, weights may be assigned to the location estimates by utilizing the parameters or functions employed in determining the estimated location to thereby weight the determination of the associated confidence measure. Further exemplary confidence measures may be a function of pdfs, distortion measures, Mahalanobis distances, etc. with respect to any one or sets of NUGs.

Exemplary weighting quantities, e.g., distortion measures, pdfs, etc., may also be derived while estimating any location from single and multiple NMRs or their subsets, and may also be utilized to estimate location error. Empirically, the magnitudes of these weighting quantities may be correlated with the expected error. This relationship may be established graphically or in tabular format as a function of environmental characteristics (e.g., urban, suburban, seasonal, etc.). As a result, given a set of weighting quantities, an associated error may be predicted for a specific location estimate.

In one embodiment of the present subject matter, if the set of derived locations utilizing a set and/or subset of NMRs exhibit clusters, cluster separation may be employed between the highest aggregate weighted clusters to define an expected error. Such a distance may be termed as an inverse confidence measure as the larger the distance becomes, the greater the chance of error in the final location estimate if the corresponding cluster were selected. It follows that if the aggregate weight for a distant cluster is small, this distance should be modified to de-weight the associated distance by the weight of the cluster. An exemplary determination may multiply the cluster distance by a ratio of the weight of a selected cluster to the weight of a distant cluster; however, many such variations of this fundamental idea are clearly conceivable and such an example should not limit the scope of the claims appended herewith.

In another embodiment of the present subject matter, when each of the individual location estimates are generally at the same location (e.g., each located at the same calibration or grid point) the resulting error estimate would be zero or near zero. In such a scenario, the error estimate may be bounded by a minimum error value such as, but not limited to, a configurable constant based upon the overall expected system accuracy (e.g., the 25th percentile of overall system error, etc.).

It should be noted that the statistical averaged or weighted averaged location accuracy improves as the number of individual location estimates averaged or determined increases. For example, a final location estimate that comprises the average of two individual locations may generally be less accurate than a final location estimate comprising an average of twenty individual location estimates. Further, the optimal number of location estimates to combine or consider is dependent upon several factors including, but not limited to, the speed of the mobile device, the rate of acquiring NMRs, etc. This relationship may also be utilized to improve the error estimate as the number of individual location estimates increases.

In embodiments of the present subject matter wherein any one or multiple individual location estimates are "fall back" locations (e.g., default locations that may be based upon serving cell identification location), a default error estimate may be determined based upon an expected statistical accuracy of cell identification location. This determination may be a function of cell site geometry in an associated or corresponding operating market and may also be determined empirically through accuracy testing. Exemplary scenarios in which default locations may be encountered include, but are not limited to, when the NMR does not contain any NC measurements, when the available set of NMRs for the mobile device location generates a set of candidate locations that does not cluster (e.g., when the individual location estimates appear to be randomly distributed over a geographic region), when an NMR has very few reporting NCs and the confidence measure is poor, and combinations thereof.

In embodiments of the present subject matter where NMR data may be missing or invalid, the coordinates of the cell serving a mobile device may be retrieved from a respective site database from the serving cell identifier. In this instance, an exemplary default location may be a location that is a configurable distance away from the serving site. The configurable distance may or may not be positioned at a heading along the serving sector azimuth. For air standards in which certain parameters (e.g., timing advance, round trip timing, etc.) are available, this data may also be converted to an approximate range estimate from the serving site and utilized with other applicable parameters. For example, when such parameters are available, the default location may be enhanced by selecting a location on the serving cell azimuth at a distance from the site given by a TA range estimate.

In embodiments of the present subject matter where an NMR may include Time Difference of Arrival ("TDOA") data, this parameter may be utilized to derive a region within the cell to constrain the default location. For example, the TDOA, assuming the base station time offsets are known, defines a hyperbola in the region of interest. An intersection of this hyperbola with the applicable TA region to this cell may be utilized as a default location estimate. Alternatively, a default location estimate may be employed that does not rely on a serving sector heading if there exists a priori knowledge of sector coverage density. For example, if a sector coverage region can be determined (e.g., through drive testing, etc.), then the centroid of the sector coverage region may be stored in the respective site database by sector for each site and retrieved as a default location.

A further aspect of embodiments of the present subject matter may also improve location accuracy by interpolating between grid point locations when more than one grid point matches the calibration or reported data within a predetermined value. Generally, grid-based signal strength pattern matching location systems determine a quantitative measure of how close each candidate grid point (e.g., NUG or UG) matches mobile device reported measurement parameters. The location estimate of the mobile device may be given by the grid point having a match within a predetermined range. Further, as the actual location of the mobile device is generally not constrained to lie at a grid point location, interpolation between grid points may result in a more accurate location estimate.

During an exemplary interpolation according to one embodiment of the present subject matter, an analysis of whether interpolation should be performed may be determined as well as a selection of the appropriate grid or calibration points for the interpolation. Distance metrics may also be determined on any number of grid points. Exemplary metrics are discussed above and may include, but are not limited to, pdfs, Mahalanobis distance between parameter vectors, ordering number between ordered NCs in the NMR, NUG, UG, and combinations thereof. By way of a non-limiting example, it may be assumed that the distance metric for each of N candidate grid points (N>1) is determined and sorted. Representing the distance metric as C, then for each ith candidate, i=1 . . . N, an appropriate metric may be determined by the following relationship:

$$C_\text{Ratio}_i=[C_i-C_{min}]/[C_N-C_{min}] \tag{3}$$

where C_i is a metric associated with an ith candidate grid point, C_N is a metric associated with the worst corresponding candidate grid point, and C_{min} is a metric associated with the best corresponding candidate grid point. It follows that grid points having a C_{ratio} less than a predetermined and configurable threshold value may be a candidate for interpolation.

Generally, interpolation occurs between adjacent or nearby grid points. To minimize or prevent interpolation across widely spaced grid points, the distance from each interpolation candidate grid point to the minimum cost grid point may be less than a configurable distance threshold.

In embodiments when there are few grid point candidates or when there are fewer than a configurable number of candidate grid points, an appropriate metric may be determined by the following relationship:

$$C_\text{Ratio}_i=[C_i-C_{min}]/[C_{min}] \tag{4}$$

where C_i is a metric associated with an ith grid point and C_{min} is a metric associated with the best corresponding grid point. Equation (4) may thus enable an identification of appropriate grid points for interpolation when N is small. Equation (4) may also be performed to prevent interpolation between widely separated grid points.

Once the grid points for interpolation have been identified, one embodiment of the present subject matter may employ weighted averaging to determine a final interpolated location. An exemplary weight assigned to the ith grid point in computing the final interpolated location may be determined by the following relationship:

$$Wi = \frac{\frac{1}{Ci}}{\sum_{i=1}^{N}\left(\frac{1}{Ci}\right)} \tag{5}$$

where C_i is a metric associated with an ith grid point. Weighted averaging may also be utilized rather than uniform weighting to ensure that the best matching grid point (i.e., minimum cost grid point) exerts a larger influence on the final location estimate.

As discussed above, each grid point (NUG or UG) may provide one or a plurality of parameters and/or functions characterizing the grid point. Given a received set of one or more NMRs obtained at an unknown location, an accurate estimation of the unknown location may be determined using a characterization of the grid points over a geographic region. In one embodiment of the present subject matter, a distortion measure may be determined between available NMRs and grid point characteristics to assist in the estimation.

Generally, embodiments of the present subject matter may utilize any number of methods to determine a distortion measure, e.g., a mismatch distance between mobile reported measurements and a candidate grid point's stored measurement data. The associated "cost" value may also be inversely proportional to an increasing function of the probability that the mobile device is located at or in the vicinity of a grid point.

In one embodiment of the present subject matter, a distortion measure may comprise a combination of the values of each parameter in an NMR and each corresponding parameter in the grid point (NUG or UG) characteristics. The distortion measure may generally increase as the mismatch between any of the parameters increases and vice versa. For example, an exemplary cost value may be determined utilizing a Mahalanobis distance provided by the following relationship:

$$\text{COST} = \alpha(TA_{rpt} - TA_{cand})^2 + \sum_i\left[\left(\frac{RxLevDiff(i)^2}{MAXDIFF^2}\right)NCCU\right] \tag{6}$$

where α is 0 or 1 which controls whether TA differences are included in the determination (e.g., 1 for GSM and 0 for iDEN), TA_{rpt} is the TA for the NMR, TA_{cand} is the TA for the candidate grid point in the calibration database and/or a representative value, RxLevDiff(i) represents the difference in RxLev (received signal strength) for the ith neighbor cell or serving cell, I is an index to neighbor or serving cells (e.g., if only NC received signal strengths are used and there are six reporting NCs, then i=1 to 6; if in addition, a serving cell signal strength is included then i=1 to 7), NCCU represents an NC cost unit where an increasing NCCU increases the cost penalty for RxLev difference relative to the cost penalty for TA difference, and MAXDIFF is a configurable parameter that limits the cost incurred for differences in signal strengths. MAXDIFF may be set to 20 dB or another configurable value. RxLev differences exceeding MAXDIFF would not incur an additional cost penalty.

Embodiments of the present subject matter may determine RxLevDiff(i) through any number of methods including, but not limited to, the following relationships:

$$\text{RxLevDiff}(i)=(\text{RxLevServ}-\text{RxLevNeigh}(i))_{NMR}-(\text{RxLevServ}-\text{RxLevNeigh}(i))_{CND} \tag{7}$$

for i=1:6;

$$\text{RxLevDiff}(i)=(\text{RxLevNeigh}(i))_{NMR}-(\text{RxLevNeigh}(i))_{CND} \quad (8)$$

for i=1:6;

$$\text{RxLevDiff}(i)=(\text{RxLevNeigh}(l)-\text{RxLevNeigh}(i))_{NMR}-(\text{RxLevNeigh}(l)-\text{RxLevNeigh}(i))_{CND} \quad (9)$$

for i=2:6;

$$\text{RxLevDiff}(i)=(\text{AvgRxLevNeigh}-\text{RxLevNeigh}(i))_{NMR}-(\text{AvgRxLevNeigh}-\text{RxLevNeigh}(i))_{CND} \quad (10)$$

for i=1:6;

$$\text{RxLevDiff}(i)=(\text{AvgRxLev}-\text{RxLev}(i))_{NMR}-(\text{AvgRxLev}-\text{RxLev}(i))_{CND} \quad (11)$$

for i=1:7.

With reference to the above relationships, Equation (7) provides a comparison between the signal strengths of the serving cell and the ith NC between NMR and candidate points, Equation (8) provides a comparison between the signal strengths of the ith NC between NMR and candidate points, Equation (9) provides a comparison between the signal strengths of a first common NC and the ith NC between NMR and candidate points, Equation (10) provides a comparison between the average signal strengths of the NCs and the signal strengths of the ith NC between NMR and candidate points, and Equation (11) provides a comparison of the average signal strengths of the serving cells and NCs and the signal strengths of the ith serving cell and NC between NMR and candidate points.

In a further aspect of embodiments of the present subject matter, an estimated location may be generated for a mobile device given a received NMR and a region "R" over which a set "S" of grid points (NUGs or UGs) have been established. As described above, each grid point may include a series of parameters, components and/or functions characterizing the respective grid point. Provided a received set of one or more NMRs obtained at some unknown location, an estimation of that unknown location may be determined as a function of a characterization of the grid points over this region R.

In one embodiment of the present subject matter, an estimated location of a mobile device may be determined using any single NMR (drawn from a set or subset of NMRs) by any number of the following methods or combinations thereof. For example, one embodiment may match an ordered list of NCs, where the ordering may be in terms of any one of a number of parameters characterizing the NMR, such as, for example, NC power level, in a respective NMR to a similarly ordered list of NCs in the grid point(s) (NUG or UG) and (a) generate the estimated location as the centroid of the best cluster of matching grid points, (b) generate the estimated location as the location of the highest joint probability matching grid point, (c) generate the estimated location as the (joint probability) weighted sum of the locations of a set of matching grid points, (d) generate the estimated location as the (joint probability) weighted sum of the clustered locations of a set of matching grid points (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as weight for the respective cluster), (e) generate the estimated location by combining locations derived from NMR subsets, or any combination thereof.

In an additional embodiment, if the ordered list of NCs in the NMR (ordered with respect to the magnitude of any particular parameter characterizing the NMR) does not provide an exact match to the ordered list of NCs that may be available as a characteristic of a grid point, the method may evaluate those grid points (NUGs or UGs) including an ordered list thereof that may contain an ordered list in the NMR. Thus, the ordered list in the NMR may form a subset of the ordered list in the grid point, and the method may (a) generate an estimated location as the centroid of the best cluster of matching grid points, (b) generate the estimated location as the location of the highest joint probability matching grid point, (c) generate the estimated location as the (joint probability) weighted sum of the locations of a set of matching grid points, (d) generate the estimated location as the (joint probability) weighted sum of the clustered locations of a set of matching grid points, (e) generate the estimated location by combining locations derived from NMR subsets, or any combination thereof.

In embodiments of the present subject matter where the ordered list of NCs in the NMR is not contained in the ordered list of NCs for any grid point, then the method may utilize the highest power subset of NCs in the NMR (e.g., ordered from highest to lowest power) that provides either an exact match or is contained in the ordered list of NCs in the grid point. The method may then (a) generate an estimated location as the centroid of the best cluster of matching grid points, (b) generate the estimated location as the location of the highest joint probability matching grid point, (c) generate the estimated location as the (joint probability) weighted sum of the locations of a set of matching grid points, (d) generate the estimated location as the (joint probability) weighted sum of the clustered locations of a set of matching grid points, (e) generate the estimated location by combining locations derived from NMR subsets, or any combination thereof.

In a further embodiment of the present subject matter, the individual pdf of each NC power level or other parameter in the NMR over the set of available grid points (NUGs or UGs) may be evaluated. A joint probability may then be determined as the product of such marginal probabilities and an estimated location generated as (a) the location of the highest joint probability matching grid point, (b) the (joint probability) weighted sum of the locations of a set of matching grid points, (c) the (joint probability) weighted sum of the clustered locations of a set of matching grid points, (d) a combination of locations derived from NMR subsets, or any combination thereof.

In one embodiment, the joint probability of the NMR NC power levels or other parameters may be evaluated over the set of available grid points. The method may then generate an estimated location as (a) the location of the highest joint probability matching grid point, (b) the (joint probability) weighted sum of the locations of a set of matching grid points, (c) the (joint probability) weighted sum of the clustered locations of a set of matching grid points, (d) a combination of locations derived from NMR subsets, or any combination thereof.

In another embodiment, a distortion measure may be determined between the grid point measured parameters (e.g., mean NC power level, TA value, RTT value, etc.) and corresponding parameters in the NMR. Exemplary distortion measures have been provided above and may be, but are not limited to, a Mahalanobis distance, etc. Any weighting in this distance over dissimilar parameters may also be optimized empirically or determined by calculation. Utilizing an exemplary distortion measure, the method may generate an estimated location as (a) the location of the grid point with a least distortion measure, (b) the weighted sum of the locations of the set of grid points (weights may also be applied as a function of the distortion measure), (c) the weighted sum of any one or multiple clustered locations of a set of grid points,

(d) a combination of locations derived from NMR subsets (where the measure set M is the distortion measure).

In yet another embodiment, an estimated location may be selected by matching the NC power level or other parameter ordering in the NMR to the NC power or other parameter ordering in the grid points (NUG or UG) and utilize an ordering number evaluation. An exemplary ordering number may be an indicator regarding the number of relative shifts in position occurring between the NMR and the grid point(s) NC ordered power levels or other parameters. By way of a non-limiting example, in an NMR the NC power levels may be ordered as ABCDE whereas the selected grid point may provide an ordering of BACDE. This results in an ordering number of 1 (a single shift). Multiple variations of the ordering number may be considered and determined, however, these variations may be a measure of the distortion in ordering between the NC power levels evident in the grid point as compared to the NC parameters seen in the NMR. An aggregate ordering number for a set of NMRs may then be obtained by combining the ordering numbers for each individual NMR. A final estimated location may be a grid point cluster having the smallest ordering number. In a further embodiment, the ordering number or ordering of an exemplary characteristic may also be regarded as a distortion measure such that the method may generate an estimated location as (a) the location of the grid point with a least distortion measure, (b) the weighted sum of the locations of the set of grid points (weights may also be applied as a function of the distortion measure), (c) the weighted sum of any one or multiple clustered locations of a set of grid points, (d) a combination of locations derived from NMR subsets (where the measure set M is the distortion measure).

With respect to any of the various methods described above, embodiments of the present subject matter may also filter parameters prior to generating an estimated location. For example, an embodiment may match the serving cell/sector of candidate grid points to the serving cell/sector of the NMR and then proceed with any of the methods previously described. A further embodiment may also filter candidate grid points using other available parameters (e.g., TA, RTT, etc.) for the NMR and then proceed with any of the methods previously described. This exemplary filtering may also be set wider than the actual parameter (TA, RTT, etc.) determined value by a configurable threshold.

Candidate grid points may also be filtered by utilizing a mobile orientation parameter (e.g., indoors, outdoors, facing North or South, titled upwards, azimuth and elevation, etc.) applied during construction of the grid points, by utilizing those grid points where the serving cell identifier and serving control channel agrees with the NMR data, by utilizing the magnitude of the serving cell forward link control channel received signal level (and applying a configurable tolerance to this parameter), by eliminating those grid points not having at least N (configurable) NC received signal levels in common with the NMR, or any combination thereof and then proceeding with any of the methods previously described.

In embodiments of the present subject matter where a set of NMRs obtained at some unknown location (or locations in close proximity to each other) may be available, the aforementioned methods may be expanded to exploit the multiplicity of information. For example, an estimated location may be generated for each NMR in a set of NMRs by any or all of the methods applicable to a single NMR as indicated above and a tightest cluster of a single NMR location may be determined. Such a determination may also utilize a metric derived while locating that NMR (e.g., joint probability, Mahalanobis distance, etc.) to weight the clusters.

In another example, a representative NMR may be generated from a set of NMRs and any or all of the methods applicable to a single NMR as indicated above may be applied thereto. The representative NMR may be generated by obtaining a representative value for each of the NCs seen in the respective set of NMRs, and similarly obtaining a representative value for each of the other parameters seen in the NMRs. In another embodiment, these representative values may be obtained as a function of the available set of values, e.g., for NC power level mean or median power may be utilized.

In a further example, transitions in any of the parameters within the set of NMRs may be observed. Transitions may be utilized in reducing the applicable region for an estimated location. As many parameters represent a range of location possibilities, when a parameter changes, it may be inferred that the region of interest is at a boundary of the ranges represented by the parameter prior to and after the change. Therefore, any one of these boundaries determined for any parameter change within the applicable set may reduce the candidate region for the mobile device location. Exemplary parameter changes may be, but are not limited to, changes in signal power levels with respect to a particular NC, rate or pattern of dropping in and out of a particular NC signal, changes in serving cell or sector, changes in TA, RTT or equivalent parameter, and combinations thereof.

Additional embodiments may determine a distortion measure between the grid point characteristics or measured parameters and corresponding parameters of all NMRs taken collectively without reduction to representative values. Any weighting in this measure over dissimilar parameters may be optimized empirically. Utilizing a distortion measure, exemplary methods may generate an estimated location as (a) the location of the grid point having the least distortion measure, (b) the weighted sum of the locations of a set of grid points (any weights applied may also be a function of the distortion measure), (c) the weighted sum of clustered locations of a set of grid points, (d) as a combination of locations derived from NMR subsets (where the measure set M is now the distortion measure).

Further embodiments may match a variety of parameters and functions generated and stored describing a grid point (i.e., the grid point characteristics) with similar parameters and functions determined for the set of NMRs by utilizing a distortion measure to evaluate the similarity therebetween. Exemplary parameters and functions may be, but are not limited to, the following: (a) an ordered list of neighboring cells; (b) functions defined on the absolute neighboring cell power levels (e.g., mean, median, k^{th} moment, cluster-mean, etc.); (c) functions defined on the relative neighboring cell power differences (e.g., mean, median, k^{th} moment, cluster-mean, etc.); (d) serving cell/sector; (e) timing advance parameter (or equivalent); (f) individual pdf (probability density function or probability distribution function) of each neighboring cell power level; (g) joint pdf of neighboring cell power levels; (h) mean and variance of neighboring cell power levels; (i) mobile device orientation (e.g., indoors, outdoors, direction mobile device is facing (e.g., North, South, etc.), tilted upwards, azimuth, elevation, etc.); (j) a compact and/or efficient representation that enables retrieval of the calibration data NMR vectors assigned to this grid point; (k) the network state as indicated in the calibration data; (l) a confidence measure indicative of the reliability of the calibration data feeding this grid point; and (m) any combinations of the above. In this exemplary method, further embodiments may also construct a pdf for the set of NMRs and determine a similarity to the pdf for a grid point by a

measure applicable to pdfs such as, but not limited to, the Bhattacharya distance, Kullback-Liebler divergence or other measures for probability distributions. Having generated such measures with respect to the set of candidate grid points the method may generate an estimated location as (a) the location of the grid point with the least distortion measure, (b) the weighted sum of the locations of a set of grid points (any weights applied as a function of the distortion measure), (c) the weighted sum of clustered locations of a set of grid points, (d) a combination of locations derived from NMR subsets (where the measure set M is the distortion measure).

One aspect of the present subject matter may generate a location estimate of a mobile device through methods of intersections using any single NMR or set of NMRs. Utilizing a single NMR, an exemplary intersection method may generate an estimated location based upon an observation that the region of validity for any one of the parameters in a particular NMR may define a region where the estimated location of a mobile device should exist. By way of a non-limiting example, the power level or other parameter of a particular NC (e.g., NC**1**) in an NMR having a power level of P dBm may be evaluated. With regard to the calibration data such that for every NMR in a respective set of calibration data, the particular NC power level may be within +/−x dBm of P. As discussed above, every calibration data vector provides an associated location, and the location of each such data vector in a respective calibration data subset may form a representative region, R1, defining a region within a location space having a power constraint upon NC**1**. R1 may or may not be contiguous, and may even be empty. In the event that R1 is empty, then the value of x may be increased by a predetermined value (or iteratively increased) until a nonempty region emerges and comprises valid calibration data points satisfying (e.g., falling into the range of) the obtained NMR power or parameter requirement. This may then define a region formed of discrete points in two dimensional location space. Similar regions may be constructed for each of the NCs and for each of the parameters or functions in the NMR. It follows that a range array may thus be generated containing range that define maximum and minimum values for each parameter of the form of two aggregated vectors.

An intersection of the aforementioned regions may then be determined. If a non-empty intersection occurs, the range array may be modified to approach the actual NMR data vector. Any such modification may be attempted in each NC power level or other NMR parameter level individually. In this method, the intersection region may be reduced until the smallest (and possibly clustered) intersection occurs. An estimated location for a mobile device may then be determined as the centroid of this intersection or may be determined through an evaluation of the pdf or other exemplary statistical measure for the calibration data within the intersection or a selected region. Further, an estimated location may also be determined utilizing any one or combination of the methods described above with reference to the generation of a location estimate utilizing any single NMR or set of NMRs. If, however, the intersection is empty, the range array may be modified to be wider than the actual NMR vector until a feasible solution can be found. If no solution is found with the respective range array at a higher threshold, a subset of the NCs in the NMR may be evaluated (e.g., by dropping the lowest power NC in the NMR, etc.) and the entire process described above may then be employed.

A distortion measure may also be determined along with a respective range array that generates a finite intersection region. The applicable distortion measure may be determined as, but not limited to, the largest width of any NMR NC power level or parameter level in the range array, a weighted combination of the individual widths of the NMR NC power or parameter levels in the range array, the area of the final intersection region, or any combination thereof. This distortion measure can then be an indicator of the quality or expected accuracy of the eventual location estimate.

Additionally, any subsets of the NMR(s) may be examined for intersection regions. If multiple disjoint regions occur with different NMR subsets, these disjointed regions may be regarded as a set of grid points (NUGs or UGs) and evaluated for an estimated location employing any one or combination of the methods described above with reference to the generation of a location estimate utilizing a single NMR or set of NMRs. By way of a non-limiting example, a pdf may be generated for each disjointed region, and then the techniques of location estimation described above utilizing any single NMR or set of NMRs may be employed to determine which of the regions may be the best location estimate.

Utilizing a set of NMRs, an exemplary intersection method may generate an estimated location for each NMR in the set of NMRs by any or all of the methods applicable to a single NMR as discussed in the previous paragraphs and (a) determine the tightest cluster of such single NMR locations (optionally using a metric derived while locating that NMR to weight the clusters such as a distortion measure (e.g., joint probability, Mahalanobis distance, cluster radius, etc.)), (b) if multiple disjoint regions occur for one or more NMRs, use the methods described above with reference to the generation of a location estimate utilizing any single NMR or set of NMRs to determine the most likely estimate for the location estimate, and/or (c) if multiple disjoint regions occur for some NMRs but not for others, utilizing regions having an appropriate weighting and/or utilizing a distortion measure and any additional weighting that may allocate a greater likelihood to those NMRs generating a non-disjoint region.

Utilizing a set of NMRs, an exemplary intersection method may also generate a representative NMR from the set of NMRs and apply the methods described above with regard to a single NMR to the representative NMR. The representative NMR may be generated by determining a representative value for each of the NCs available in the set of NMRs and determining a representative value for each of the other parameters available in the respective NMRs. Exemplary representative values may be obtained as a function of the available set of values (e.g., for NC power, mean or median). In the alternative, this exemplary method may also consider a set of NC power or parameter levels (applicable to each NMR NC level) when viewed over the set of NMRs and select that NC level requiring the narrowest range to provide a valid region. This power or parameter level may be the applicable level in the representative NMR. It should be noted that embodiments of the present subject matter employing this exemplary method may produce results different from the aforementioned grid point approach as calibration data too few in number to effectively emerge in a pdf of the grid point(s) to which the data are applied may, however, emerge in this exemplary method.

It is also another aspect of embodiments of the present subject matter to generate a location estimate for a mobile device utilizing multiple constructions of characterizing information from grid points (NUGs or UGs) over the same region. By way of a non-limiting example, an exemplary method may utilize multiple sets of grid points constructed on the same calibration data (or over several such sests of calibration data) and select a set of grid points such that, when evaluated over the methods described above regarding single NMRs or sets of NMRs, representative NMRs, etc., provides

the best criteria of fit. Exemplary criteria may be, but are not limited to total probability, cluster radius, Euclidean norm, Mahalanobis distance or other exemplary parameters that are an indicator of a "goodness" of fit. The estimated location within the grid point construction providing the best criteria of fit may be determined as the final location estimate for a respective mobile device.

In a further embodiment of the present subject matter, clustering of data vectors may also occur in another dimension of construction space (rather than occurring purely in the location space). Therefore, if a particular location exists in the best cluster over multiple grid point constructions, that location may be determined as the correct location for the estimate. The estimated location may then be obtained by applying the methods described above regarding single NMRs or sets of NMRs, representative NMRs, etc. within selected grid point set (NUG or UG) or over all grid point sets. It follows that each construction method may also be visualized as a layer in three dimensional space having a separate set of candidate locations or clusters (associated weights may also be applied thereupon). Exemplary weights may be, but are not limited to, distortion measures, probabilities, etc. In a further embodiment of the present subject matter, a vertical combination of candidate locations across the various constructions forming the third dimension may also be employed; thus, clustering in this instance may be a process that, when viewed in each location space (which is two dimensional) and in the vertical dimension, examines each or combinations of different constructions. An acceptable location estimate may generally be expected to cluster well in both location space and construction space, and the tightness of this cluster may then be employed as an additional confidence measure upon the respective location estimate and utilized in the methods described above.

FIG. **29** is a flow chart for a method for locating a mobile device according to one embodiment of the present subject matter. With reference to FIG. **29**, at block **2910**, a plurality of calibration or grid points may be provided in a geographic region. At block **2920**, a plurality of NMRs may be provided for a mobile device in the geographic region. Ones of the plurality of grid points may be compared to one or more parameters of ones of the plurality of NMRs in block **2930**. In another embodiment of the present subject matter, the comparison may further comprise generating a distortion measure that is a function of a combination of parameters of ones of the plurality of network measurement reports and corresponding parameters of ones of the plurality of grid points. An exemplary distortion measure may be, but is not limited to, a Mahalanobis distance, a comparison of received signal strengths of a serving cell and a neighboring cell between ones of the plurality of NMRs and grid points, a comparison of received signal strengths of a neighboring cell between ones of the plurality of NMRs and grid points, a comparison of received signal strengths of a first common neighboring cell and another neighboring cell between ones of the plurality of NMRs and grid points, a comparison of average received signal strengths of reporting neighboring cells and received signal strengths of a neighboring cell between ones of the plurality of NMRs and grid points, a comparison of average received signal strengths of serving and reporting neighbor cells received signal strengths of a selected neighbor or serving cell between ones of the plurality of NMRs and grid points, and any combination thereof. A first location estimate of the mobile device may be generated for each of the ones of the plurality of NMRs in block **2940**, and in block **2950**, a second location estimate of the mobile device may be determined as a function of at least one of the generated first location estimates.

FIG. **30** is a flow chart for a method for locating a mobile device according to one embodiment of the present subject matter including identifying and omitting outlier first location estimates. With reference to FIG. **30**, blocks **3010**, **3020**, **3030**, **3040** and **3050** are similar to blocks **2910**, **2920**, **2930**, **2940** and **2950**, respectively. At block **3060**, the method may further determine a Mahalanobis distance from each first location estimate to the second location estimate and at block **3070**, determine a distance threshold from a median of the determined Mahalanobis distances multiplied by a predetermined factor. At block **3080**, a third location estimate may then be determined by averaging two or more of the first location estimates. In such a determination the first location estimates having a Mahalanobis distance to the second location estimate greater than a predetermined distance threshold may be omitted from the third location estimate determination.

FIG. **31** is a flow chart for a method for locating a mobile device according to another embodiment of the present subject matter. With reference to FIG. **31**, blocks **3110**, **3120**, **3130**, **3140** and **3150** are similar to blocks **2910**, **2920**, **2930**, **2940** and **2950**, respectively. At block **3151**, the determination of a second location estimate may further comprise averaging two or more first location estimates, or at block **3152**, the determination of a second location estimate may further comprise employing a weighted averaging of ones of the first location estimates. At block **3153**, the determination of a second location estimate may further comprise weighting a first location estimate by an inverse of a distance metric, or at block **3154**, the determination of a second location estimate may further comprise normalizing a first location estimate by a sum of an inverse of a distance metric. Further, at block **3155**, the determination of a second location estimate may further comprise weighting a first location estimate as a function of the number of reporting neighboring cells to a serving cell serving the mobile device.

FIG. **32** is a flow chart for a method for locating a mobile device according to one embodiment of the present subject matter including omitting a first location estimate. With reference to FIG. **32**, blocks **3210**, **3220**, **3230**, **3240** and **3250** are similar to blocks **2910**, **2920**, **2930**, **2940** and **2950**, respectively. At block **3260**, the method may further omit a first location estimate having an error greater than a predetermined threshold.

FIG. **33** is a flow chart for a method for locating a mobile device according to one embodiment of the present subject matter including interpolating between grid points. With reference to FIG. **33**, blocks **3310**, **3320**, **3330**, **3340** and **3350** are similar to blocks **2910**, **2920**, **2930**, **2940** and **2950**, respectively. At block **3360**, the method may further interpolate between ones of the plurality of grid points when more than one grid point corresponds to a parameter of the plurality of NMRs.

FIG. **34** is a flow chart for a method for locating a mobile device according to another embodiment of the present subject matter including interpolating between grid points and/or assigning weights to selected grid points. With reference to FIG. **34**, blocks **3410**, **3420**, **3430**, **3440**, **3450** and **3460** are similar to blocks **3310**, **3320**, **3330**, **3340**, **3350** and **3360**, respectively. At block **3461**, the interpolation may be a function of the relationship provided in Equation (3) above. With reference to Equation (3), a grid point having a C_Ratio_i less than a predetermined threshold may be a candidate grid point for the interpolation in one embodiment and/or a grid point

having a distance from the best corresponding grid point less than a predetermined threshold may be a candidate grid point for the interpolation. At block **3462**, the interpolation may also be a function of the relationship provided in Equation (4) above. At block **3470**, the method may further assign weights to an ith grid point as a function of the relationship provided in Equation (5) above.

FIG. **35** is a flow chart for a method for locating a mobile device according to another embodiment of the present subject matter including providing a default location. With reference to FIG. **35**, blocks **3510**, **3520**, **3530**, **3540**, and **3550** are similar to blocks **2910**, **2920**, **2930**, **2940** and **2950**, respectively. At block **3560**, the method may further comprise providing a default location for the second location estimate if a second location estimate cannot be determined as a function of at least one of the generated first location estimates. In one embodiment at block **3561**, the default location may be a predetermined distance from a serving cell serving the mobile device at a heading along a serving sector azimuth. In another embodiment at block **3562**, the default location may be a function of timing advance or round trip time and/or may be an approximate range estimate from a serving cell serving the mobile device. In an additional embodiment in block **3563**, the default location may be a region determined as a function of a TDOA measurement and/or where the region is the intersection of a hyperbola defined by said TDOA with a timing advance region applicable to a serving cell serving the mobile device. In yet a further embodiment in block **3564**, the default location may be determined as a function of a priori knowledge of sector coverage density.

FIG. **36** is a flow chart for a method of improving a location estimate of a mobile device. With reference to FIG. **36**, at block **3610**, a plurality of grid points in a geographic region may be provided and at block **3620**, a set of NMRs for a mobile device in the geographic region may be provided. The set of NMRs may or may not include one or more subsets of NMRs. At block **3630**, ones of the plurality of grid points may be compared to at least one parameter of a subset of the NMRs, and at block **3640**, a first location estimate of the mobile device may be generated for each subset of NMRs. A second location estimate of the mobile device may be determined as a function of at least one of the generated first location estimates at block **3650**, and at block **3660**, an attribute of the second location estimate may be indicated as a function of a parameter of a subset of the NMRs. In additional embodiments, the attribute may be determined as a function of any one or combination of a fraction of first location estimates corresponding with the second location estimate and a fraction of total first location estimates that lie within a predetermined distance of the second location estimate.

FIG. **37** is a flow chart for a method of improving a location estimate of a mobile device according to another embodiment of the present subject matter. With reference to FIG. **37**, blocks **3710**, **3720**, **3730**, **3740**, **3750** and **3760** are similar to blocks **3610**, **3620**, **3630**, **3640**, **3650** and **3660**, respectively. At block **3751**, the determination of a second location estimate may further comprise clustering the set of NMRs without reference to parameters in any of the subsets of NMRs. At block **3752**, the second location estimate may be determined as the centroid of a region containing the tightest cluster of NMRs in the set of NMRs. The cluster may or may not possess an aggregate measure higher than a predetermined threshold. At block **3753**, the second location estimate may be determined as the centroid of ones of the plurality of grid points occurring most often in the set of NMRs. At block **3754**, the determination of a second location estimate may further comprise clustering a subset of NMRs as a function of power of neighboring cells. At block **3755**, the determination of a second location estimate may further comprise clustering a subset of NMRs as a function of power of neighboring cells and another parameter in the subset. At block **3756**, the determination of a second location estimate may further comprise averaging two or more first location estimates. At block **3757**, the determination of a second location estimate may also further comprise employing a weighted averaging of ones of the first location estimates. In another embodiment, at block **3758**, the determination of a second location estimate may further comprise weighting a first location estimate by an inverse of a distance metric. At block **3759**, the determination of a second location estimate may also comprise normalizing a first location estimate by a sum of an inverse of a distance metric, and at block **3761**, the determination of a second location estimate may further comprise weighting a first location estimate as a function of the number of reporting neighboring cells to a serving cell serving the mobile device. In another embodiment at block **3762**, the determination of a second location estimate may further comprise weighting a first location estimate as a function of the indicated attribute. Exemplary weighting may be, but is not limited to, a Mahalanobis distance, a probability density function.

FIG. **38** is a flow chart for a method of improving a location estimate of a mobile device according to another embodiment of the present subject matter including omitting a first location estimate. With reference to FIG. **38**, blocks **3810**, **3820**, **3830**, **3840**, **3850** and **3860** are similar to blocks **3610**, **3620**, **3630**, **3640**, **3650** and **3660**, respectively. At block **3870**, the method may further omit a first location estimate having an error greater than a predetermined threshold.

FIG. **39** is a flow chart for a method for locating a mobile device according to one embodiment of the present subject matter including identifying and omitting outlier first location estimates. With reference to FIG. **39**, blocks **3910**, **3920**, **3930**, **3940**, **3950** and **3960** are similar to blocks **3610**, **3620**, **3630**, **3640**, **3650** and **3660** respectively. At block **3970**, the method may further determine a Mahalanobis distance from each first location estimate to the second location estimate and at block **3980**, determine a distance threshold from a median of the determined Mahalanobis distances multiplied by a predetermined factor. At block **3990**, a third location estimate may then be determined by averaging two or more of the first location estimates. In such a determination the first location estimates having a Mahalanobis distance to the second location estimate greater than a predetermined distance threshold may be omitted from the third location estimate determination.

FIG. **40** is a flow chart for a method of improving a location estimate of a mobile device according to a further embodiment of the present subject matter. With reference to FIG. **40**, blocks **4010**, **4020**, **4030**, **4040**, **4050** and **4060** are similar to blocks **3610**, **3620**, **3630**, **3640**, **3650** and **3660**, respectively. At block **4061**, the indication of an attribute of the second location estimate may further comprise determining an error estimate as an average of distances from each first location estimate to the second location estimate. In one embodiment at block **4062**, the error estimate may be determined as a function of the relationship provided in Equation (1) above. In a further embodiment at block **4063**, the error estimate may be determined as a function of the relationship provided in Equation (2) above. With reference to Equation (2), exemplary weighting factors may be, but are not limited to probabilities determined during the first location estimate generation, probabilities determined during the second location estimate determination, distortion function values deter-

mined during the first location estimate generation, distortion function values determined during the second location estimate determination, and combinations thereof. In yet another embodiment in block **4064**, the error estimate may be determined as a function of subset NMR cluster separation between a highest aggregate weighted cluster.

FIG. **41** is a flow chart for a method of improving a location estimate of a mobile device according to a further embodiment of the present subject matter including providing a default location. With reference to FIG. **41**, blocks **4110**, **4120**, **4130**, **4140**, **4150** and **4160** are similar to blocks **3610**, **3620**, **3630**, **3640**, **3650** and **3660**, respectively. At block **4170**, a default location may be provided for the second location estimate if the attribute is less than a predetermined threshold. In one embodiment at block **4171**, the default location may be a predetermined distance from a serving cell serving the mobile device at a heading along a serving sector azimuth. In another embodiment at block **4172**, the default location may be a function of timing advance or round trip time and/or may be an approximate range estimate from a serving cell serving the mobile device. In an additional embodiment in block **4173**, the default location may be a region determined as a function of a TDOA measurement and/or where the region is the intersection of a hyperbola defined by said TDOA with a timing advance region applicable to a serving cell serving the mobile device. In yet a further embodiment in block **4174**, the default location may be determined as a function of a priori knowledge of sector coverage density.

FIG. **42** is a flow chart for a method of locating a mobile device in a geographic region according to an embodiment of the present subject matter. With reference to FIG. **42**, at block **4210**, a plurality of grid points may be provided in a geographic region where each of the grid points may include at least one characterizing parameter or characterizing function, and where each of the grid points is located on a grid defined over the geographic region. At block **4220**, a plurality of NMRs may be provided for a mobile device in the geographic region, and at block **4230**, an estimated location may be determined for the mobile device from one NMR as a function of the at least one parameter. Of course, one or more of the grid points may be randomly located within the geographic region, and one or more of the grid points may be located on a predetermined fixed uniform grid defined over the geographic region.

FIG. **43** is a flow chart for a method of locating a mobile device in a geographic region according to another embodiment of the present subject matter. With reference to FIG. **43**, blocks **4310**, **4320** and **4330** are similar to blocks **4210**, **4220** and **4230**, respectively. At block **4340**, the determination of an estimated location for the mobile device may further include comparing an ordered list of cells neighboring a cell serving the mobile device in the one NMR to an ordered list of neighboring cells in the grid. The ordering may be in terms of any one of a number of parameters characterizing a respective NMR, e.g., NC power level or NC measurement quality. At block **4350**, an estimated location may be generated for the mobile device which may comprise a centroid of a cluster of best matching grid points in the grid, a highest joint probability matching grid point in the grid, a weighted sum of the locations of a set of matching grid points in the grid (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching grid points in the grid (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), as a function of locations determined from subsets of the plurality of NMRs, or any combination thereof. At block **4360**, a further embodiment may also filter available grid points as a function of any one or combination of selected characteristics, such as, but not limited to, a matching of serving cell or sector for grid points in the grid to the serving cell (provided such a characterization is available for the respective grid points) or sector of the one NMR, a TA parameter from the one NMR, a RTT parameter from the one NMR, a mobile device orientation parameter, a serving cell identifier, a serving control channel, a magnitude of a serving cell forward link control channel received signal level, a predetermined number of cell received signal levels common to the one NMR, or any combination thereof.

FIG. **44** is a flow chart for a method of locating a mobile device in a geographic region according to an additional embodiment of the present subject matter. With reference to FIG. **44**, blocks **4410**, **4420** and **4430** are similar to blocks **4210**, **4220** and **4230**, respectively. At block **4440**, the determination of an estimated location for the mobile device may further include comparing an ordered list of cells neighboring a cell serving the mobile device in the one NMR to a similarly ordered list of neighboring cells in the grid. The ordering may be in terms of any one of a number of parameters characterizing a respective NMR, e.g., NC power level. At block **4450**, if no exact match exists between the ordered list of neighboring cells of the one NMR and any grid point on the grid, then a largest subset of the ordered list of neighboring cells in the grid points may be formed that matches the NMR. At block **4460**, an estimated location may be generated for the mobile device which may comprise a centroid of a cluster of thus matched grid points, clustered by location, in the grid, a highest joint probability matching grid point in the grid, a weighted sum of the locations of a set of matching grid points in the grid (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching grid points in the grid (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), as a function of locations determined from subsets of the plurality of NMRs, or any combination thereof. At block **4470**, a further embodiment may also filter available grid points as a function of any one or combination of selected characteristics, such as, but not limited to, a matching of serving cell or sector for grid points (provided such a characterization is available for those grid points) in the grid to the serving cell or sector of the one NMR, a TA parameter from the one NMR, a RTT parameter from the one NMR, a mobile device orientation parameter, a serving cell identifier, a serving control channel, a magnitude of a serving cell forward link control channel received signal level, a predetermined number of cell received signal levels common to the one NMR, or any combination thereof.

FIG. **45** is a flow chart for a method of locating a mobile device in a geographic region according to a further embodiment of the present subject matter. With reference to FIG. **45**, blocks **4510**, **4520** and **4530** are similar to blocks **4210**, **4220** and **4230**, respectively. At block **4540**, the determination of an estimated location for the mobile device may further include comparing an ordered list of cells neighboring a cell serving the mobile device in the one NMR to an ordered list of neighboring cells in the grid. The ordering may be in terms of any one of a number of parameters characterizing a respective NMR, e.g., NC power level. At block **4550**, if the ordered list of neighboring cells of the one NMR is not contained in the ordered list of neighboring cells for the grid, then a largest

ordered subset of neighboring cells in the one NMR may be utilized having either an exact match or is contained in the ordered list of neighboring cells in the grid. At block **4560**, an estimated location of the mobile device may be generated that may comprise a centroid of a cluster, clustered by location, of thus matched grid points in the grid, a highest joint probability matching grid point in the grid, a weighted sum of the locations of a set of matching grid points in the grid (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching grid points in the grid (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), and as a function of locations determined from subsets of the plurality of NMRs. At block **4570**, a further embodiment may also filter available grid points as a function of any one or combination of selected characteristics, such as, but not limited to, a matching of serving cell or sector for grid points (provided such a characterization is available for those grid points) in the grid to the serving cell or sector of the one NMR, a TA parameter from the one NMR, a RTT parameter from the one NMR, a mobile device orientation parameter, a serving cell identifier, a serving control channel, a magnitude of a serving cell forward link control channel received signal level, a predetermined number of cell received signal levels common to the one NMR, or any combination thereof.

FIG. **46** is a flow chart for a method of locating a mobile device in a geographic region according to yet another embodiment of the present subject matter. With reference to FIG. **46**, blocks **4610**, **4620** and **4630** are similar to blocks **4210**, **4220** and **4230**, respectively. At block **4640**, the determination of an estimated location for the mobile device may further include evaluating a probability density function for each power level of a cell neighboring a cell serving the mobile device in the one NMR over each grid point of a set of available grid points in the grid. At block **4650**, a joint probability may then be determined as a function of the individual probability density functions, and at block **4660**, an estimated location of the mobile device may be generated that may comprise a centroid of a cluster of highest probability grid points, clustered by location, in the grid, a highest joint probability matching grid point in the grid, a weighted sum of the locations of a set of matching grid points in the grid (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching grid points in the grid (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), and as a function of locations determined from subsets of the plurality of NMRs. At block **4670**, a further embodiment may also filter available grid points as a function of any one or combination of selected characteristics, such as, but not limited to, a matching of serving cell or sector for grid points (provided such a characterization is available for the respective grid points) in the grid to the serving cell or sector of the one NMR, a TA parameter from the one NMR, a RTT parameter from the one NMR, a mobile device orientation parameter, a serving cell identifier, a serving control channel, a magnitude of a serving cell forward link control channel received signal level, a predetermined number of cell received signal levels common to the one NMR, or any combination thereof.

FIG. **47** is a flow chart for a method of locating a mobile device in a geographic region according to yet another embodiment of the present subject matter. With reference to FIG. **47**, blocks **4710**, **4720** and **4730** are similar to blocks **4210**, **4220** and **4230**, respectively. At block **4740**, the determination of an estimated location for the mobile device may further include directly evaluating a joint probability (i.e., as an aggregate rather than through computation of the product of marginal pdfs) of power levels for at least one cell neighboring a cell serving the mobile device in the one NMR over a set of available grid points in the grid. At block **4750**, an estimated location of the mobile device may be generated that may comprise a highest joint probability matching grid point in the grid, a weighted sum of the locations of a set of matching grid points in the grid (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching grid points in the grid (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), and as a function of locations determined from subsets of the plurality of NMRs. At block **4760**, a further embodiment may also filter available grid points as a function of any one or combination of selected characteristics, such as, but not limited to, a matching of serving cell or sector for grid points (provided such a characterization is available for the respective grid points) in the grid to the serving cell or sector of the one NMR, a TA parameter from the one NMR, a RTT parameter from the one NMR, a mobile device orientation parameter, a serving cell identifier, a serving control channel, a magnitude of a serving cell forward link control channel received signal level, a predetermined number of cell received signal levels common to the one NMR, or any combination thereof.

FIG. **48** is a flow chart for a method of locating a mobile device in a geographic region according to yet another embodiment of the present subject matter. With reference to FIG. **48**, blocks **4810**, **4820** and **4830** are similar to blocks **4210**, **4220** and **4230**, respectively. At block **4840**, the determination of an estimated location for the mobile device may further include determining a distortion measure between a characteristic function or parameter of a grid point and a corresponding function or parameter obtained for the one NMR. At block **4850**, an estimated location of the mobile device may be generated that may comprise a location of a grid point having the smallest distortion measure, a weighted sum of the locations of a set of matching grid points in the grid (where the weighting applied to each of the matching grid points may be a function of the distortion measure), a weighted sum of clustered locations of a set of matching grid points in the grid, as a function of locations determined from subsets of the plurality of NMRs, or any combination thereof. At block **4860**, a further embodiment may also filter available grid points as a function of any one or combination of selected characteristics, such as, but not limited to, a matching of serving cell or sector for grid points (provided such a characterization is available for the respective grid points) in the grid to the serving cell or sector of the one NMR, a TA parameter from the one NMR, a RTT parameter from the one NMR, a mobile device orientation parameter, a serving cell identifier, a serving control channel, a magnitude of a serving cell forward link control channel received signal level, a predetermined number of cell received signal levels common to the one NMR, or any combination thereof. In an additional embodiment, the distortion measure may be, but is not limited to, a Mahalanobis distance.

FIG. **49** is a flow chart for a method of locating a mobile device in a geographic region according to yet another

embodiment of the present subject matter. With reference to FIG. **49**, blocks **4910**, **4920** and **4930** are similar to blocks **4210**, **4220** and **4230**, respectively. At block **4940**, the determination of an estimated location for the mobile device may further include matching cell power ordering of cells neighboring a cell serving the mobile device in the one NMR to neighboring cell power ordering in each of the grid points in the grid. At block **4950**, an estimated location may then be selected as a function of a quality of the matching. The quality may be a function of a relative shift in the ordering sequence occurring between the one NMR and grid point cell power ordering. It is also envisioned that this same concept may be applied to any other vector parameter characterizing NMRs and/or grid points and such an example should not limit the scope of the claims appended herewith. At block **4960**, a further embodiment may also filter available grid points as a function of any one or combination of selected characteristics, such as, but not limited to, a matching of serving cell or sector for grid points (provided such a characterization is available for the respective grid points) in the grid to the serving cell or sector of the one NMR, a TA parameter from the one NMR, a RTT parameter from the one NMR, a mobile device orientation parameter, a serving cell identifier, a serving control channel, a magnitude of a serving cell forward link control channel received signal level, a predetermined number of cell received signal levels common to the one NMR, or any combination thereof.

FIG. **50** is a flow chart for another method of locating a mobile device in a geographic region according to an embodiment of the present subject matter. With reference to FIG. **50**, at block **5010**, a plurality of grid points may be provided in a geographic region where each of the grid points may include at least one characterizing parameter and each of the grid points may be located on a grid defined over the geographic region. At block **5020**, a plurality of NMRs may be provided for a mobile device in the geographic region, and at block **5030**, an estimated location may be determined for the mobile device from a set of said plurality of network measurement reports as a function of the parameter. Of course, one or more of the grid points may be randomly located within the geographic region, and one or more of the grid points may be located on a predetermined fixed uniform grid defined over the geographic region.

FIG. **51** is a flow chart for another method of locating a mobile device in a geographic region according to an embodiment of the present subject matter. With reference to FIG. **51**, blocks **5110**, **5120** and **5130** are similar to blocks **5010**, **5020** and **5030**, respectively. At block **5140**, the determination of an estimated location for the mobile device may also include determining a cluster for each NMR characteristic or parameter, clustered by location, in the set of NMRs. The clustering may further be weighted by an exemplary metric that may be, but is not limited to, a Mahalanobis distance, joint probability, probability density function, and any combination thereof.

FIG. **52** is a flow chart for another method of locating a mobile device in a geographic region according to an additional embodiment of the present subject matter. With reference to FIG. **52**, blocks **5210**, **5220** and **5230** are similar to blocks **5010**, **5020** and **5030**, respectively. At block **5240**, the determination of an estimated location for the mobile device may include determining a representative value for each parameter occurring in the set of NMRs. At block **5250**, a cluster for each representative value may also be weighted by an exemplary metric (e.g., a Mahalanobis distance, joint probability, probability density function, etc.) to weight the cluster. An exemplary representative value may be, but is not limited to, serving cell power level, neighboring cell power level, timing advance, round trip time, or any combination thereof. Further, the representative value may be determined as a function of a mean or median of a set of parameter values obtained over the set of NMRs.

FIG. **53** is a flow chart for another method of locating a mobile device in a geographic region according to a further embodiment of the present subject matter. With reference to FIG. **53**, blocks **5310**, **5320** and **5330** are similar to blocks **5010**, **5020** and **5030**, respectively. At block **5340**, the determination of an estimated location for the mobile device may also include observing a transition in a parameter occurring in one or more of the NMRs within an applicable set of NMRs. At block **5350**, a location of the mobile device may be estimated on a boundary defined by a first range represented by the parameter before the transition and by a second range represented by the parameter after the transition. An exemplary parameter may be, but is not limited to, signal power level, signal quality, rate of dropping in/out of a neighboring cell signal, pattern of dropping in/out of a neighboring cell signal, changes in serving cell, changes in serving sector, RTT, TA, and any combinations thereof.

FIG. **54** is a flow chart for another method of locating a mobile device in a geographic region according to an additional embodiment of the present subject matter. With reference to FIG. **54**, blocks **5410**, **5420** and **5430** are similar to blocks **5010**, **5020** and **5030**, respectively. At block **5440**, the determination of an estimated location for the mobile device may also determine a distortion measure between a parameter or function of ones of the grid points and a corresponding parameter or function in each NMR in the set. At block **5450**, an estimated location of the mobile device may be generated where the estimated location may be, but is not limited to, a location of the grid point having the smallest distortion measure, a weighted sum of the locations of a set of matching grid points in the grid (where the weighting applied to each grid point may be a function of the distortion measure), a weighted sum of clustered locations of a set of matching grid points in the grid (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), as a function of estimated locations determined from subsets of the set of NMRs by the preceding methods, and any combination thereof. An exemplary distortion measure may be, but is not limited to, a Mahalanobis distance.

FIG. **55** is a flow chart for another method of locating a mobile device in a geographic region according to yet another embodiment of the present subject matter. With reference to FIG. **55**, blocks **5510**, **5520** and **5530** are similar to blocks **5010**, **5020** and **5030**, respectively. At block **5540**, the determination of an estimated location for the mobile device may determine a representative value for each cell neighboring a serving cell serving the mobile device in the set of NMRs. More generally, for each parameter type held in common by an non-empty subset of the NMRs, a representative value may be generated. At block **5550**, a distortion measure for each representative value may be determined as a function of a comparison between a parameter of ones of the grid points and a corresponding parameter for each representative value. At block **5560**, an estimated location of the mobile device may be generated where the estimated location may comprise a location of the grid point having the smallest overall distortion measure (computed over all parameters of the set of NMRs), a weighted sum of the locations of a set of matching grid points in the grid (where the weighting may be a function of the distortion measure), a weighted sum of clustered locations of a set of matching grid points in the grid, as a function

of estimated locations determined from subsets of the set of NMRs by the preceding methods, or any combination thereof.

FIG. **56** is a flow chart for a method of estimating the location of a mobile device in a geographic region according to an embodiment of the present subject matter. With reference to FIG. **56**, at block **5610**, calibration data may be provided for each of one or more calibration points in a geographic region where the calibration data may include a collection of NMRs having associated known locations. Of course, each of the NMRs provide at least one characterizing parameter. The calibration data may take the form of a collection of NMRs having associated locations as discussed above. Exemplary NMRs in the calibration data may be defined as an (n×1) vector with n parameters. Exemplary parameters may be, but are not limited to, observed power levels for adjacent neighbor cell control channels, TAs, RTTs, etc., each of which are a set of observed or collected information obtained at a particular location. A particular value of n, i.e., the size of each NMR vector, may be variable (e.g., n may range from at least one to fifteen or higher within a respective calibration data set). At block **5610**, a candidate NMR may also be received from a mobile device at an unknown location. Thus, the geographical location from which the candidate NMR was generated should be estimated. At block **5620**, a first region may be defined within the calibration data as a function of a first characterizing parameter of the candidate NMR and a predetermined range of the first parameter. At block **5630**, a second region may be defined within the calibration data as a function of a second characterizing parameter of the candidate NMR and a predetermined range of the second parameter.

By way of a non-limiting example, if the candidate NMR is a (4×1) vector including components that represent the power levels observed for some cells A, B and H and a fourth component that represents a TA value with respect to cell D, the candidate NMR vector may be provided by the following relationship:

$$\text{NMR_c} = \begin{bmatrix} Pa \\ Pb \\ Ph \\ TAd \end{bmatrix} \tag{12}$$

With reference to Equation 12, if the first characterizing parameter of the candidate NMR considered is the power level observed for cell A, then the calibration data may be examined for each NMR (or data vector) having a power level observed for cell A that may be within a predetermined range about the value Pa. A set of such exemplary NMRs (or data vectors) within the calibration data satisfying this condition defines a region R1 in a two dimensional location space where a location is desired. As each such piece of calibration data (e.g., each NMR in the calibration data) that fits (i.e., fits the range constraint upon the first parameter) has an associated location, it follows that a collection of such pieces or data vectors of calibration data may define a region. Further, assuming the second characterizing parameter considered is the power level observed for cell H, the same technique may also be applied to generate a second region R2. These regions may then represent areas in a location space that are potential or candidate solution regions for the location of the unknown (e.g., candidate) NMR. The intersection of these two (or more) regions defines a region satisfying the two characterizing parameters considered within a respective range for each. Of course, a multitude of parameters may be considered and a multitude of regions defined, thus, the simplistic example provided above should not limit the scope of the claims appended herewith.

The steps represented by blocks **5620** and **5630** may be repeated for each characterizing parameter in the candidate NMR and calibration data at block **5640**. An intersection of the defined regions may be determined at block **5650** and at block **5660**, the location of a mobile device in the geographic region may be estimated as a function of the intersection. It may be noted that any such intersection region may be equivalent to the geographic locations of the set of corresponding calibration points whose parameters, when suitably expanded in range define this intersection region. Alternatively, the intersection region can be equivalently treated as a subset of the original calibration points obtained by expanding the parameter ranges of the candidate NMR. Any one or plural calibration points may be located on a predetermined fixed uniform grid defined over the geographic region or randomly located within said geographic region. The calibration data may also comprise information from at least one NMR, may be obtained from one or more mobile devices located in close proximity to the one calibration point, and/or may be obtained from a signal transmitted from a mobile device in close proximity to the one calibration point and received at a receiver in or in proximity to the geographic region. In one embodiment of the present subject matter for each of select ones of the calibration points, the calibration data may include plural data vectors and the evaluating of the calibration data may comprise a determination of clustering of the plural data vectors.

FIG. **57** is a flow chart for another method of estimating the location of a mobile device in a geographic region according to an embodiment of the present subject matter. With reference to FIG. **57**, blocks **5710**, **5720**, **5730**, **5740**, **5750** and **5760** are similar to blocks **5610**, **5620**, **5630**, **5640**, **5650** and **5660**, respectively. At block **5770**, the estimation of the location of a mobile device may further comprise estimating the location of a mobile device as a function of a statistical measure for calibration data of select ones of the calibration points (these calibration points may correspond to the final intersection). An exemplary statistical measure may be, but is not limited to, a probability density function. At block **5780**, in one embodiment of the present subject matter the estimated location of a mobile device may be the centroid of the intersection.

FIG. **58** is a flow chart for a method of estimating the location of a mobile device in a geographic region according to one embodiment of the present subject matter. With reference to FIG. **58**, blocks **5810**, **5820**, **5830**, **5840**, **5850** and **5860** are similar to blocks **5610**, **5620**, **5630**, **5640**, **5650** and **5660**, respectively. At block **5870**, in one embodiment, the intersection may be determined as a function of a distortion measure.

FIG. **59** is a flow chart for a method of estimating the location of a mobile device in a geographic region according to a further embodiment of the present subject matter. With reference to FIG. **59**, blocks **5910**, **5920**, **5930**, **5940**, **5950** and **5960** are similar to blocks **5610**, **5620**, **5630**, **5640**, **5650** and **5660**, respectively. At block **5961**, in one embodiment of the present subject matter the estimation of the location of a mobile device may comprise (a) comparing an ordered list of cells neighboring a cell serving the mobile device in the at least one NMR to an ordered list of neighboring cells in the intersection region or intersection (the ordering may be in terms of any one of a number of parameters characterizing a respective NMR, e.g., NC power level or NC measurement quality), and (b) generating an estimated location of the

mobile device. The estimated location may be, but is not limited to, a centroid of a cluster of best matching calibration points in the intersection region, a highest joint probability matching calibration point in the intersection region, a weighted sum of the locations of a set of matching calibration points in the intersection region (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching calibration points in the intersection region (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), as a function of estimated locations determined from a subset of the at least one NMR, or any combination thereof.

In another embodiment of the present subject matter, at block **5962**, the estimation of the location of a mobile device may comprise (a) comparing an ordered list of cells neighboring a cell serving the mobile device in the at least one NMR to a similarly ordered list of neighboring cells in the intersection region (the ordering may be in terms of any one of a number of parameters characterizing a respective NMR, e.g., NC power level), (b) if no exact match exists between the ordered list of neighboring cells of the at least one NMR and any calibration point in the intersection region then a subset of the largest ordered list of neighboring cells may be formed in the intersection region, and (c) generating an estimated location of the mobile device. The estimated location may be, but is not limited to, a centroid of a cluster of matched calibration points in the intersection region, a highest joint probability matching calibration point in the intersection region, a weighted sum of the locations of a set of matching calibration points in the intersection region (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching calibration points in the intersection region (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), as a function of estimated locations determined from a subset of the at least one NMR, or any combination thereof.

At block **5963**, the estimation of the location of a mobile device may comprise in a further embodiment of the present subject matter (a) comparing an ordered list of cells neighboring a cell serving the mobile device in the at least one NMR to an ordered list of neighboring cells in the intersection region (the ordering may be in terms of any one of a number of parameters characterizing a respective NMR, e.g., NC power level), (b) if the ordered list of neighboring cells of the at least one NMR is not contained in the ordered list of neighboring cells for the intersection region, then a largest ordered subset of neighboring cells in the at least one NMR may be utilized having either an exact match or is contained in the ordered list of neighboring cells in the intersection region, and (c) generating an estimated location of the mobile device. The estimated location may be, but is not limited to, a centroid of a cluster of matched calibration points in the intersection region, a highest joint probability matching calibration point in the intersection region, a weighted sum of the locations of a set of matching calibration points in the intersection region (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching calibration points in the intersection region (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), as a function of estimated locations determined from a subset of the at least one NMR, or any combination thereof.

At block **5964**, in another embodiment of the present subject matter the estimation of the location of a mobile device may comprise (a) evaluating a pdf for each parameter of a cell neighboring a cell serving the mobile device in the at least one NMR over each calibration point in a set of available calibration points in the intersection region, (b) determining a joint probability as a function of the pdfs, and (c) generating an estimated location of the mobile device. The estimated location may be, but is not limited to, a centroid of a cluster of highest probability calibration points, clustered by location, in the intersection region, a highest joint probability matching calibration point in the intersection region, a weighted sum of the locations of a set of matching calibration points in the intersection region (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching calibration points in the intersection region (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), as a function of estimated locations determined from a subset of the at least one NMR, or any combination thereof.

At block **5965**, the estimation of the location of a mobile device may comprise in one embodiment of the present subject matter (a) directly evaluating a joint probability (i.e., as an aggregate rather than through computation of the product of marginal pdfs) of power levels for at least one cell neighboring a cell serving the mobile device in the at least one NMR over a set of available calibration points in the intersection region, and (b) generating an estimated location of the mobile device. The estimated location may be, but is not limited to, a highest joint probability matching calibration point in the intersection region, a weighted sum of the locations of a set of matching calibration points in the intersection region (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching calibration points in the intersection region (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), as a function of estimated locations determined from a subset of the at least one NMR, or any combination thereof.

At block **5966**, the estimation of the location of a mobile device may comprise in an additional embodiment of the present subject matter (a) determining a distortion measure between a characteristic function or parameter of a calibration point and a corresponding function or parameter in the at least one NMR and (b) generating an estimated location of the mobile device. The estimated location may be, but is not limited to, a location of a calibration point having the smallest distortion measure, a weighted sum of the locations of a set of matching calibration points in the intersection region (where the weighting applied to each of the matching calibration points may be a function of the distortion measure), a weighted sum of clustered locations of a set of matching calibration points in the intersection region, as a function of locations determined from a subset of the at least one NMR, or any combination thereof. Exemplary distortion measures are described above and may be, but are not limited to, a Mahalanobis distance, etc.

In one embodiment of the present subject matter, at block **5967** the estimation of the location of a mobile device may

comprise (a) matching cell power ordering of cells neighboring a cell serving the mobile device in the at least one NMR to neighboring cell power ordering of calibration points in each of the calibration points in the intersection region and (b) selecting an estimated location as a function of a quality of the matching. The quality may be a function of a relative shift in the ordering sequence occurring between the at least one NMR and calibration point cell power ordering. It is also envisioned that this same concept may be applied to any other vector parameter characterizing NMRs and/or grid points and such an example should not limit the scope of the claims appended herewith.

FIG. **60** is a flow chart for a method of estimating the location of a mobile device in a geographic region. At block **6010**, calibration data may be provided for a plurality of calibration points in the geographic region. The calibration data may include at least one characterizing parameter and for each of select ones of the calibration points the calibration data may also include plural data vectors. Of course, the calibration data may include a collection of NMRs having associated known locations, each of the NMRs providing at least one characterizing parameter. The calibration data may take the form of a collection of NMRs having associated locations as discussed above. Exemplary NMRs in the calibration data may be defined as an (n×1) vector with n parameters. Exemplary parameters may be, but are not limited to, observed power levels for adjacent neighbor cell control channels, TAs, RTTs, etc., each of which are a set of observed or collected information obtained at a particular location. A particular value of n, i.e., the size of each NMR vector, may also be variable (e.g., n may range from at least one to fifteen or higher within a respective calibration data set). A candidate set of NMRs may also be received from a mobile device at an unknown location. Thus, the geographical location from which the candidate set was generated should be estimated.

At block **6020**, a first region within the calibration data may be defined as a function of a first characterizing parameter of the set of NMRs and a predetermined range of the first parameter. At block **6030**, a second region within the calibration data may be defined as a function of another characterizing parameter of the set of NMRs and a predetermined range of another parameter. By way of a non-limiting example, if the first characterizing parameter of the candidate set considered is the power level observed for a first cell, A, then the calibration data may be examined for each NMR in the set (or data vector) having a power level observed for cell A that may be within a predetermined range about the value Pa. Exemplary NMRs (or data vectors) within the calibration data satisfying this condition may defines a region in a two dimensional location space where a location is desired. As each such piece of calibration data that fits the range constraint upon the first parameter has an associated location, it follows that a collection of such pieces or data vectors of calibration data may define a region. Further, assuming the second characterizing parameter considered is the power level observed for cell B, the same technique may also be applied to generate a second region. These regions may then represent areas in a location space that are potential or candidate solution regions for the location of the unknown set of NMRs. The intersection of these two (or more) regions defines a region satisfying the two characterizing parameters considered within a respective range for each. Of course, a multitude of parameters may be considered and a multitude of regions defined, and an intersection of this multitude of regions may also be obtained. Thus, the simplistic example provided above should not limit the scope of the claims appended herewith.

The steps represented by blocks **6020** and **6030** may be repeated for each characterizing parameter in the set of calibration data at block **6040**. At block **6050**, a clustering of the plural data vectors, whether directly in the regions obtained or for those data vectors than are contained in the intersection, may be determined. In another embodiment of the present subject matter, the clustering may be determined as a function of a metric, such as, but not limited to, joint probability, Mahalanobis distance, cluster radius, etc. It may be noted that clustering may also be generally viewed as a process generating an intersection region. At block **6060**, a location of a mobile device in the intersection region may be estimated as a function of the clustering. In one embodiment, any number or combination of the calibration points may be located on a predetermined fixed uniform grid defined over the geographic region or may be randomly located within the geographic region. Further, any of the calibration data may comprise information from a network measurement report. The calibration data for one of the calibration points may be obtained from one or more mobile devices located in close proximity to the one calibration point in another embodiment, and/or the calibration data for one of the calibration points may be obtained from a signal transmitted from a mobile device in close proximity to the one calibration point and received at a receiver in or in proximity to the geographic region.

FIG. **61** is a flow chart for a method of estimating the location of a mobile device in a geographic region according to another embodiment of the present subject matter. With reference to FIG. **61**, at block **6110**, calibration data for each of one or more calibration points in a geographic region may be provided where the calibration data includes at least one characterizing parameter. Further, a set of network measurement reports may be received from a mobile device at an unknown location where at least one of the network measurement reports in the set also includes at least one characterizing parameter. At block **6120**, a representative value may be determined for each available characterizing parameter in the set as a function of a variation of the available characterizing parameter in each network measurement report in the set. In one embodiment of the present subject matter, the representative value may be obtained as a function of an available set of representative values, may be determined as a function of a mean or median of an available set of representative values, or may be selected as a function of a predetermined range. At block **6130**, one or more representative network measurement reports may be determined as a function of the representative value, and at block **6140** the location of a mobile device may be estimated in the geographic region as a function of the one or more representative network measurement reports. Any one or plural calibration points may be located on a predetermined fixed uniform grid defined over the geographic region or randomly located within the geographic region. The calibration data may also comprise information from at least one NMR, may be obtained from one or more mobile devices located in close proximity to the one calibration point, and/or may be obtained from a signal transmitted from a mobile device in close proximity to the one calibration point and received at a receiver in or in proximity to the geographic region. In one embodiment of the present subject matter, for each of select ones of the calibration points, the calibration data may include plural data vectors and the evaluating of the calibration data may comprise a determination of clustering of the plural data vectors.

FIG. **62** is a flow chart for a method of estimating the location of a mobile device in a geographic region according to a further embodiment of the present subject matter. With reference to FIG. **62**, blocks **6210**, **6220**, **6230** and **6240** are

similar to blocks **6110**, **6120**, **6130** and **6140**, respectively. In one embodiment the method may further define a first region as a function of a first representative value for a first characterizing parameter and a predetermined range of the first value at block **6250** and at block **6260** define a second region as a function of a second representative value for a second characterizing parameter and a predetermined range of the second value. The steps represented by blocks **6250** and **6260** may be repeated for each characterizing parameter in the one or more representative NMRs at block **6270**. At block **6280**, an intersection of each defined region may be determined and at block **6290**, the location of a mobile device in the geographic region may be estimated as a function of the intersection. At block **6291**, in one embodiment of the present subject matter the location of a mobile device may be estimated as the centroid of the intersection, or at block **6292**, the location of the mobile device may be estimated as a function of a statistical measure for calibration data of select ones of the calibration points. An exemplary statistical measure may be, but is not limited to, a probability density function.

FIG. **63** is a flow chart for a method of estimating the location of a mobile device in a geographic region according to an additional embodiment of the present subject matter. With reference to FIG. **63**, blocks **6310**, **6320**, **6330**, **6340**, **6350**, **6360**, **6370**, **6380** and **6390** are similar to blocks **6210**, **6220**, **6230**, **6240**, **6250**, **6260**, **6270**, **6280** and **6290**, respectively. At block **6381**, in one embodiment of the present subject matter an intersection of each defined region may be determined as a function of a distortion measure.

FIG. **64** is a flow chart for a method of estimating the location of a mobile device in a geographic region according to a further embodiment of the present subject matter. With reference to FIG. **64**, blocks **6410**, **6420**, **6430**, **6440**, **6450**, **6460**, **6470**, **6480** and **6490** are similar to blocks **6210**, **6220**, **6230**, **6240**, **6250**, **6260**, **6270**, **6280** and **6290** respectively. At block **6491**, in one embodiment of the present subject matter the estimation of the location of a mobile device may comprise (a) comparing an ordered list of cells neighboring a cell serving the mobile device in the one or more representative network measurement reports to an ordered list of neighboring cells in each calibration point of the intersection where the ordering may be a function of any parameter of the one or more representative network measurement reports (the ordering may be in terms of any one of a number of parameters characterizing a respective NMR, e.g., NC power level or NC measurement quality); and (b) generating an estimated location of the mobile device. The estimated location may be, but is not limited to, a centroid of a cluster of matching calibration points in the intersection; a highest joint probability matching calibration point in the intersection; a weighted sum of the locations of a set of matching calibration points in the intersection (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.); a weighted sum of clustered locations of a set of matching calibration points in the intersection (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), and as a function of estimated locations determined from a subset of the one or more representative network measurement reports, or any combination thereof.

In another embodiment of the present subject matter, at block **6492**, the estimation of the location of a mobile device may comprise (a) comparing an ordered list of cells neighboring a cell serving the mobile device in the one or more representative network measurement reports to an ordered list of neighboring cells in each calibration point of the intersection where the ordering may be a function of any parameter in the one or more representative network measurement reports (the ordering may be in terms of any one of a number of parameters characterizing a respective NMR, e.g., NC power level or NC measurement quality), (b) if no exact match is made between the ordered list of neighboring cells of the one or more representative network measurement reports and any calibration point in the intersection then forming a largest subset of the ordered list of neighboring cells in the calibration points that provide a match, and (c) generating an estimated location of the mobile device. The estimated location may be, but is not limited to, a centroid of a cluster of matching calibration points in the intersection, a highest joint probability matching calibration point in the intersection, a weighted sum of the locations of a set of matching calibration points in the intersection (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching calibration points in the intersection (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), and as a function of estimated locations determined from a subset of the one or more representative network measurement reports, or any combination thereof.

At block **6493**, the estimation of the location of a mobile device may comprise in a further embodiment of the present subject matter (a) comparing an ordered list of cells neighboring a cell serving the mobile device in the one or more representative network measurement reports to an ordered list of neighboring cells in each calibration point of the intersection where the ordering may be a function of any parameter in the one or more representative network measurement reports (the ordering may be in terms of any one of a number of parameters characterizing a respective NMR, e.g., NC power level), (b) if the ordered list of neighboring cells of the one or more representative network measurement reports is not contained in the ordered list of neighboring cells for the intersection then using a largest subset of ordered neighboring cells in the one or more representative network measurement reports having either an exact match or contained in the ordered list of neighboring cells in the intersection, and (c) generating an estimated location of the mobile device. The estimated location may be, but is not limited to, a centroid of a cluster of matching calibration points in the intersection, a highest joint probability matching calibration point in the intersection, a weighted sum of the locations of a set of matching calibration points in the intersection (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching calibration points in the intersection (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), and as a function of estimated locations determined from a subset of the one or more representative network measurement reports, or any combination thereof.

At block **6494**, in another embodiment of the present subject matter the estimation of the location of a mobile device may comprise (a) evaluating a probability density function for each power level of a cell neighboring a cell serving the mobile device in the one or more representative network measurement reports over each calibration point in a set of available calibration points in the intersection, (b) determining a joint probability as a function of the individual probability density functions, and (c) generating an estimated location of the mobile device. The estimated location may be,

but is not limited to, a highest joint probability matching calibration point in the intersection, a weighted sum of the locations of a set of matching calibration points in the intersection (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching calibration points in the intersection (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), and as a function of estimated locations determined from a subset of the one or more representative network measurement reports, or any combination thereof.

At block **6495**, the estimation of the location of a mobile device may comprise in one embodiment of the present subject matter (a) directly evaluating a joint probability (i.e., as an aggregate rather than through computation of the product of marginal pdfs) of power levels for at least one cell neighboring a cell serving the mobile device in the one or more representative network measurement reports over a set of available calibration points in the intersection, and (b) generating an estimated location of the mobile device. The estimated location may be, but is not limited to, a highest joint probability matching calibration point in the intersection, a weighted sum of the locations of a set of matching calibration points in the intersection (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching calibration points in the intersection (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), and as a function of estimated locations determined from a subset of the one or more representative network measurement reports, or any combination thereof.

At block **6496**, the estimation of the location of a mobile device may comprise in an additional embodiment of the present subject matter (a) determining a distortion measure between a parameter or function of a calibration point contained in the intersection and a corresponding parameter or function in the one or more network measurement reports, and (b) generating an estimated location of the mobile device. The estimated location may be, but is not limited to, a location of a calibration point having the smallest distortion measure, a weighting of the locations of a set of matching calibration points in the intersection (where the weighting applied to each of the matching calibration points may be a function of the distortion measure), a weighted sum of clustered locations of a set of matching calibration points in the intersection, and as a function of estimated locations determined from a subset of the one or more representative network measurement reports. Exemplary distortion measures are described above and may be but, but are not limited to, a Mahalanobis distance, etc.

In one embodiment of the present subject matter, at block **6497** the estimation of the location of a mobile device may comprise (a) matching cell power ordering of cells neighboring a cell serving the mobile device in the one or more representative network measurement reports to neighboring cell power ordering of calibration points in each of the calibration points in the intersection region, and (b) selecting an estimated location as a function of a quality of the matching. The quality may be a function of a relative shift in the ordering sequence occurring between the one or more representative network measurement reports and calibration point cell power ordering. It is also envisioned that this same concept may be applied to any other vector parameter characterizing NMRs and/or grid points and such an example should not limit the scope of the claims appended herewith.

FIG. **65** is a diagram for a system for estimating the location of a mobile device in a geographic region according to an embodiment of the present subject matter. With reference to FIG. **65**, at block **6510**, the system may comprise a database and, at block **6520**, a processor operably connected thereto for receiving calibration data for each of one or more calibration points in a geographic region where the calibration data may include at least one characterizing parameter. The processor may also be programmed to receive an NMR from a mobile device at an unknown location. The processor may be programmed to determine a first region within the calibration data as a function of a first characterizing parameter of the received NMR and a predetermined range of the first parameter and repeat the determination for each characterizing parameter in the NMR at block **6521**, and determine an intersection for each defined region at block **6522**. The processor may be further programmed to estimate the location of a mobile device in the geographic region as a function of the intersection at block **6523**. Any one or plural calibration points may be located on a predetermined fixed uniform grid defined over the geographic region or randomly located within said geographic region. The calibration data may also comprise information from at least one NMR, may be obtained from one or more mobile devices located in close proximity to the one calibration point, and/or may be obtained from a signal transmitted from a mobile device in close proximity to the one calibration point and received at a receiver in or in proximity to the geographic region. In one embodiment of the present subject matter for each of select ones of the calibration points, the calibration data may include plural data vectors and the evaluating of the calibration data may comprise a determination of clustering of the plural data vectors.

FIG. **66** is a diagram for a system for estimating the location of a mobile device in a geographic region according to an additional embodiment of the present subject matter. With reference to FIG. **66**, at block **6610**, the system may comprise a database and, at block **6620**, a processor operably connected thereto for receiving calibration data for each of one or more calibration points in a geographic region where the calibration data may include at least one characterizing parameter. The processor may also receive a set of network measurement reports from a mobile device at an unknown location, at least one of the network measurement reports in the set may also include at least one characterizing parameter. The processor may be programmed to determine a representative value for each available characterizing parameter in the set as a function of a variation of the available characterizing parameter in each network measurement report in the set at block **6621** and determine one or more representative network measurement reports as a function of the representative value at block **6622**. At block **6623**, the processor may also be programmed to estimate the location of a mobile device in the geographic region as a function of the one or more representative network measurement reports.

In a further embodiment, the processor may be programmed to determine a first region as a function of a first representative value for a first characterizing parameter and a predetermined range of the first value and repeat said determination for each characterizing parameter in the one or more representative network measurement reports, determine an intersection of each determined region. The processor may also be programmed to estimate the location of a mobile device in the geographic region as a function of the intersection. Of course, any one or plural calibration points may be located on a predetermined fixed uniform grid defined over

the geographic region or randomly located within said geographic region. The calibration data may also comprise information from at least one NMR, may be obtained from one or more mobile devices located in close proximity to the one calibration point, and/or may be obtained from a signal transmitted from a mobile device in close proximity to the one calibration point and received at a receiver in or in proximity to the geographic region. In one embodiment of the present subject matter for each of select ones of the calibration points, the calibration data may include plural data vectors and the evaluating of the calibration data may comprise a determination of clustering of the plural data vectors.

FIG. **67** is a flow chart for a method of determining the location of a mobile device in a geographic region according to one embodiment of the present subject matter. With reference to FIG. **67**, at block **6710**, the method may comprise providing calibration data for each of one or more calibration points in a geographic region where the calibration data includes one or more characterizing parameters. At block **6710**, at least one NMR from a mobile device at an unknown location may be received. Of course, a set of NMRs may also be received in another embodiment of the present subject matter. At block **6720**, one or more sets of grid points for the calibration data may be generated, and at block **6730**, the at least one network measurement report may be evaluated with each of the sets of grid points as a function of select ones of the characterizing parameters. A set of grid points may be selected as a function of a predetermined criteria at block **6740**, and at block **6750**, the location of a mobile device may be determined in the geographic region as a function of the selected set of grid points. Exemplary predetermined criteria may be, but are not limited to, total probability, cluster radius, Euclidean norm, joint probability, and Mahalanobis distance. Of course, any one or plural grid points may be located on a predetermined fixed uniform grid defined over the geographic region or randomly located within the geographic region. The calibration data may also comprise information from at least one NMR. In one embodiment of the present subject matter for each of select ones of the grid points, the calibration data may include plural data vectors and the evaluating of the calibration data may comprise a determination of clustering of the plural data vectors. An exemplary characterizing parameter (which may have been extracted from the calibration points that were assigned to the corresponding grid point) may be, but is not limited to, signal strength for a signal transmitted by a transmitter having a known location as received by a receiver at the grid point, signal strength of a signal transmitted by a transmitter located at the grid point as received by a receiver at a known location, round trip time for a signal traveling between the grid point and a known location, timing advance of a signal received by the mobile device at the grid point, time difference of arrival of plural signals at the grid point with respect to a pair of known locations as measured by a receiver at the grid point or at the known locations, the identification of a serving cell or serving sector of the mobile device located at the grid point, a state of a wireless network serving the mobile device, and combinations thereof.

FIG. **68** is a flow chart for a method of determining the location of a mobile device in a geographic region according to another embodiment of the present subject matter. With reference to FIG. **68**, blocks **6810**, **6820**, **6830**, **6840**, and **6850** are similar to blocks **6710**, **6720**, **6730**, **6740**, and **6750**, respectively. At block **6831**, in one embodiment of the present subject matter the evaluation of the at least one NMR may include (i) comparing select ones of the sets of grid points to at least one characterizing parameter of the at least one NMR, (ii) generating a first location estimate of the mobile device for each parameter of the NMR, and (iii) determining a second location estimate of the mobile device as a function of at least one of the generated first location estimates. At block **6832**, another embodiment of the present subject matter may further comprise the step of identifying and omitting outlier first location estimates by (i) determining a Mahalanobis distance from each first location estimate to the second location estimate, (ii) determining a distance threshold from a median of the Mahalanobis distances multiplied by a predetermined factor, and (iii) determining a third location estimate by averaging two or more of the first location estimates. First location estimates having a Mahalanobis distance to the second location estimate greater than the distance threshold may be omitted from the determined third location estimate.

At block **6833**, embodiments of the present subject matter may determine a second location estimate by averaging two or more first location estimates, or omit a first location estimate having an error greater than a predetermined threshold, at block **6834**. At block **6835**, embodiments of the present subject matter may also determine a second location estimate by employing a weighted averaging of ones of the first location estimates, or at block **6836**, determine a second location estimate by weighting a first location estimate by an inverse of a distance metric. At block **6837**, embodiments of the present subject matter may also determine a second location estimate by normalizing a first location estimate by a sum of an inverse of a distance metric, or at block **6838**, determine a second location estimate by weighting a first location estimate as a function of the number of reporting neighboring cells to a serving cell serving the mobile device.

FIG. **69** is a flow chart for a method of determining the location of a mobile device in a geographic region according to a further embodiment of the present subject matter. With reference to FIG. **69**, blocks **6910**, **6920**, **6930**, **6940** and **6950** are similar to blocks **6710**, **6720**, **6730**, **6740**, and **6750**, respectively. At block **6931**, in one embodiment of the present subject matter the evaluation of the at least one NMR may include (i) comparing an ordered list of cells neighboring a cell serving the mobile device in the NMR to an ordered list of neighboring cells in each grid point of the geographic region where the ordering may be a function of any parameter of the NMR; and (ii) generating an estimated location of the mobile device. The estimated location may be, but is not limited to, a centroid of a cluster of matching grid points in the geographic region, a highest joint probability matching grid point in the geographic region, a weighted sum of the locations of a set of matching grid points in the geographic region (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching grid points in the geographic region (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), as a function of locations determined from subsets of the calibration data, and any combination thereof.

At block **6932** in another embodiment of the present subject matter, the evaluation of the at least one NMR may include (i) comparing an ordered list of cells neighboring a cell serving the mobile device in the NMR to an ordered list of neighboring cells in each grid point of the geographic region where the ordering may be a function of any parameter of the NMR, (ii) if no exact match is made between the ordered list of neighboring cells of the NMR and any grid point in the geographic region then forming a largest subset of the ordered list of neighboring cells in the grid points that provide a

match, and (iii) generating an estimated location of the mobile device. The estimated location may be, but is not limited to a centroid of a cluster of matching grid points in the geographic region, a highest joint probability matching grid point in the geographic region, a weighted sum of the locations of a set of matching grid points in the geographic region (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching grid points in the geographic region (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), as a function of locations determined from subsets of the calibration data, or any combination thereof.

In another embodiment of the present subject matter, the evaluation of the at least one NMR may comprise at block **6933** (i) comparing an ordered list of cells neighboring a cell serving the mobile device in the NMR to an ordered list of neighboring cells in each grid point of the geographic region, where the ordering may be a function of any parameter of the NMR, (ii) using a largest subset of neighboring cells in the NMR having either an exact match or is contained in the ordered list of neighboring cells in the geographic region if the ordered list of neighboring cells of the NMR is not contained in the ordered list of neighboring cells for the geographic region, and (iii) generating an estimated location of the mobile device. The estimated location may be, but is not limited to, a centroid of a cluster of matching grid points in the geographic region, a highest joint probability matching grid point in the geographic region, a weighted sum of the locations of a set of matching grid points in the geographic region (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching grid points in the geographic region (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), as a function of locations determined from subsets of the calibration data, or any combination thereof.

At block **6934**, in another embodiment of the present subject matter the evaluation of the at least one NMR may include (i) evaluating a probability density function for each power level of a cell neighboring a cell serving the mobile device in the NMR over each grid point in a set of available grid points in the geographic region; (ii) determining a joint probability as a function of the individual pdfs, and (iii) generating an estimated location of the mobile device. The estimated location may be, but is not limited to, a highest joint probability matching grid point in the geographic region, a weighted sum of the locations of a set of matching grid points in the geographic region (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching grid points in the geographic region (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), as a function of locations determined from subsets of the calibration data, or any combination thereof.

In an additional embodiment of the present subject matter, the evaluation of the at least one NMR may comprise at block **6935** (i) directly evaluating a joint probability (i.e., as an aggregate rather than through computation of the product of marginal pdfs) of power levels for at least one cell neighboring a cell serving the mobile device in the NMR over a set of available grid points in the geographic region, and (ii) generating an estimated location of the mobile device. The estimated location may be, but is not limited to, a highest joint probability matching grid point in the geographic region, a weighted sum of the locations of a set of matching grid points in the geographic region (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching grid points in the geographic region (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), as a function of locations determined from subsets of the calibration data, or any combination thereof. At block **6936**, the evaluation of the at least one NMR may include in another embodiment of the present subject matter (i) determining a distortion measure between a parameter of a grid point and a corresponding parameter in the NMR, and (ii) generating an estimated location of the mobile device. The estimated location may be, but is not limited to, a location of a grid point having the smallest distortion measure, a weighted sum of the locations of a set of matching grid points in the geographic region (where the weighted sum may be a function of the distortion measure), a weighted sum of clustered locations of a set of matching grid points in the geographic region, as a function of locations determined from subsets of the calibration data.

In a further embodiment of the present subject matter, the evaluation of the at least one NMR may include at block **6937** (i) matching cell power ordering of cells neighboring a cell serving the mobile device in the NMR to neighboring cell power ordering of grid points in the geographic region, and (ii) selecting an estimated location as a function of a quality of the matching. An exemplary quality may be, but is not limited to, a function of a relative shift in an ordering sequence occurring between the NMR and grid point cell power ordering. At block **6938**, the evaluation of the at least one NMR may comprise in another embodiment of the present subject matter (i) defining a first region within the calibration data as a function of a first characterizing parameter of the at least one NMR and a predetermined range of the first parameter, (ii) defining a second region within the calibration data as a function of another characterizing parameter of the at least one NMR and a predetermined range of the another parameter, and (iii) repeating steps (i)-(ii) for each characterizing parameter in the at least one NMR. The evaluation may further comprise (iv) determining an intersection of each defined region, and (v) estimating the location of a mobile device in the geographic region as a function of the intersection.

At block **6939**, the evaluation of the at least one NMR may also comprise (i) defining a first region within the calibration data as a function of a first characterizing parameter of a NMR within a set of NMRs and a predetermined range of the first parameter, (ii) defining a second region within the calibration data as a function of another characterizing parameter of the NMR within the set of NMRs and a predetermined range of the another parameter, and (iii) repeating steps (i)-(ii) for each characterizing parameter in the set of NMRs. The evaluation may further include (iv) determining a clustering of data vectors in the set of NMRs, and (v) estimating the location of a mobile device in the geographic region as a function of the clustering. At block **6941**, the evaluation of the at least one NMR may comprise in one embodiment of the present subject matter (i) determining a representative value for each available characterizing parameter in a set of NMRs as a function of a variation of available characterizing parameters in each available network measurement report, (ii) determin-

ing one or more representative network measurement reports as a function of the representative value, and (iii) estimating the location of a mobile device in the geographic region as a function of the one or more representative network measurement reports. Another embodiment of the present subject matter may define a first region as a function of a first representative value for a first characterizing parameter and a predetermined range of the first value and define a second region as a function of a second representative value for a second characterizing parameter and a predetermined range of the second value. A multitude of regions may be defined for each characterizing parameter in the one or more representative network measurement reports. The method may further determine an intersection of each defined region, and estimate the location of a mobile device in the geographic region as a function of the intersection.

FIG. **70** is a diagram for a system for determining the location of a mobile device in a geographic region according to an embodiment of the present subject matter. With reference to FIG. **70**, the system may comprise at block **7010** a database, and at block **7020** a processor for receiving calibration data for each of one or more calibration points in a geographic region and receiving at least one NMR from a mobile device at an unknown location in the geographic region. Of course, the calibration data and NMR may include at least one or plural characterizing parameters. At block **7021**, the processor may be programmed to (i) generate one or more sets of grid points for the calibration data, (ii) evaluate the at least one NMR with each of the sets of grid points as a function of select ones of the characterizing parameters, (iii) select a set of grid points as a function of a predetermined criteria, and (iv) determine the location of a mobile device in the geographic region as a function of the selected set. Of course, the at least one NMR may be plural NMRs such as a set of NMRs. Exemplary predetermined criteria may be, but are not limited to, total probability, cluster radius, Euclidean norm, joint probability, and Mahalanobis distance. Of course, any one or plural grid points may be located on a predetermined fixed uniform grid defined over the geographic region or randomly located within the geographic region. The calibration data may also comprise information from at least one NMR, may be obtained from one or more mobile devices located in close proximity to the one grid point, and/or may be obtained from a signal transmitted from a mobile device in close proximity to the one grid point and received at a receiver in or in proximity to the geographic region. In one embodiment of the present subject matter for each of select ones of the grid points, the calibration data may include plural data vectors and the evaluating of the calibration data may comprise a determination of clustering of the plural data vectors. An exemplary characterizing parameter (which may have been extracted from the calibration points that were assigned to the corresponding grid point) may be, but is not limited to, signal strength for a signal transmitted by a transmitter having a known location as received by a receiver at the grid point, signal strength of a signal transmitted by a transmitter located at the grid point as received by a receiver at a known location, round trip time for a signal traveling between the grid point and a known location, timing advance of a signal received by the mobile device at the grid point, time difference of arrival of plural signals at the grid point with respect to a pair of known locations as measured by a receiver at the grid point or at the known locations, the identification of a serving cell or serving sector of the mobile device located at the grid point, a state of a wireless network serving the mobile device, and combinations thereof.

FIG. **71** is a diagram for a system for determining the location of a mobile device in a geographic region according to another embodiment of the present subject matter. With reference to FIG. **71**, blocks **7110**, **7120** and **7121** are similar to blocks **7010**, **7020** and **7021**, respectively. At block **7122**, in one embodiment of the present subject matter the processor may be programmed to (v) compare select ones of the sets of grid points to at least one characterizing parameter of the at least one NMR, (vi) generate a first location estimate of the mobile device for each parameter of the NMR, and (vii) determine a second location estimate of the mobile device as a function of at least one of the generated first location estimates. At block **7123**, in another embodiment of the present subject matter the processor may be programmed to identify and omit outlier first location estimates. The process may identify and omit outlier first location estimates by (1) determining a Mahalanobis distance from each first location estimate to the second location estimate, (2) determining a distance threshold from a median of the Mahalanobis distances multiplied by a predetermined factor, and (3) determining a third location estimate by averaging two or more of the first location estimates. First location estimates having a Mahalanobis distance to the second location estimate greater than the distance threshold may then be omitted from the determined third location estimate. At block **7124**, the processor, in one embodiment, may be programmed to determine an estimated location for the mobile device from the at least one NMR as a function of at least one characterizing parameter.

FIG. **72** is a diagram for a system for determining the location of a mobile device in a geographic region according to another embodiment of the present subject matter. With reference to FIG. **72**, blocks **7210** and **7220** are similar to blocks **7010** and **7020**, respectively. At block **7221**, in one embodiment of the present subject matter the processor may be programmed to (i) compare an ordered list of cells neighboring a cell serving the mobile device in the NMR to an ordered list of neighboring cells in each grid point of the geographic region, the ordering being a function of any parameter of the NMR, and (ii) generate an estimated location of the mobile device. The estimated location may be, but is not limited to, a centroid of a cluster of matching grid points in the geographic region, a highest joint probability matching grid point in the geographic region, a weighted sum of the locations of a set of matching grid points in the geographic region (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching grid points in the geographic region (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), as a function of locations determined from subsets of the calibration data, and any combination thereof.

At block **7222** in another embodiment of the present subject matter, the processor may be programmed, to (i) compare an ordered list of cells neighboring a cell serving the mobile device in the NMR to an ordered list of neighboring cells in each grid point of the geographic region, the ordering being a function of any parameter of the NMR, (ii) form a largest subset of the ordered list of neighboring cells in the geographic region if no exact match is made between the ordered list of neighboring cells of the NMR and any grid point in the geographic region, and (iii) generate an estimated location of the mobile device. The estimated location may be, but is not limited to a centroid of a cluster of matching grid points in the geographic region, a highest joint probability matching grid point in the geographic region, a weighted sum of the loca-

tions of a set of matching grid points in the geographic region (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching grid points in the geographic region (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), as a function of locations determined from subsets of the calibration data, or any combination thereof.

In another embodiment of the present subject matter, the processor may be programmed to, at block **7223** (i) compare an ordered list of cells neighboring a cell serving the mobile device in the NMR to an ordered list of neighboring cells in each grid point of the geographic region, the ordering being a function of any parameter of the NMR, (ii) if the ordered list of neighboring cells of the NMR is not contained in the ordered list of neighboring cells for the geographic region then use a largest subset of neighboring cells in the NMR having either an exact match or is contained in the ordered list of neighboring cells in the geographic region, and (iii) generate an estimated location of the mobile device. The estimated location may be, but is not limited to, a centroid of a cluster of matching grid points in the geographic region, a highest joint probability matching grid point in the geographic region, a weighted sum of the locations of a set of matching grid points in the geographic region (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching grid points in the geographic region (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), as a function of locations determined from subsets of the calibration data, or any combination thereof.

At block **7224**, in another embodiment of the present subject matter the processor may be programmed to (i) evaluate a pdf for each power level of a cell neighboring a cell serving the mobile device in the NMR over each grid point in a set of available grid points in the geographic region, (ii) determine a joint probability as a function of the individual pdfs, and (iii) generate an estimated location of the mobile device. The estimated location may be, but is not limited to, a highest joint probability matching grid point in the geographic region, a weighted sum of the locations of a set of matching grid points in the geographic region (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching grid points in the geographic region (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), as a function of locations determined from subsets of the calibration data, or any combination thereof.

In an additional embodiment of the present subject matter, the processor may be programmed to, at block **7225** (i) directly evaluate a joint probability (i.e., as an aggregate rather than through computation of the product of marginal pdfs) of power levels for at least one cell neighboring a cell serving the mobile device in the NMR over a set of available grid points in the geographic region, and (ii) generate an estimated location of the mobile device. The estimated location may be, but is not limited to, a highest joint probability matching grid point in the geographic region, a weighted sum of the locations of a set of matching grid points in the geographic region (exemplary weights may be defined by any number of means such as, but not limited to, a joint probability derived from individual pdfs, etc.), a weighted sum of clustered locations of a set of matching grid points in the geographic region (i.e., cluster the locations of the matching grid points and then apply a cumulative probability for all contained grid points in a cluster as a weight for the respective cluster), as a function of locations determined from subsets of the calibration data, or any combination thereof. At block **7226**, the processor may be programmed to (i) determine a distortion measure between a parameter of a grid point and a corresponding parameter in the NMR, and (ii) generate an estimated location of the mobile device. The estimated location may be, but is not limited to, a location of a grid point having the smallest distortion measure, a weighted sum of the locations of a set of matching grid points in the geographic region (where the weighted sum may be a function of the distortion measure), a weighted sum of clustered locations of a set of matching grid points in the geographic region, as a function of locations determined from subsets of the calibration data.

In a further embodiment of the present subject matter, the processor may be programmed to, at block **7227** (i) match cell power ordering of cells neighboring a cell serving the mobile device in the NMR to neighboring cell power ordering of grid points in the geographic region, and (ii) select an estimated location as a function of a quality of the matching. An exemplary quality may be, but is not limited to, a function of a relative shift in an ordering sequence occurring between the NMR and grid point cell power ordering.

At block **7228**, in a further embodiment of the present subject matter the processor may be programmed to (v) determine a first region within the calibration data as a function of a first characterizing parameter of the at least one NMR and a predetermined range of said first parameter and repeat the determination for each characterizing parameter in the at least one NMR, (vi) determine an intersection for each defined region, and (vii) estimate the location of a mobile device in the geographic region as a function of the intersection.

In yet another embodiment of the present subject matter, the processor may be programmed to, at block **7229** (v) determine a first region within the calibration data as a function of a first characterizing parameter in a set of NMRs and a predetermined range of the first parameter and repeat the determination for each characterizing parameter in the set of NMRs, (vi) determine a clustering of data vectors of the set, by location, in the geographic region, and (vii) estimate the location of a mobile device in the geographic region as a function of the clustering. At block **7230**, the processor may also be programmed to in another embodiment of the present subject matter (v) determine a representative value for each available characterizing parameter in a set of NMRs as a function of a variation of available characterizing parameters in each available network measurement report, (vi) determine one or more representative NMRs as a function of the representative value, and (vii) estimate the location of a mobile device in the geographic region as a function of the one or more representative network measurement reports. A further embodiment of the processor may also determine a first region as a function of a first representative value for a first characterizing parameter and a predetermined range of said first value and repeat the determination for each characterizing parameter in the one or more representative network measurement reports. The processor may also determine an intersection of each defined region, and estimate the location of a mobile device in the geographic region as a function of the intersection.

As shown by the various configurations and embodiments illustrated in FIGS. **1-72**, a method and system for generating a location estimate using uniform and non-uniform grid points have been described.

While preferred embodiments of the present subject matter have been described, it is to be understood that the embodiments described are illustrative only and that the scope of the invention is to be defined solely by the appended claims when accorded a full range of equivalence, many variations and modifications naturally occurring to those of skill in the art from a perusal hereof.

We claim:

1. A method of determining the location of a mobile device in a geographic region comprising the steps of:

(a) providing calibration data for each of one or more calibration points in a geographic region, said calibration data having one or more characterizing parameters;

(b) generating one or more sets of grid points for said calibration data;

(c) receiving at least one network measurement report from a mobile device at an unknown location in said geographic region;

(d) evaluating said at least one network measurement report with each of said sets of grid points as a function of select ones of said characterizing parameters;

(e) selecting a set of grid points as a function of a predetermined criteria; and

(f) determining the location of a mobile device in said geographic region as a function of said selected set of grid points.

2. The method of claim **1** wherein said at least one network measurement report is a set of network measurement reports.

3. The method of claim **1** wherein said predetermined criteria is selected from the group consisting of: total probability, cluster radius, Euclidean norm, joint probability, and Mahalanobis distance.

4. The method of claim **1** wherein one of said grid points is located on a predetermined fixed uniform grid defined over said geographic region.

5. The method of claim **4** wherein one of said grid points is randomly located within said geographic region.

6. The method of claim **1** wherein one of said grid points is randomly located within said geographic region.

7. The method of claim **1** wherein said calibration data comprises information from a network measurement report.

8. The method of claim **1** wherein for each of select ones of said grid points the calibration data includes plural data vectors and the evaluating of said sets of grid points comprises a determination of clustering of said plural data vectors.

9. The method of claim **1** wherein said characterizing parameter is selected from the group consisting of: signal strength for a signal transmitted by a transmitter having a known location as received by a receiver at said grid point; signal strength of a signal transmitted by a transmitter located at said grid point as received by a receiver at a known location; round trip time for a signal traveling between said grid point and a known location; timing advance of a signal received by said mobile device at said grid point; time difference of arrival of plural signals at said grid point with respect to a pair of known locations as measured by a receiver at said grid point or at said known locations; the identification of a serving cell or serving sector of said mobile device located at said grid point; a state of a wireless network serving said mobile device, and combinations thereof.

10. The method of claim **1** wherein the step of evaluating further comprises:

(i) comparing select ones of said sets of grid points to at least one characterizing parameter of said at least one network measurement report;

(ii) generating a first location estimate of the mobile device for each parameter of said network measurement report; and

(iii) determining a second location estimate of the mobile device as a function of at least one of said generated first location estimates.

11. The method of claim **10** further comprising the step of identifying and omitting outlier first location estimates by:

(i) determining a Mahalanobis distance from each first location estimate to the second location estimate;

(ii) determining a distance threshold from a median of the Mahalanobis distances multiplied by a predetermined factor; and

(iii) determining a third location estimate by averaging two or more of said first location estimates,

wherein first location estimates having a Mahalanobis distance to the second location estimate greater than the distance threshold are omitted from said determined third location estimate.

12. The method of claim **10** wherein determining a second location estimate further comprises averaging two or more first location estimates.

13. The method of claim **10** further comprising the step of omitting a first location estimate having an error greater than a predetermined threshold.

14. The method of claim **10** wherein determining a second location estimate further comprises employing a weighted averaging of ones of said first location estimates.

15. The method of claim **10** wherein determining a second location estimate further comprises weighting a first location estimate by an inverse of a distance metric.

16. The method of claim **10** wherein determining a second location estimate further comprises normalizing a first location estimate by a sum of an inverse of a distance metric.

17. The method of claim **10** wherein determining a second location estimate further comprises weighting a first location estimate as a function of the number of reporting neighboring cells to a serving cell serving said mobile device.

18. The method of claim **1** wherein the step of evaluating further comprises:

(i) comparing an ordered list of cells neighboring a cell serving said mobile device in said network measurement report to an ordered list of neighboring cells in each grid point of said geographic region, said ordering being a function of any parameter of said network measurement report; and

(ii) generating an estimated location of said mobile device wherein said estimated location is selected from the group consisting of: a centroid of a cluster of matching grid points in said geographic region; a highest joint probability matching grid point in said geographic region; a weighted sum of the locations of a set of matching grid points in said geographic region; a weighted sum of clustered locations of a set of matching grid points in said geographic region; and as a function of locations determined from subsets of said calibration data.

19. The method of claim **1** wherein the step of evaluating further comprises:

(i) comparing an ordered list of cells neighboring a cell serving said mobile device in said network measurement report to an ordered list of neighboring cells in each grid

point of said geographic region, said ordering being a function of any parameter of said network measurement report;

(ii) if no exact match is made between the ordered list of neighboring cells of said network measurement report and any grid point in said geographic region then forming a largest subset of the ordered list of neighboring cells in said grid points that provide a match; and

(iii) generating an estimated location of said mobile device wherein said estimated location is selected from the group consisting of: a centroid of a cluster of matching grid points in said geographic region; a highest joint probability matching grid point in said geographic region; a weighted sum of the locations of a set of matching grid points in said geographic region; a weighted sum of clustered locations of a set of matching grid points in said geographic region; and as a function of locations determined from subsets of said calibration data.

20. The method of claim **1** wherein the step of evaluating further comprises:

(i) comparing an ordered list of cells neighboring a cell serving said mobile device in said network measurement report to an ordered list of neighboring cells in each grid point of said geographic region, said ordering being a function of any parameter of said network measurement report;

(ii) if the ordered list of neighboring cells of said network measurement report is not contained in the ordered list of neighboring cells for said geographic region then using a largest subset of neighboring cells in said network measurement report having either an exact match or is contained in the ordered list of neighboring cells in said geographic region; and

(iii) generating an estimated location of said mobile device wherein said estimated location is selected from the group consisting of: a centroid of a cluster of matching grid points in said geographic region; a highest joint probability matching grid point in said geographic region; a weighted sum of the locations of a set of matching grid points in said geographic region; a weighted sum of clustered locations of a set of matching grid points in said geographic region; and as a function of locations determined from subsets of said calibration data.

21. The method of claim **1** wherein the step of evaluating further comprises:

(i) evaluating a probability density function for each power level of a cell neighboring a cell serving said mobile device in said network measurement report over each grid point in a set of available grid points in said geographic region;

(ii) determining a joint probability as a function of said individual probability density functions; and

(iii) generating an estimated location of said mobile device wherein said estimated location is selected from the group consisting of: a highest joint probability matching grid point in said geographic region; a weighted sum of the locations of a set of matching grid points in said geographic region; a weighted sum of clustered locations of a set of matching grid points in said geographic region; and as a function of locations determined from subsets of said calibration data.

22. The method of claim **1** wherein the step of evaluating further comprises:

(i) evaluating a joint probability of power levels for at least one cell neighboring a cell serving said mobile device in said network measurement report over a set of available grid points in said geographic region; and

(ii) generating an estimated location of said mobile device wherein said estimated location is selected from the group consisting of: a highest joint probability matching grid point in said geographic region; a weighted sum of the locations of a set of matching grid points in said geographic region; a weighted sum of clustered locations of a set of matching grid points in said geographic region; and as a function of locations determined from subsets of said calibration data.

23. The method of claim **1** wherein the step of evaluating further comprises:

(i) determining a distortion measure between a parameter of a grid point and a corresponding parameter in said network measurement report; and

(ii) generating an estimated location of said mobile device wherein said estimated location is selected from the group consisting of: a location of a grid point having the smallest distortion measure; a weighted sum of the locations of a set of matching grid points in said geographic region, said weighted sum being a function of said distortion measure; a weighted sum of clustered locations of a set of matching grid points in said geographic region; and as a function of locations determined from subsets of said calibration data.

24. The method of claim **1** wherein the step of evaluating further comprises:

(i) matching cell power ordering of cells neighboring a cell serving said mobile device in said network measurement report to neighboring cell power ordering of grid points in said geographic region; and

(ii) selecting an estimated location as a function of a quality of said matching,

wherein said quality is a function of a relative shift in an ordering sequence occurring between said network measurement report and grid point cell power ordering.

25. The method of claim **1** wherein the step of evaluating further comprises:

(i) defining a first region within said calibration data as a function of a first characterizing parameter of said at least one network measurement report and a predetermined range of said first parameter;

(ii) defining a second region within said calibration data as a function of another characterizing parameter of said at least one network measurement report and a predetermined range of said another parameter;

(iii) repeating steps (i)-(ii) for each characterizing parameter in said at least one network measurement report;

(iv) determining an intersection of each defined region; and

(v) estimating the location of a mobile device in said geographic region as a function of said intersection.

26. The method of claim **1** wherein the step of evaluating further comprises:

(i) defining a first region within said calibration data as a function of a first characterizing parameter of a network measurement report within a set of network measurement reports and a predetermined range of said first parameter;

(ii) defining a second region within said calibration data as a function of another characterizing parameter of said network measurement report within the set of network measurement reports and a predetermined range of said another parameter;

(iii) repeating steps (i)-(ii) for each characterizing parameter in said set of network measurement reports;

(iv) determining a clustering of data vectors in said set of network measurement reports; and

(v) estimating the location of a mobile device in said geographic region as a function of said clustering.

27. The method of claim **1** wherein the step of evaluating further comprises:

(i) determining a representative value for each available characterizing parameter in a set of network measurement reports as a function of a variation of said available characterizing parameter in each available network measurement report;

(ii) determining one or more representative network measurement reports as a function of said representative value; and

(iii) estimating the location of a mobile device in said geographic region as a function of said one or more representative network measurement reports.

28. The method of claim **27** further comprising the steps of:

(iv) defining a first region as a function of a first representative value for a first characterizing parameter and a predetermined range of said first value;

(v) defining a second region as a function of a second representative value for a second characterizing parameter and a predetermined range of said second value;

(vi) repeating steps (iv)-(v) for each characterizing parameter in said one or more representative network measurement reports;

(vii) determining an intersection of each defined region; and

(viii) estimating the location of a mobile device in said geographic region as a function of said intersection.

29. The method of claim **1** wherein the step of selecting further comprises selecting a set of grid points as a function of a criteria of fit.

30. The method of claim **29** wherein the criteria of fit is selected from the group consisting of: total probability, cluster radius, Euclidean norm, Mahalanobis distance, distortion measure, confidence measure, and any combination thereof.

31. The method of claim **1** wherein the step of selecting further comprises:

(i) selecting one or more candidate locations from one or more of said sets of grid points; and

(ii) evaluating said selected one or more candidate locations across said one or more sets of grid points,

wherein the determined location of the mobile device is a function of said evaluation of said selected locations.

32. A system for determining the location of a mobile device in a geographic region comprising:

(a) a database; and

(b) a processor for receiving calibration data for each of one or more calibration points in a geographic region and receiving at least one network measurement report from a mobile device at an unknown location in said geographic region, said calibration data and network measurement report having at least one characterizing parameter and said processor is programmed to:

(i) generate one or more sets of grid points for said calibration data,

(ii) evaluate said at least one network measurement report with each of said sets of grid points as a function of select ones of said characterizing parameters,

(iii) select a set of grid points as a function of a predetermined criteria, and

(iv) determine the location of a mobile device in said geographic region as a function of said selected set.

33. The system of claim **32** wherein said at least one network measurement report is a set of network measurement reports.

34. The system of claim **32** wherein said predetermined criteria is selected from the group consisting of: total probability, cluster radius, Euclidean norm, joint probability, and Mahalanobis distance.

35. The system of claim **32** wherein one of said grid points is located on a predetermined fixed uniform grid defined over said geographic region.

36. The system of claim **35** wherein one of said grid points is randomly located within said geographic region.

37. The system of claim **32** wherein one of said grid points is randomly located within said geographic region.

38. The system of claim **32** wherein said calibration data comprises information from a network measurement report.

39. The system of claim **32** wherein for each of select ones of said grid points the calibration data includes plural data vectors and the evaluating of said grid points comprises a determination of clustering of said plural data vectors.

40. The system of claim **32** wherein said characterizing parameter is selected from the group consisting of: signal strength for a signal transmitted by a transmitter having a known location as received by a receiver at said grid point; signal strength of a signal transmitted by a transmitter located at said grid point as received by a receiver at a known location; round trip time for a signal traveling between said grid point and a known location; timing advance of a signal received by said mobile device at said grid point; time difference of arrival of plural signals at said grid point with respect to a pair of known locations as measured by a receiver at said grid point or at said known locations; the identification of a serving cell or serving sector of said mobile device located at said grid point; a state of a wireless network serving said mobile device, and combinations thereof.

41. The system of claim **32** wherein the processor is further programmed to:

(v) compare select ones of said sets of grid points to at least one characterizing parameter of said at least one network measurement report;

(vi) generate a first location estimate of the mobile device for each parameter of said network measurement report; and

(vii) determine a second location estimate of the mobile device as a function of at least one of said generated first location estimates.

42. The system of claim **41** wherein the processor is further programmed to identify and omit outlier first location estimates by:

(1) determine a Mahalanobis distance from each first location estimate to the second location estimate;

(2) determine a distance threshold from a median of the Mahalanobis distances multiplied by a predetermined factor; and

(3) determine a third location estimate by averaging two or more of said first location estimates,

wherein first location estimates having a Mahalanobis distance to the second location estimate greater than the distance threshold are omitted from said determined third location estimate.

43. The system of claim **32** wherein the processor is further programmed to:

(v) determine an estimated location for said mobile device from said at least one network measurement report as a function of at least one characterizing parameter.

44. The system of claim **32** wherein the processor is further programmed to:

(v) compare an ordered list of cells neighboring a cell serving said mobile device in said network measurement report to an ordered list of neighboring cells in each grid point of said geographic region, said ordering being a function of any parameter of said network measurement report; and

(vi) generate an estimated location of said mobile device wherein said estimated location is selected from the group consisting of: a centroid of a cluster of matching grid points in said geographic region; a highest joint probability matching grid point in said geographic region; a weighted sum of the locations of a set of matching grid points in said geographic region; a weighted sum of clustered locations of a set of matching grid points in said geographic region; and as a function of locations determined from subsets of said calibration data.

45. The system of claim **32** wherein the processor is further programmed to:

(v) compare an ordered list of cells neighboring a cell serving said mobile device in said network measurement report to an ordered list of neighboring cells in each grid point of said geographic region, said ordering being a function of any parameter of said network measurement report;

(vi) if no exact match is made between the ordered list of neighboring cells of said network measurement report and any grid point in said geographic region then form a largest subset of the ordered list of neighboring cells in said grid points that provide a match; and

(vii) generate an estimated location of said mobile device wherein said estimated location is selected from the group consisting of: a centroid of a cluster of matching grid points in said geographic region; a highest joint probability matching grid point in said geographic region; a weighted sum of the locations of a set of matching grid points in said geographic region; a weighted sum of clustered locations of a set of matching grid points in said geographic region; and as a function of locations determined from subsets of said calibration data.

46. The system of claim **32** wherein the processor is further programmed to:

(v) compare an ordered list of cells neighboring a cell serving said mobile device in said network measurement report to an ordered list of neighboring cells in each grid point of said geographic region, said ordering being a function of any parameter of said network measurement report;

(vi) if the ordered list of neighboring cells of said network measurement report is not contained in the ordered list of neighboring cells for said geographic region then use a largest subset of neighboring cells in said network measurement report having either an exact match or is contained in the ordered list of neighboring cells in said geographic region; and

(vii) generate an estimated location of said mobile device wherein said estimated location is selected from the group consisting of: a centroid of a cluster of matching grid points in said geographic region; a highest joint probability matching grid point in said geographic region; a weighted sum of the locations of a set of matching grid points in said geographic region; a weighted sum of clustered locations of a set of matching grid points in said geographic region; and as a function of locations determined from subsets of said calibration data.

47. The system of claim **32** wherein the processor is further programmed to:

(v) evaluate a probability density function for each power level of a cell neighboring a cell serving said mobile device in said network measurement report over each grid point in a set of available grid points in said geographic region;

(vi) determine a joint probability as a function of said individual probability density functions; and

(vii) generate an estimated location of said mobile device wherein said estimated location is selected from the group consisting of: a highest joint probability matching grid point in said geographic region; a weighted sum of the locations of a set of matching grid points in said geographic region; a weighted sum of clustered locations of a set of matching grid points in said geographic region; and as a function of locations determined from subsets of said calibration data.

48. The system of claim **32** wherein the processor is further programmed to:

(v) evaluate a joint probability of power levels for at least one cell neighboring a cell serving said mobile device in said network measurement report over a set of available grid points in said geographic region; and

(vi) generate an estimated location of said mobile device wherein said estimated location is selected from the group consisting of: a highest joint probability matching grid point in said geographic region; a weighted sum of the locations of a set of matching grid points in said geographic region; a weighted sum of clustered locations of a set of matching grid points in said geographic region; and as a function of locations determined from subsets of said calibration data.

49. The system of claim **32** wherein the processor is further programmed to:

(v) determine a distortion measure between a parameter of a grid point and a corresponding parameter in said network measurement report; and

(vi) generate an estimated location of said mobile device wherein said estimated location is selected from the group consisting of: a location of a grid point having the smallest distortion measure; a weighted sum of the locations of a set of matching grid points in said geographic region, said weighted sum being a function of said distortion measure; a weighted sum of clustered locations of a set of matching grid points in said geographic region; and as a function of locations determined from subsets of said calibration data.

50. The system of claim **32** wherein the processor is further programmed to:

(v) match cell power ordering of cells neighboring a cell serving said mobile device in said network measurement report to neighboring cell power ordering of grid points in said geographic region; and

(vi) selecting an estimated location as a function of a quality of said matching,

wherein said quality is a function of a relative shift in an ordering sequence occurring between said network measurement report and grid point cell power ordering.

51. The system of claim **32** wherein the processor is further programmed to:

(v) determine a first region within said calibration data as a function of a first characterizing parameter of said at least one network measurement report and a predetermined range of said first parameter and repeat said determination for each characterizing parameter in said at least one network measurement report;

(vi) determine an intersection for each defined region; and

(vii) estimate the location of a mobile device in said geographic region as a function of said intersection.

52. The system of claim **32** wherein the processor is further programmed to:

(v) determine a first region within said calibration data as a function of a first characterizing parameter in a set of network measurement reports and a predetermined range of said first parameter and repeat said determination for each characterizing parameter in said set of network measurement reports;

(vi) determine a clustering of data vectors of said set, by location, in said geographic region; and

(vii) estimate the location of a mobile device in said geographic region as a function of said clustering.

53. The system of claim **32** wherein the processor is further programmed to:

(v) determine a representative value for each available characterizing parameter in a set of network measurement reports as a function of a variation of available characterizing parameters in each available network measurement report;

(vi) determine one or more representative network measurement reports as a function of said representative value; and

(vii) estimate the location of a mobile device in said geographic region as a function of said one or more representative network measurement reports.

54. The system of claim **53** wherein the processor is further programmed to:

(viii) determine a first region as a function of a first representative value for a first characterizing parameter and a predetermined range of said first value and repeat said determination for each characterizing parameter in said one or more representative network measurement reports;

(ix) determine an intersection of each defined region; and

(x) estimate the location of a mobile device in said geographic region as a function of said intersection.

55. The system of claim **32** wherein the processor is further programmed to select a set of grid points as a function of a criteria of fit.

56. The system of claim **55** wherein the criteria of fit is selected from the group consisting of: total probability, cluster radius, Euclidean norm, Mahalanobis distance, distortion measure, confidence measure, and any combination thereof.

57. The system of claim **32** wherein the processor is further programmed to:

(i) select one or more candidate locations from one or more of said sets of grid points; and

(ii) evaluate said selected one or more candidate locations across said one or more sets of grid points,

wherein the determined location of the mobile device is a function of said evaluated selected locations.

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