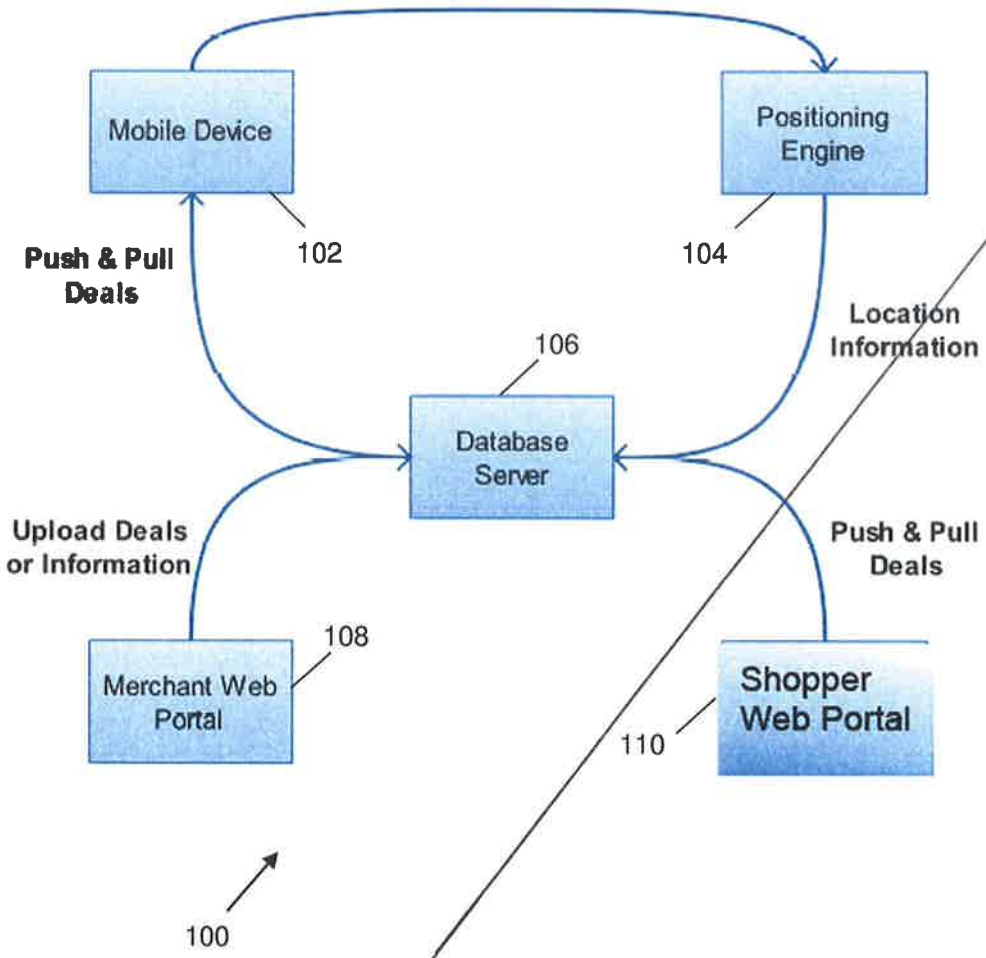

Mobile Device
Positioning Engine
102
104
Push & Pull Deals
Location Information
106
Database Server
Upload Deals or Information
Push & Pull Deals
108
Merchant Web Portal
Shopper Web Portal
110
100

Figure 1

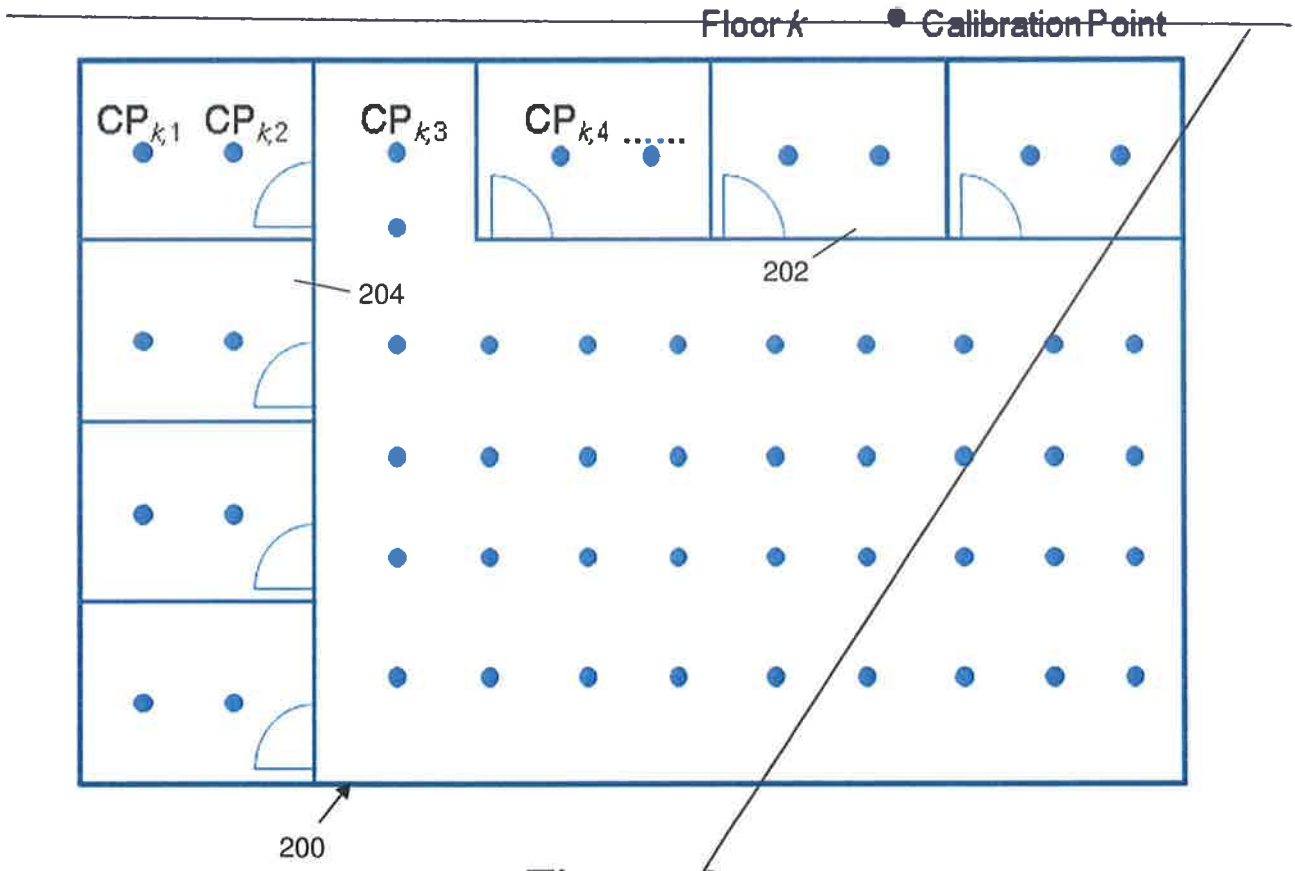


Figure 2

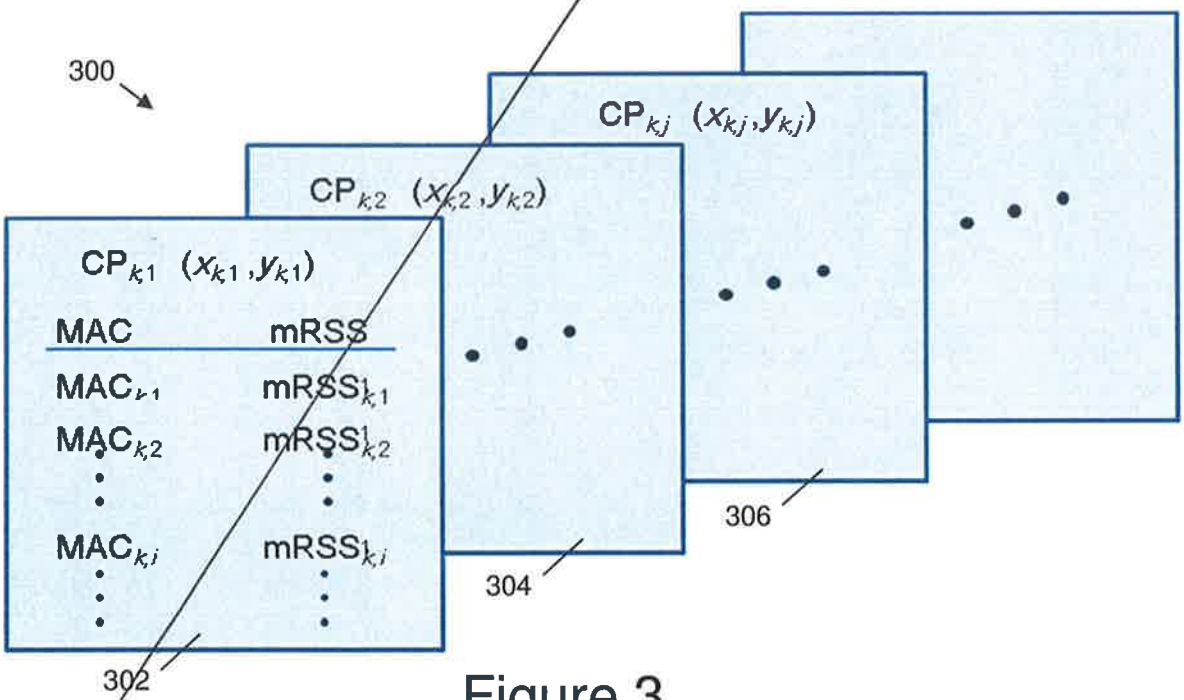


Figure 3

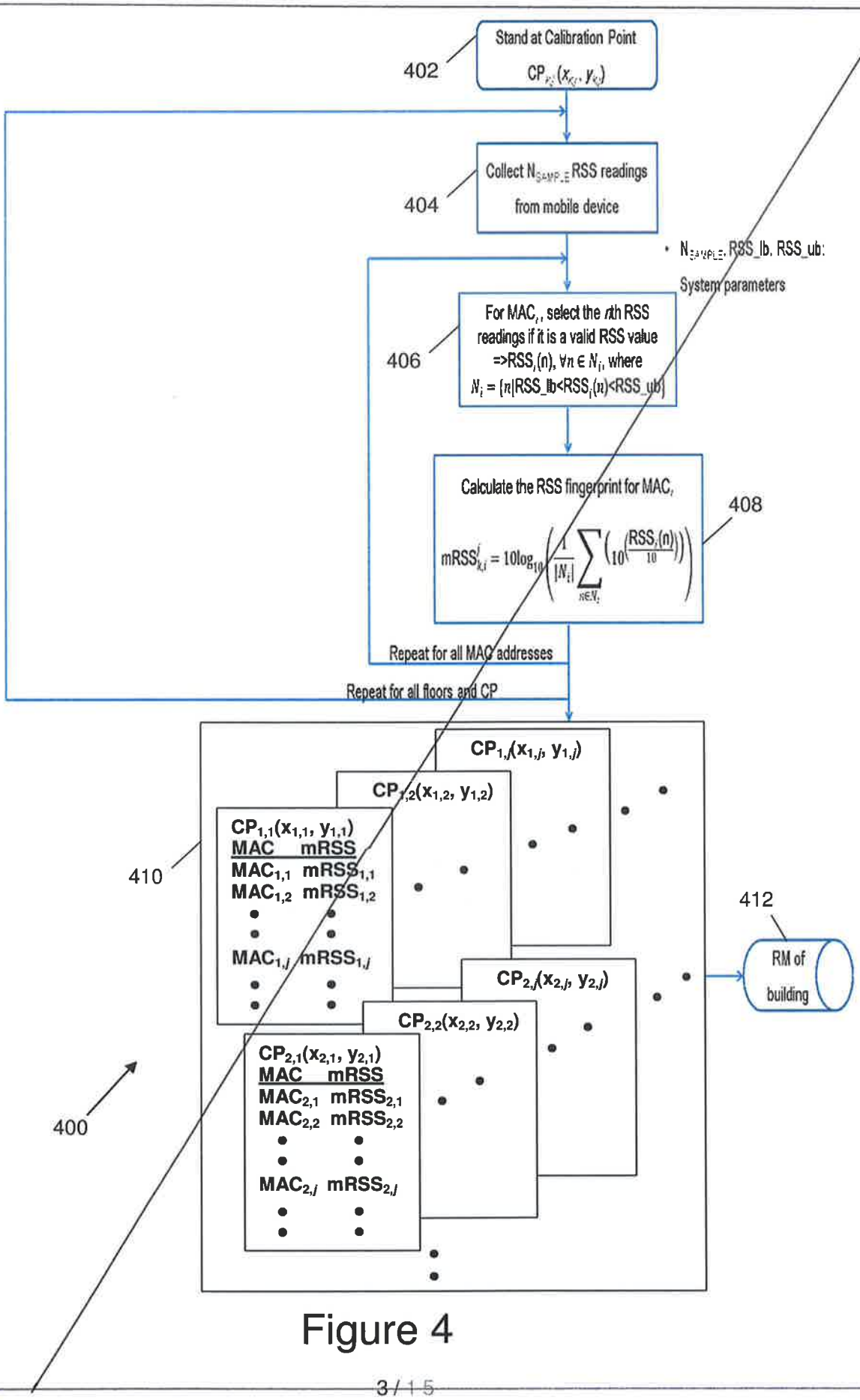

Stand at Calibration Point
$CP_{i,j}(x_{i,j}, y_{i,j})$
402
Collect N_{SAMPLE} RSS readings from mobile device
404
N_{SAMPLE}, RSS_lb, RSS_ub: System parameters
For MAC_i, select the nth RSS readings if it is a valid RSS value $\Rightarrow RSS_i(n), \forall n \in N_i$, where $N_i = \{n | RSS_lb < RSS_i(n) < RSS_ub\}$
406
Calculate the RSS fingerprint for MAC_i
$mRSS_{x,i}^{j} = 10\log_{10}\left(\frac{1}{|N_i|}\sum_{n \in N_i}\left(10^{\left(\frac{RSS_i(n)}{10}\right)}\right)\right)$
408
Repeat for all MAC addresses
Repeat for all floors and CP
$CP_{1,1}(x_{1,1}, y_{1,1})$
MAC mRSS
$MAC_{1,1}$ $mRSS_{1,1}$
$MAC_{1,2}$ $mRSS_{1,2}$
$MAC_{1,j}$ $mRSS_{1,j}$
$CP_{1,2}(x_{1,2}, y_{1,2})$
$CP_{1,j}(x_{1,j}, y_{1,j})$
410
$CP_{2,1}(x_{2,1}, y_{2,1})$
MAC mRSS
$MAC_{2,1}$ $mRSS_{2,1}$
$MAC_{2,2}$ $mRSS_{2,2}$
$MAC_{2,j}$ $mRSS_{2,j}$
$CP_{2,2}(x_{2,2}, y_{2,2})$
$CP_{2,j}(x_{2,j}, y_{2,j})$
412
RM of building
400

Figure 4

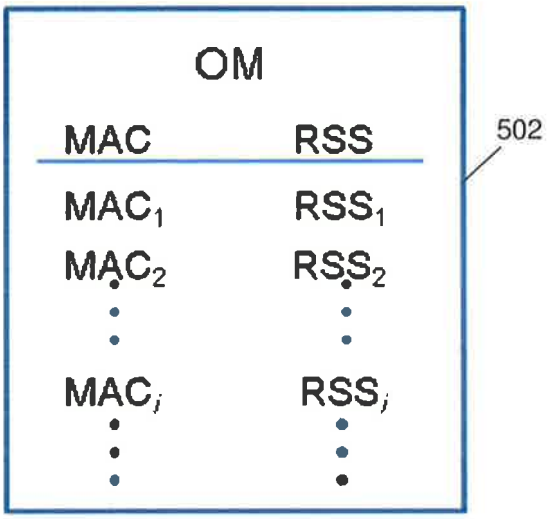


Figure 5

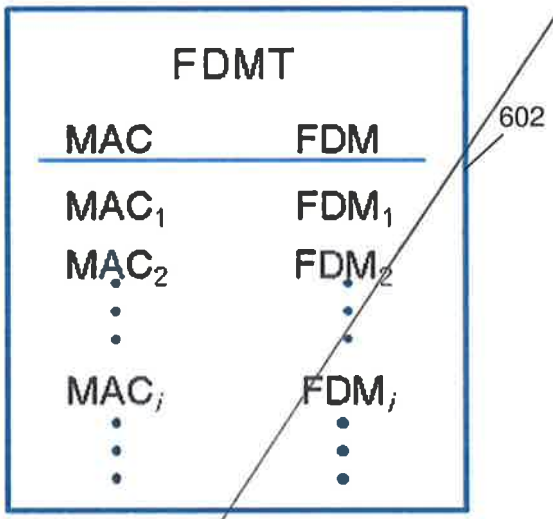


Figure 6

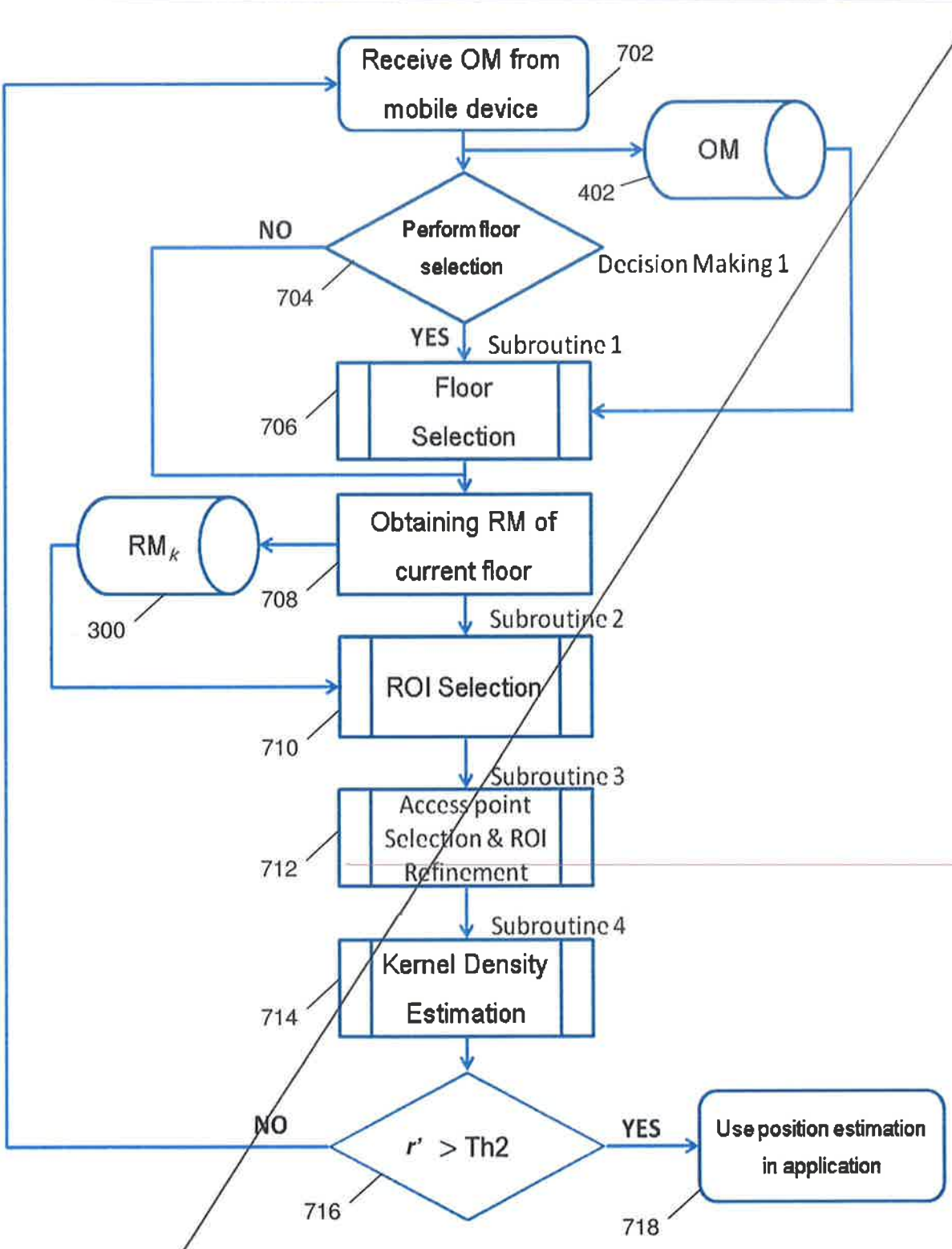

Receive OM from mobile device
702
OM
402
Perform floor selection
NO
704
Decision Making 1
YES
Subroutine 1
Floor Selection
706
Obtaining RM of current floor
708
RM$_k$
300
Subroutine 2
ROI Selection
710
Subroutine 3
Access point Selection & ROI Refinement
712
Subroutine 4
Kernel Density Estimation
714
r' > Th2
NO
716
YES
Use position estimation in application
718

Figure 7

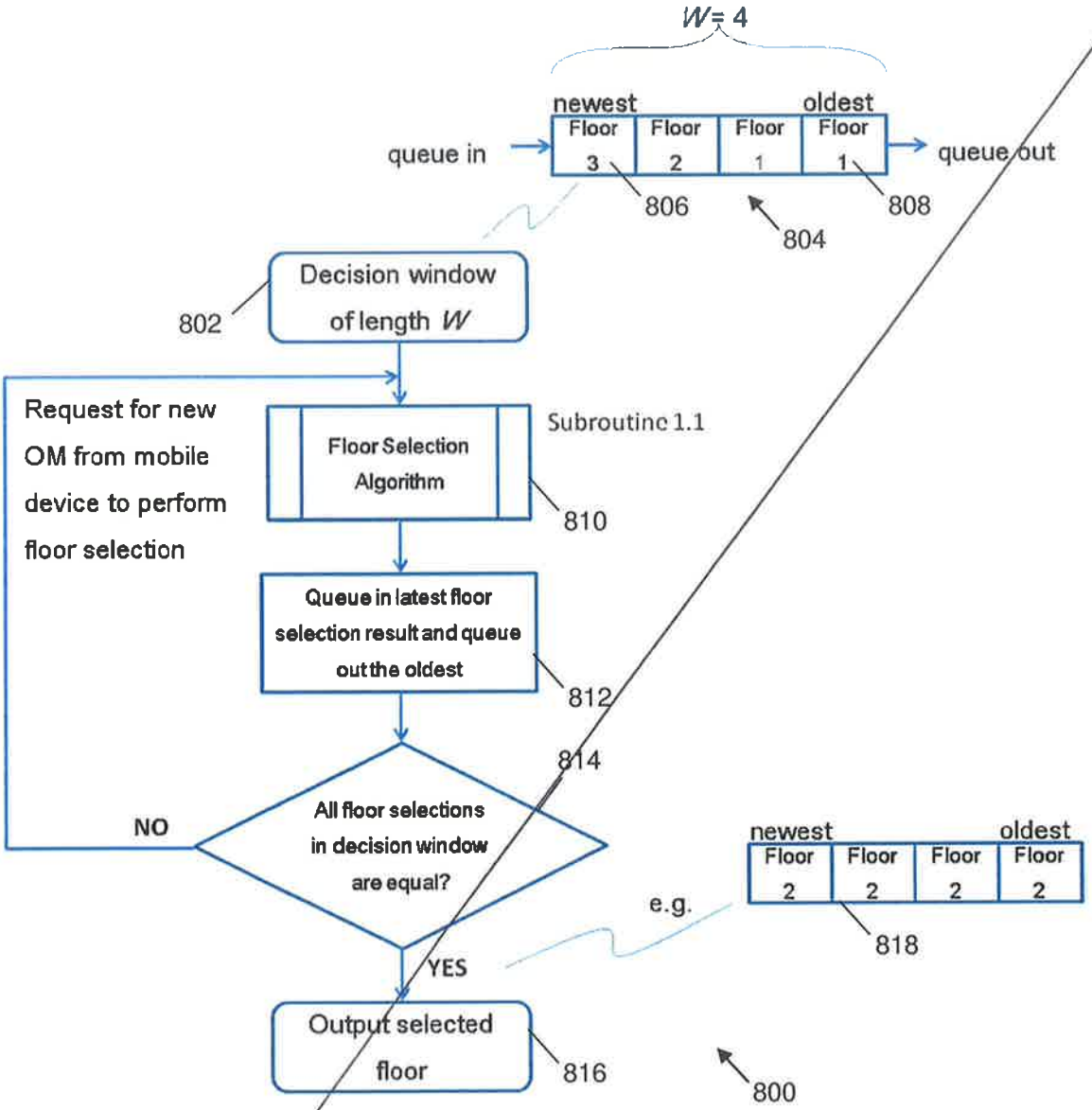

W = 4
newest
oldest
Floor 3
Floor 2
Floor 1
Floor 1
queue in
queue out
806
808
804
802
Decision window of length W
Request for new OM from mobile device to perform floor selection
Floor Selection Algorithm
Subroutine 1.1
810
Queue in latest floor selection result and queue out the oldest
812
814
NO
All floor selections in decision window are equal?
YES
e.g.
newest
oldest
Floor 2
Floor 2
Floor 2
Floor 2
818
Output selected floor
816
800

Figure 8

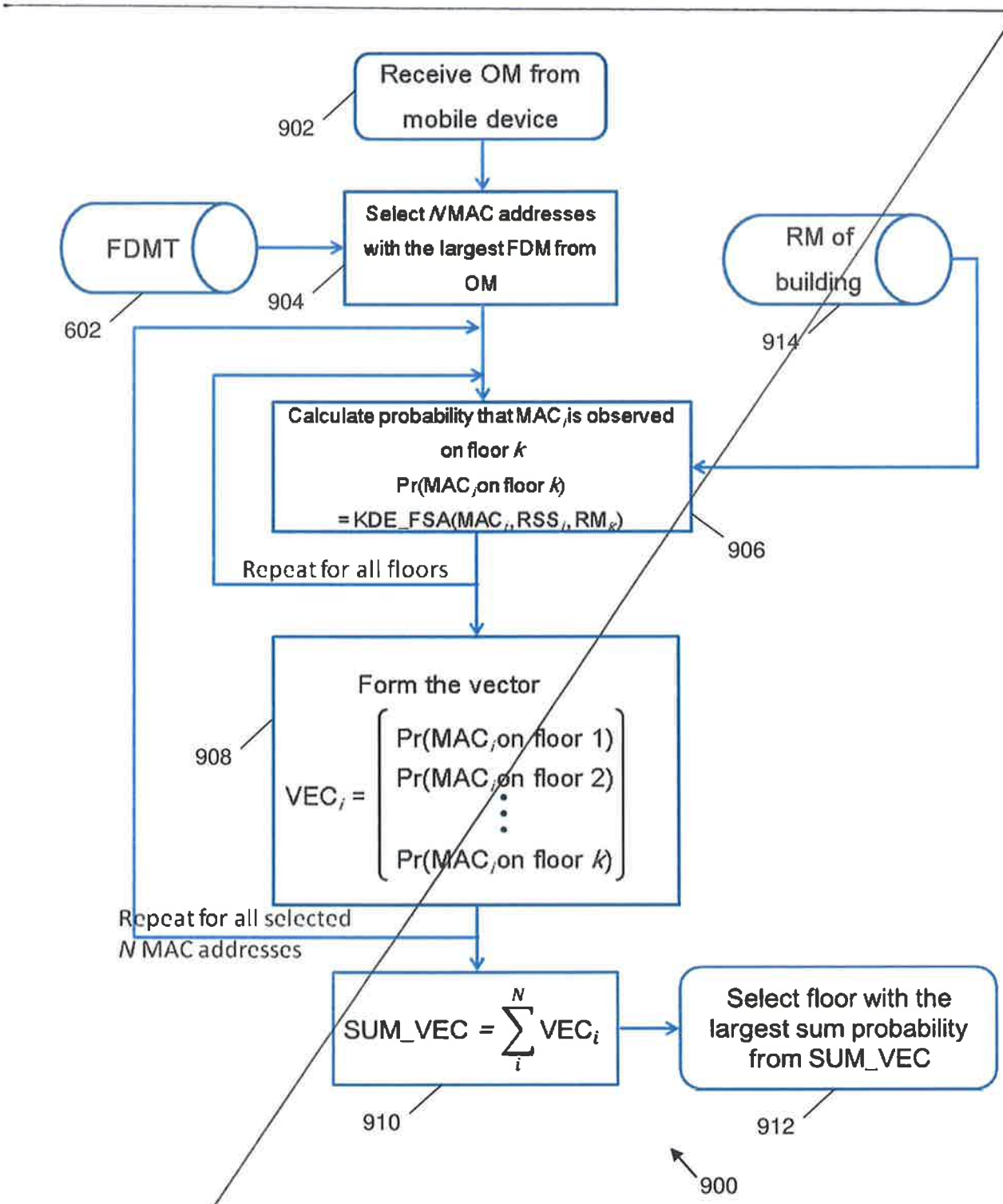

Receive OM from mobile device
902
Select N MAC addresses with the largest FDM from OM
904
FDMT
602
RM of building
914
Calculate probability that MAC_i is observed on floor k
Pr(MAC_i on floor k)
= KDE_FSA(MAC_i, RSS_i, RM_k)
906
Repeat for all floors
Form the vector
908
VEC_i = [Pr(MAC_i on floor 1); Pr(MAC_i on floor 2); ⋮; Pr(MAC_i on floor k)]
Repeat for all selected N MAC addresses
SUM_VEC = Σ_i^N VEC_i
910
Select floor with the largest sum probability from SUM_VEC
912
900

Figure 9

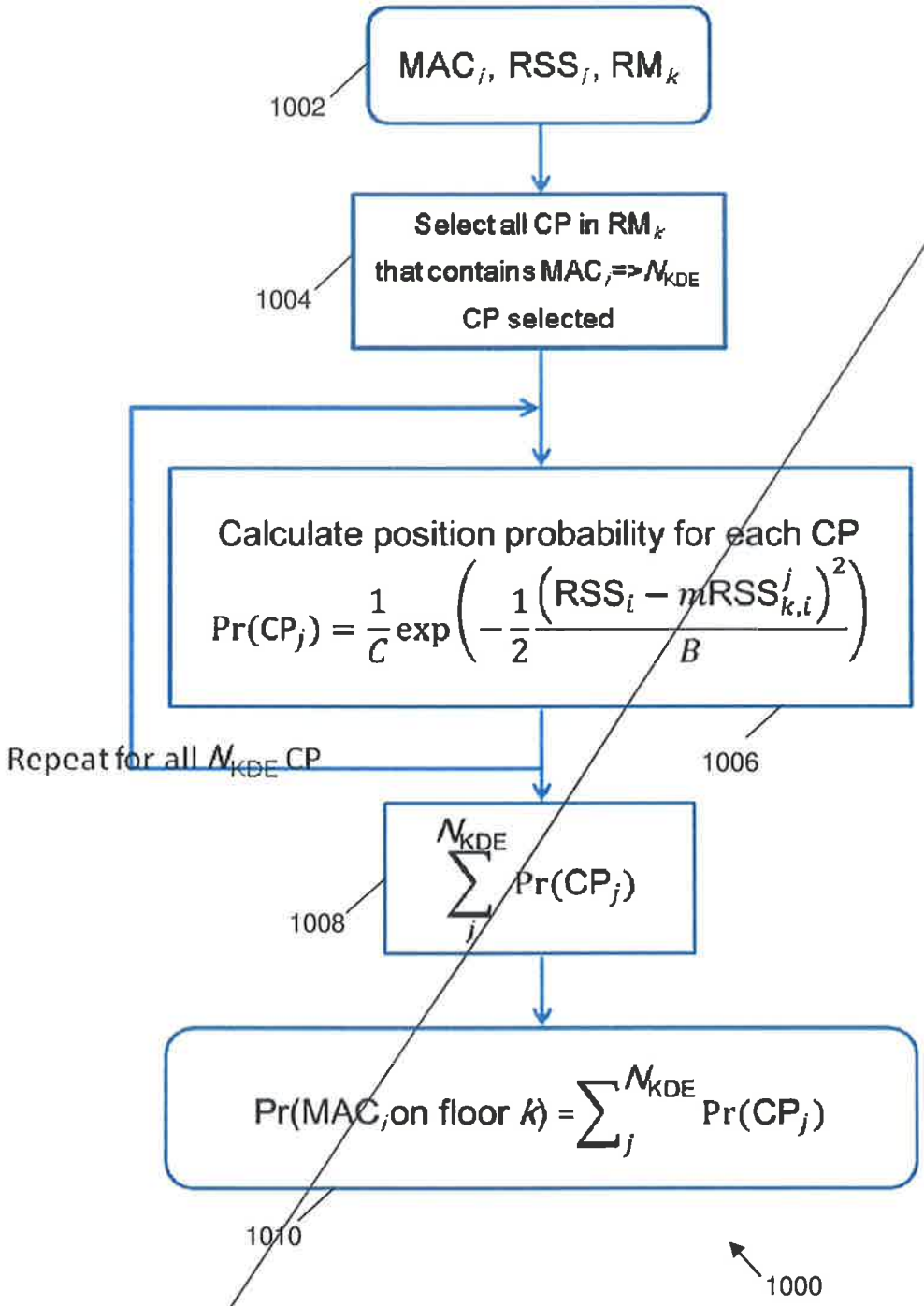

MAC_i, RSS_i, RM_k
1002
Select all CP in RM_k that contains MAC_i => N_{KDE} CP selected
1004
Calculate position probability for each CP
$\Pr(CP_j) = \frac{1}{C}\exp\left(-\frac{1}{2}\frac{\left(RSS_i - mRSS_{k,i}^{j}\right)^2}{B}\right)$
1006
Repeat for all N_{KDE} CP
$\sum_{j}^{N_{KDE}} \Pr(CP_j)$
1008
$\Pr(MAC_i \text{ on floor } k) = \sum_{j}^{N_{KDE}} \Pr(CP_j)$
1010
1000

Figure 10

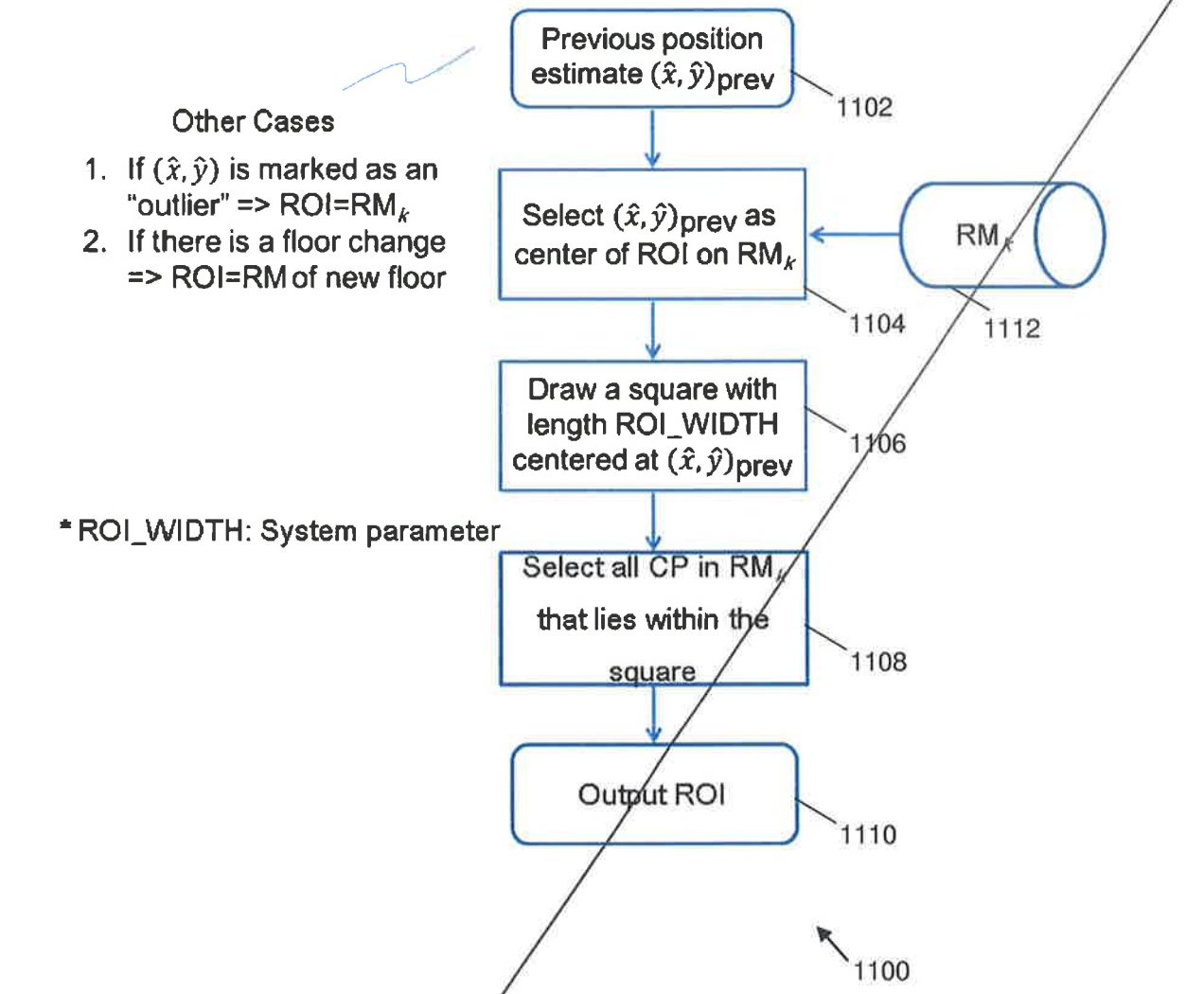

Previous position estimate $(\hat{x}, \hat{y})_{prev}$
1102
Other Cases
1. If $(\hat{x}, \hat{y})$ is marked as an "outlier" => ROI=RM_k
2. If there is a floor change => ROI=RM of new floor
Select $(\hat{x}, \hat{y})_{prev}$ as center of ROI on RM_k
RM_k
1104
1112
Draw a square with length ROI_WIDTH centered at $(\hat{x}, \hat{y})_{prev}$
1106
* ROI_WIDTH: System parameter
Select all CP in RM_k that lies within the square
1108
Output ROI
1110
1100

Figure 11

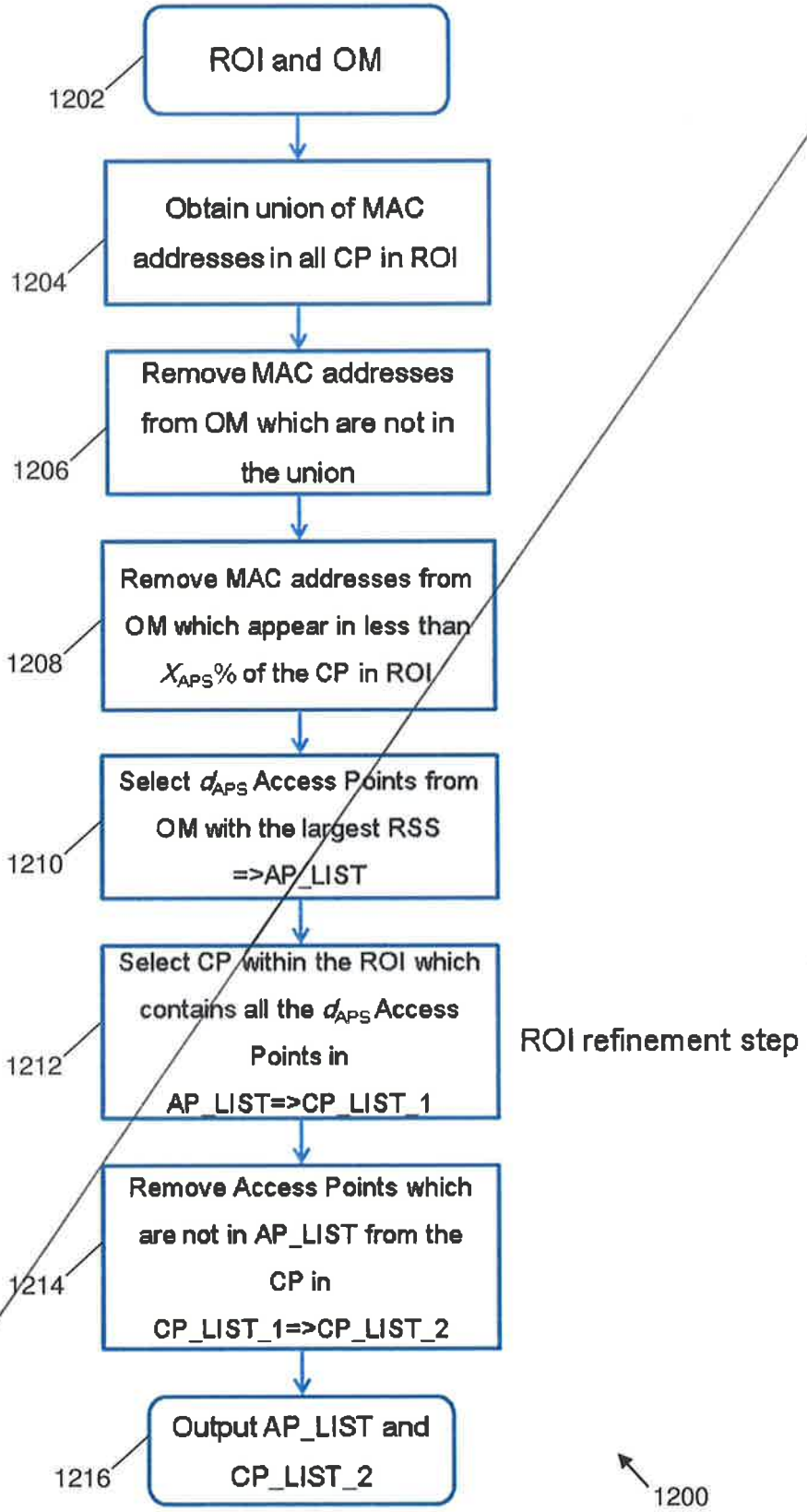

ROI and OM
1202
Obtain union of MAC addresses in all CP in ROI
1204
Remove MAC addresses from OM which are not in the union
1206
Remove MAC addresses from OM which appear in less than X_{APS}% of the CP in ROI
1208
Select d_{APS} Access Points from OM with the largest RSS =>AP_LIST
1210
Select CP within the ROI which contains all the d_{APS} Access Points in AP_LIST=>CP_LIST_1
1212
ROI refinement step
Remove Access Points which are not in AP_LIST from the CP in CP_LIST_1=>CP_LIST_2
1214
Output AP_LIST and CP_LIST_2
1216
1200

Figure 12

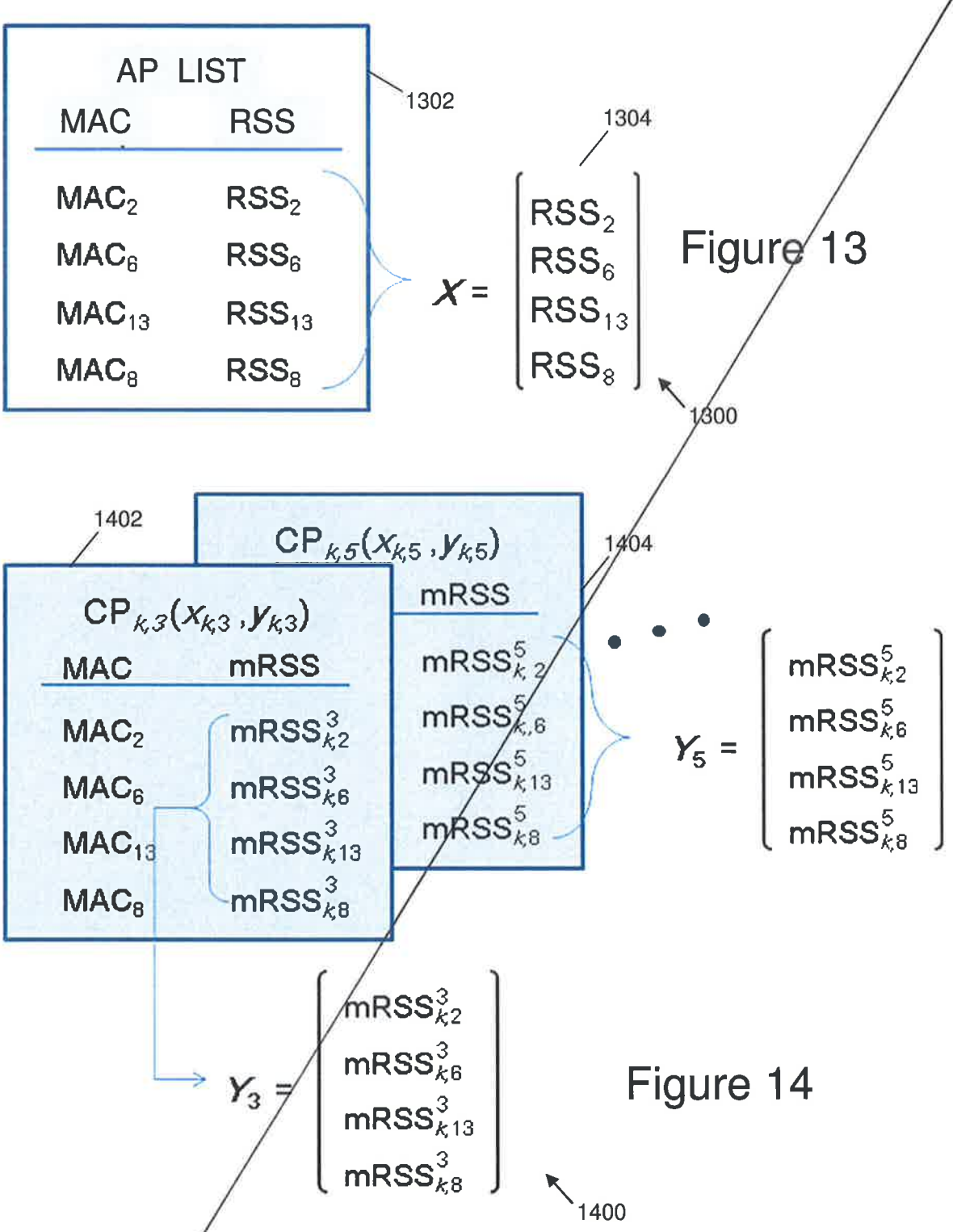


Figure 13

Figure 14

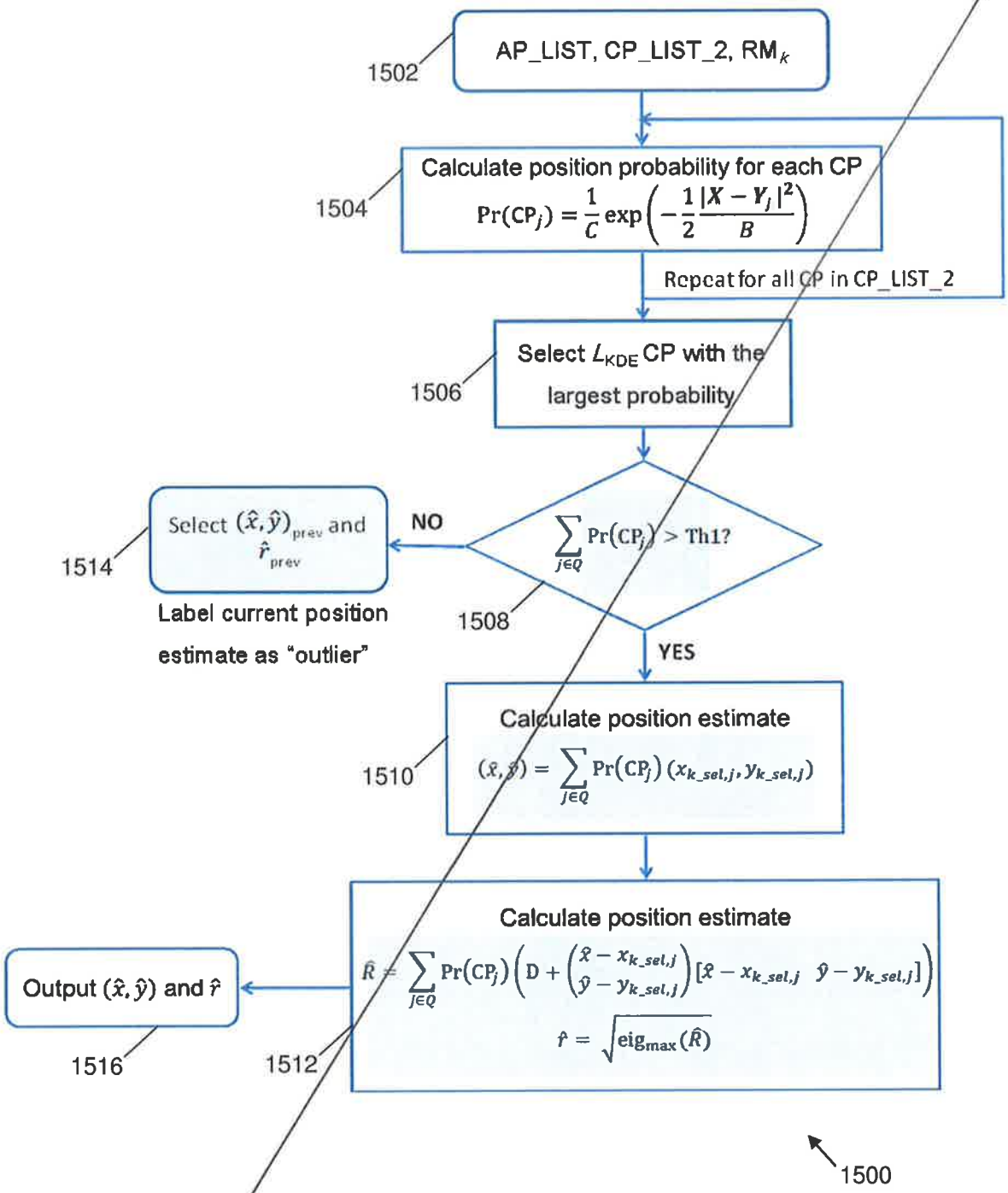

1502
AP_LIST, CP_LIST_2, RM$_k$
1504
Calculate position probability for each CP
$\Pr(CP_j) = \frac{1}{C}\exp\left(-\frac{1}{2}\frac{|X - Y_j|^2}{B}\right)$
Repeat for all CP in CP_LIST_2
1506
Select L_{KDE} CP with the largest probability
1508
$\sum_{j\in Q}\Pr(CP_j) > Th1?$
NO
1514
Select $(\hat{x},\hat{y})_{prev}$ and $\hat{r}_{prev}$
Label current position estimate as "outlier"
YES
1510
Calculate position estimate
$(\hat{x},\hat{y}) = \sum_{j\in Q}\Pr(CP_j)\,(x_{k_sel,j}, y_{k_sel,j})$
1512
Calculate position estimate
$\hat{R} = \sum_{j\in Q}\Pr(CP_j)\left(D + \begin{pmatrix}\hat{x}-x_{k_sel,j}\\ \hat{y}-y_{k_sel,j}\end{pmatrix}[\hat{x}-x_{k_sel,j} \quad \hat{y}-y_{k_sel,j}]\right)$
$\hat{r} = \sqrt{eig_{max}(\hat{R})}$
1516
Output $(\hat{x},\hat{y})$ and $\hat{r}$
1500

Figure 15

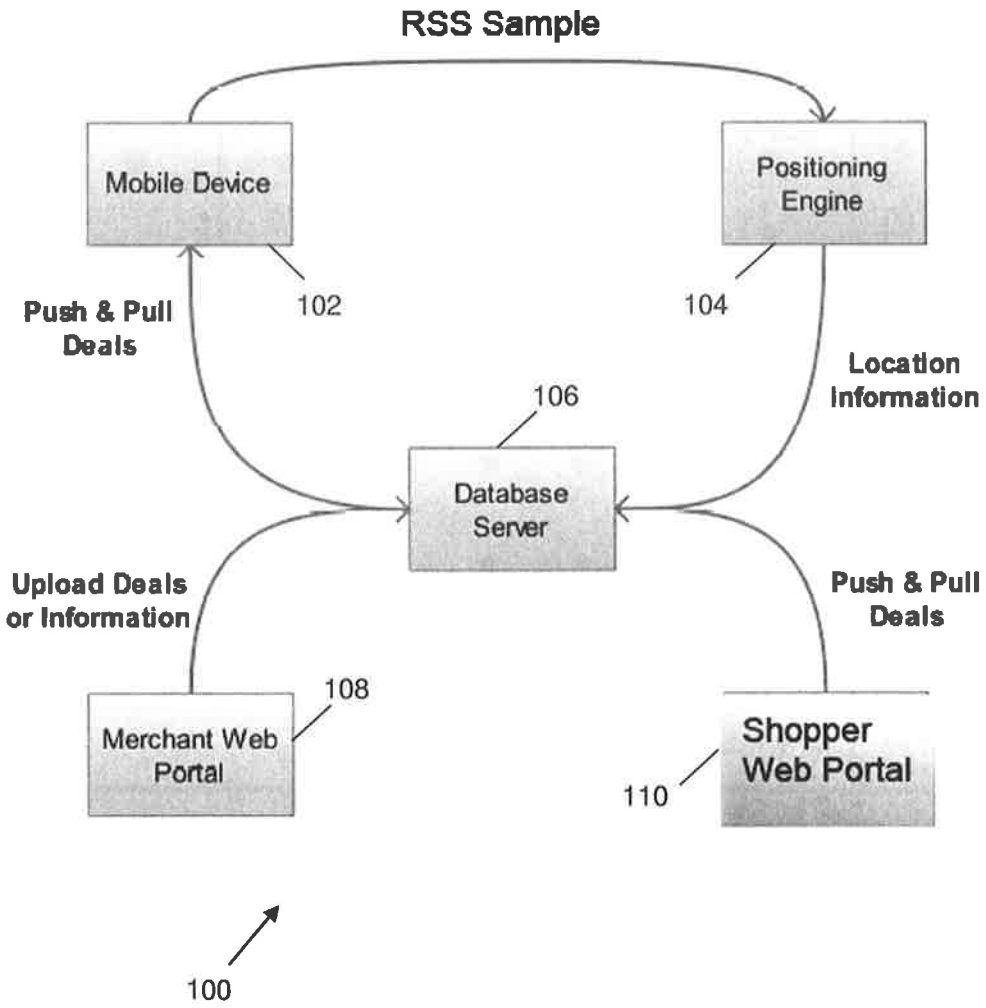

RSS Sample
Mobile Device
Positioning Engine
102
104
Push & Pull Deals
Location Information
106
Database Server
Upload Deals or Information
Push & Pull Deals
108
Merchant Web Portal
Shopper Web Portal
110
100

Figure 1

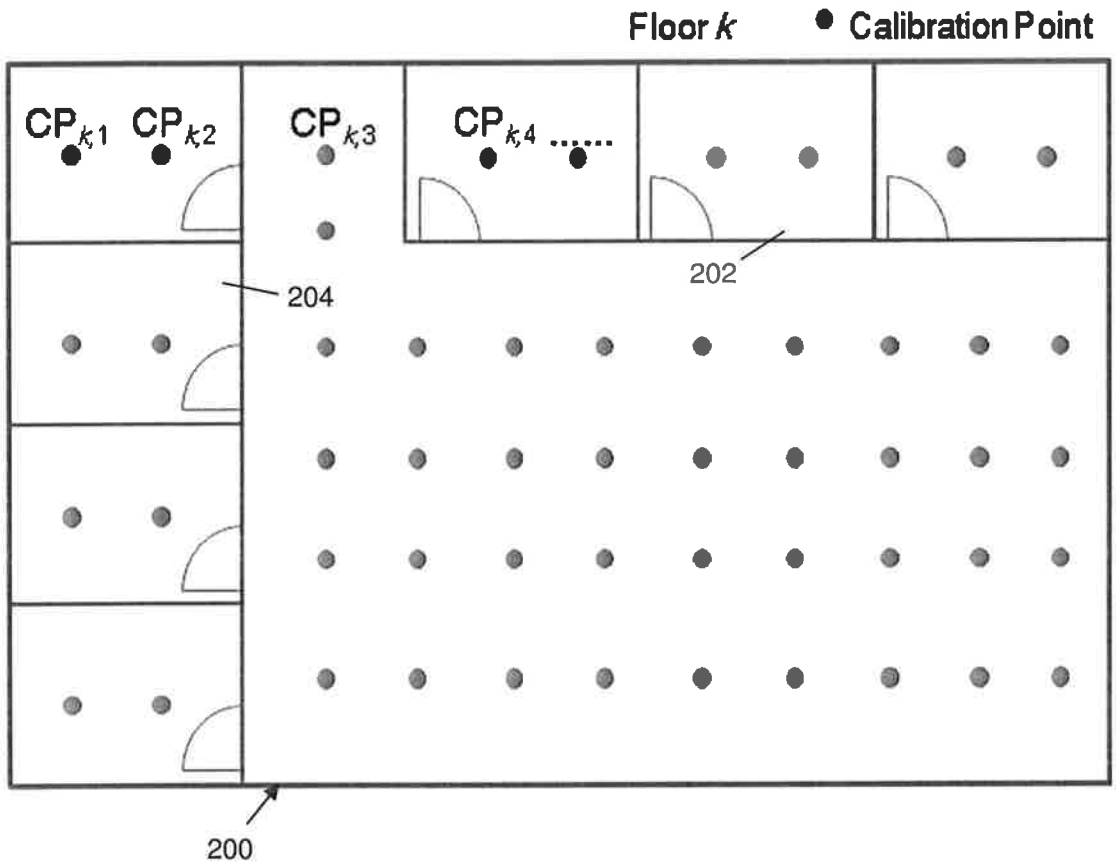


Figure 2

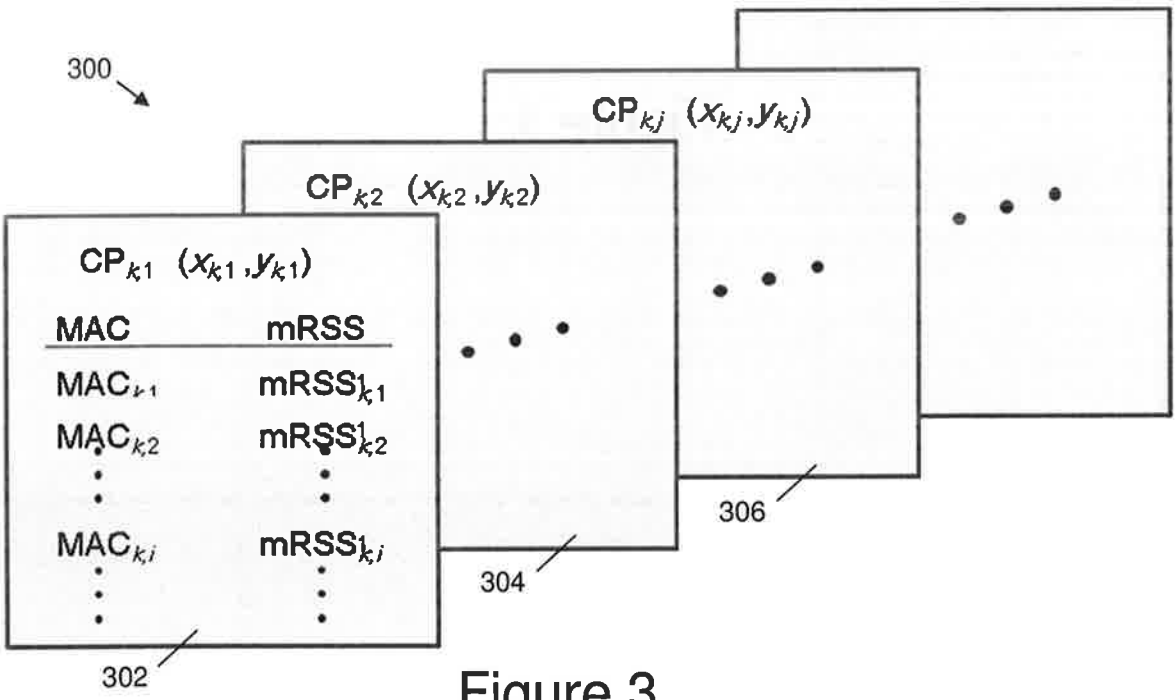


Figure 3

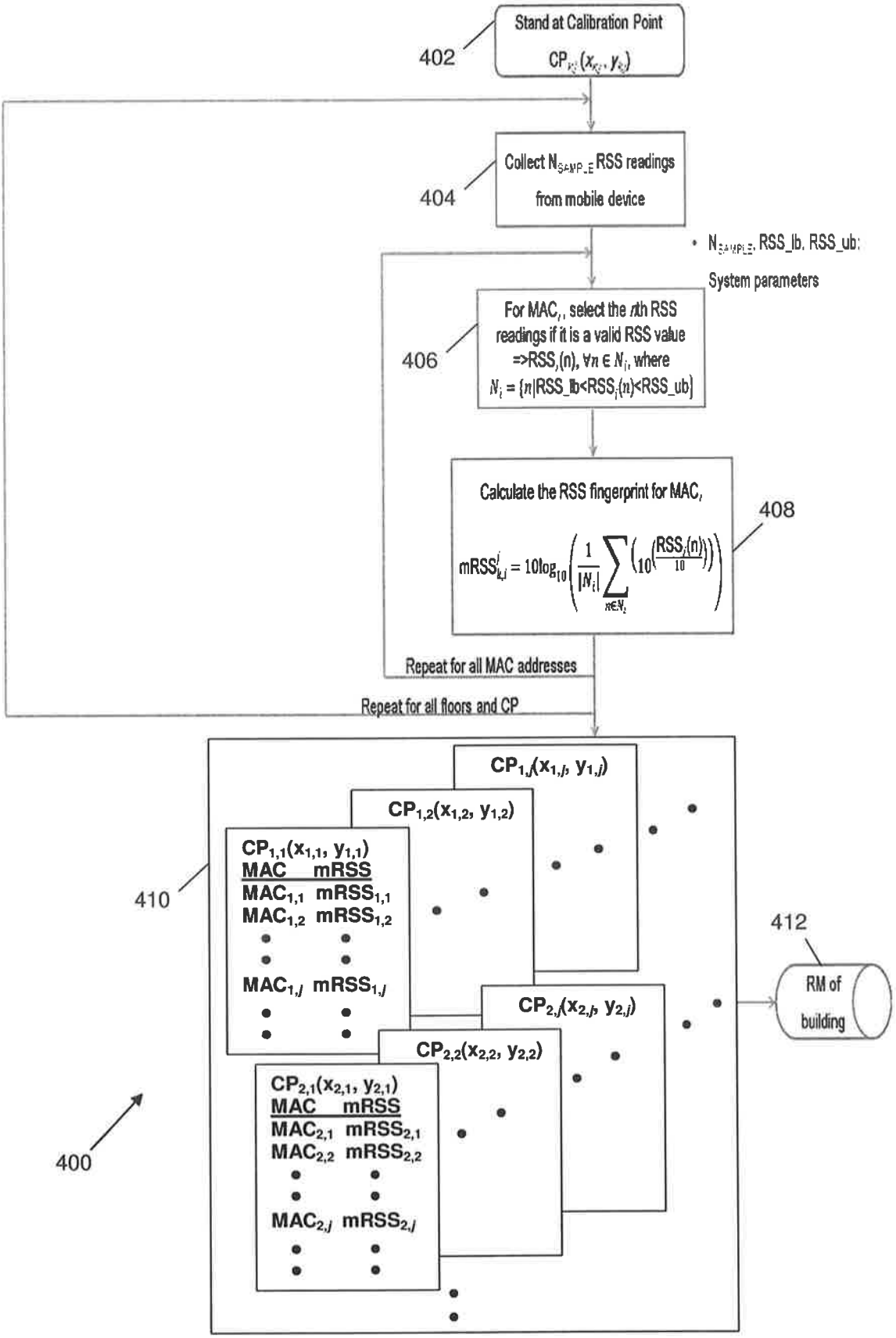

Stand at Calibration Point
$CP_{i,j}(x_{i,j}, y_{i,j})$
402
Collect N_{SAMPLE} RSS readings from mobile device
404
N_{SAMPLE}, RSS_lb, RSS_ub: System parameters
For MAC_i, select the nth RSS readings if it is a valid RSS value $\Rightarrow RSS_i(n), \forall n \in N_i$, where $N_i = \{n | RSS_lb < RSS_i(n) < RSS_ub\}$
406
Calculate the RSS fingerprint for MAC_i
$mRSS_{i,j}^{'} = 10\log_{10}\left(\frac{1}{|N_i|}\sum_{n \in N_i}\left(10^{\left(\frac{RSS_i(n)}{10}\right)}\right)\right)$
408
Repeat for all MAC addresses
Repeat for all floors and CP
$CP_{1,j}(x_{1,j}, y_{1,j})$
$CP_{1,2}(x_{1,2}, y_{1,2})$
$CP_{1,1}(x_{1,1}, y_{1,1})$
MAC mRSS
$MAC_{1,1}$ $mRSS_{1,1}$
$MAC_{1,2}$ $mRSS_{1,2}$
$MAC_{1,j}$ $mRSS_{1,j}$
410
412
RM of building
$CP_{2,j}(x_{2,j}, y_{2,j})$
$CP_{2,2}(x_{2,2}, y_{2,2})$
$CP_{2,1}(x_{2,1}, y_{2,1})$
MAC mRSS
$MAC_{2,1}$ $mRSS_{2,1}$
$MAC_{2,2}$ $mRSS_{2,2}$
$MAC_{2,j}$ $mRSS_{2,j}$
400

Figure 4

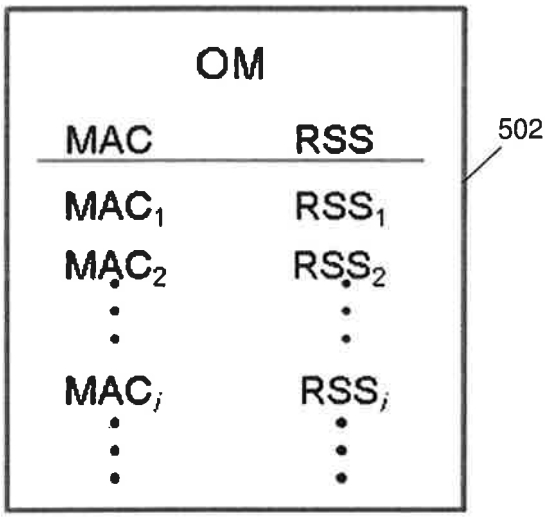


Figure 5

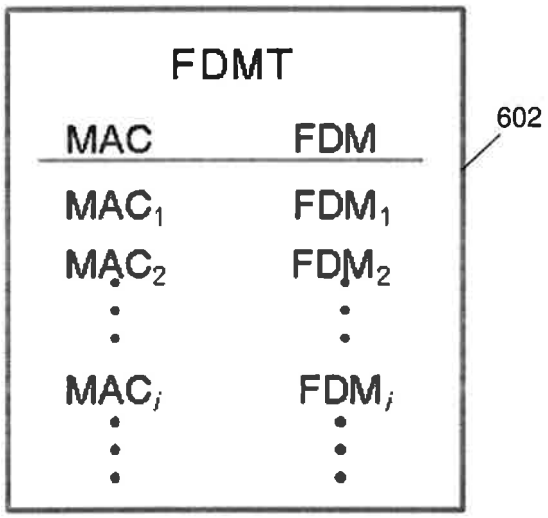


Figure 6

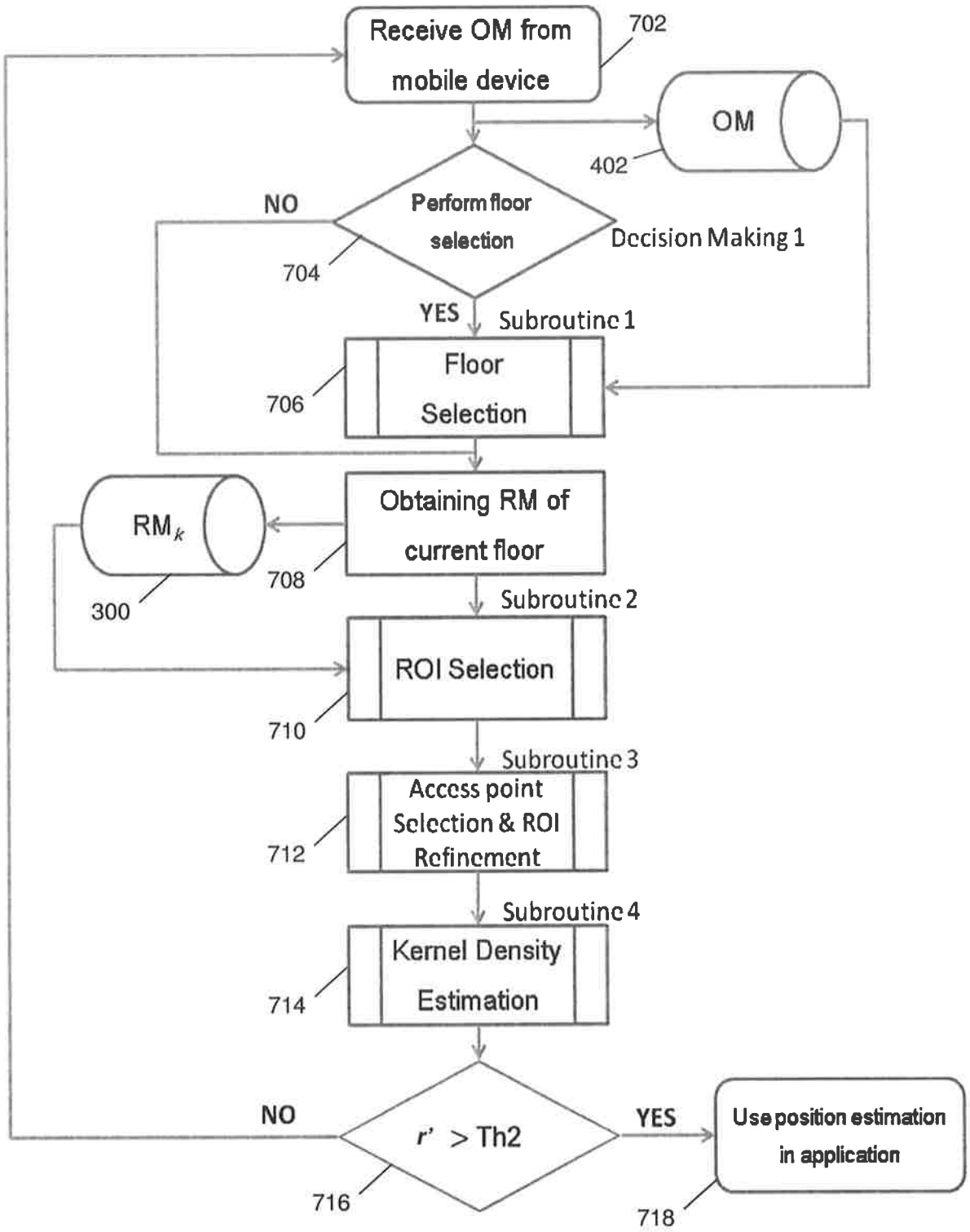

Receive OM from mobile device
702
OM
402
Perform floor selection
Decision Making 1
NO
704
YES
Subroutine 1
Floor Selection
706
RM$_k$
300
Obtaining RM of current floor
708
Subroutine 2
ROI Selection
710
Subroutine 3
Access point Selection & ROI Refinement
712
Subroutine 4
Kernel Density Estimation
714
NO
$r' > Th2$
716
YES
Use position estimation in application
718

Figure 7

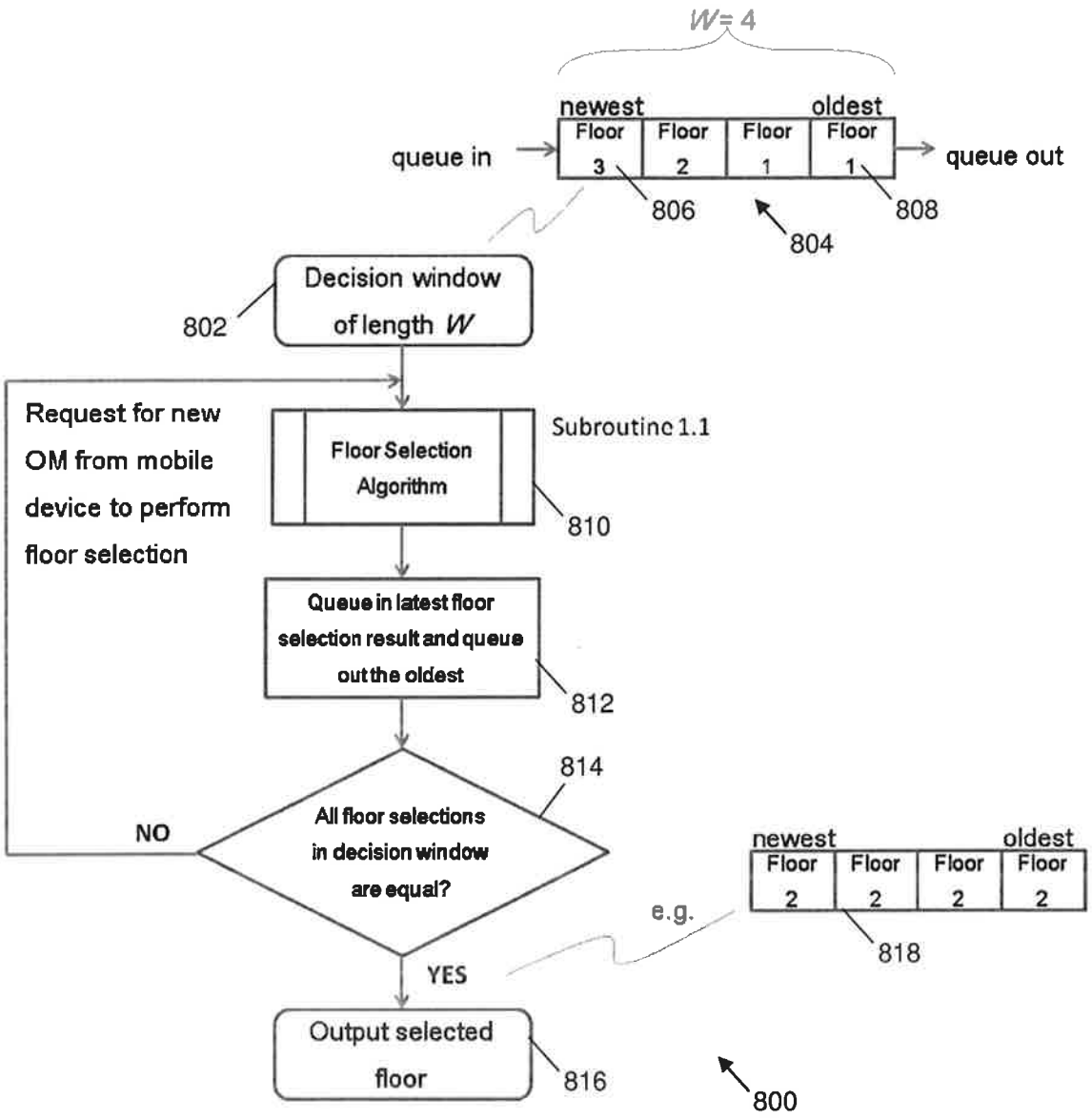

W = 4
newest
oldest
Floor 3
Floor 2
Floor 1
Floor 1
queue in
queue out
806
808
804
802
Decision window of length W
Request for new OM from mobile device to perform floor selection
Floor Selection Algorithm
Subroutine 1.1
810
Queue in latest floor selection result and queue out the oldest
812
814
All floor selections in decision window are equal?
NO
YES
e.g.
newest
oldest
Floor 2
Floor 2
Floor 2
Floor 2
818
Output selected floor
816
800

Figure 8

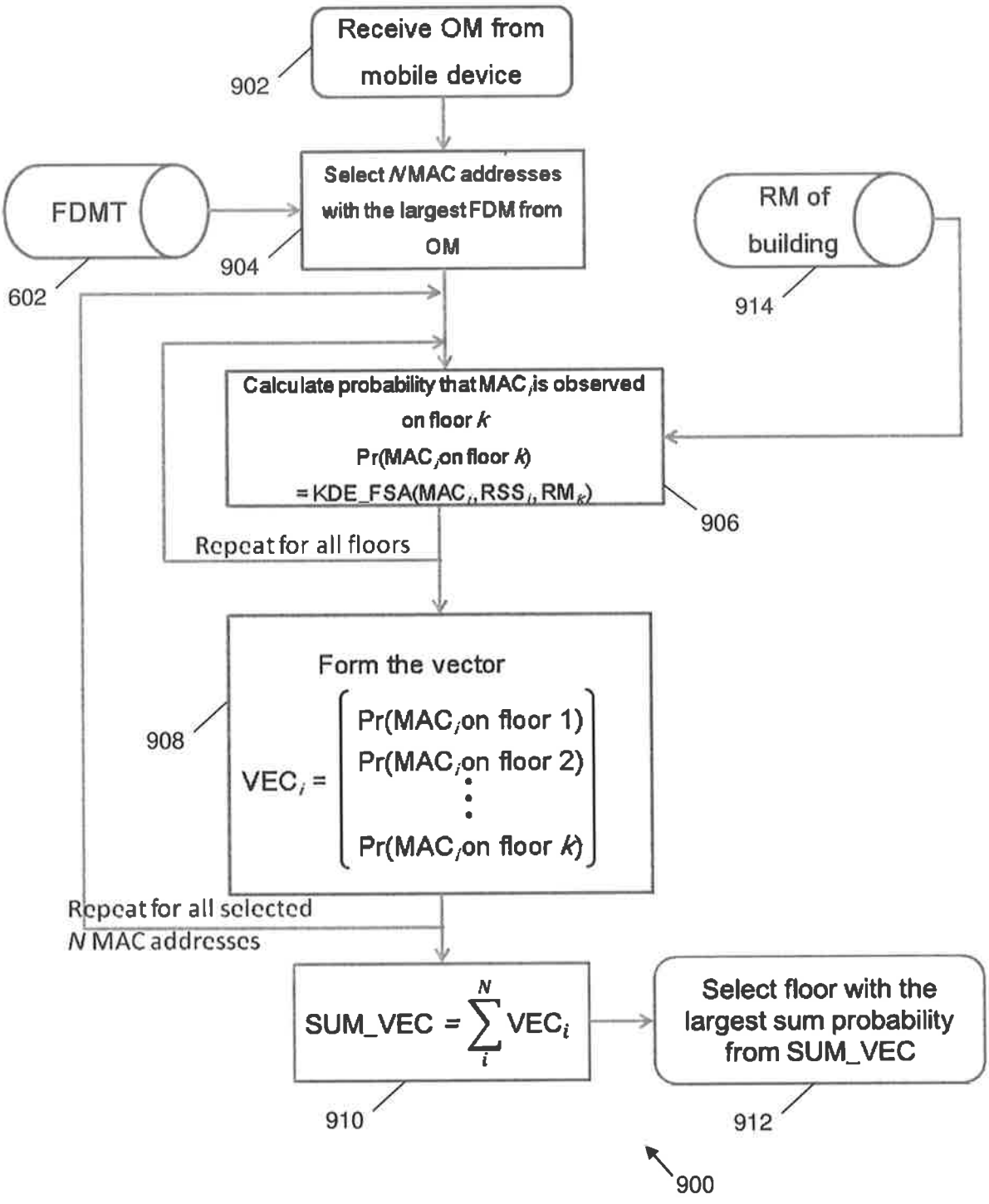

Receive OM from mobile device
902
Select N MAC addresses with the largest FDM from OM
904
FDMT
602
RM of building
914
Calculate probability that MAC_i is observed on floor k
Pr(MAC_i on floor k)
= KDE_FSA(MAC_i, RSS_i, RM_k)
906
Repeat for all floors
Form the vector
908
VEC_i = [Pr(MAC_i on floor 1); Pr(MAC_i on floor 2); ⋮; Pr(MAC_i on floor k)]
Repeat for all selected N MAC addresses
SUM_VEC = Σ_i^N VEC_i
910
Select floor with the largest sum probability from SUM_VEC
912
900

Figure 9

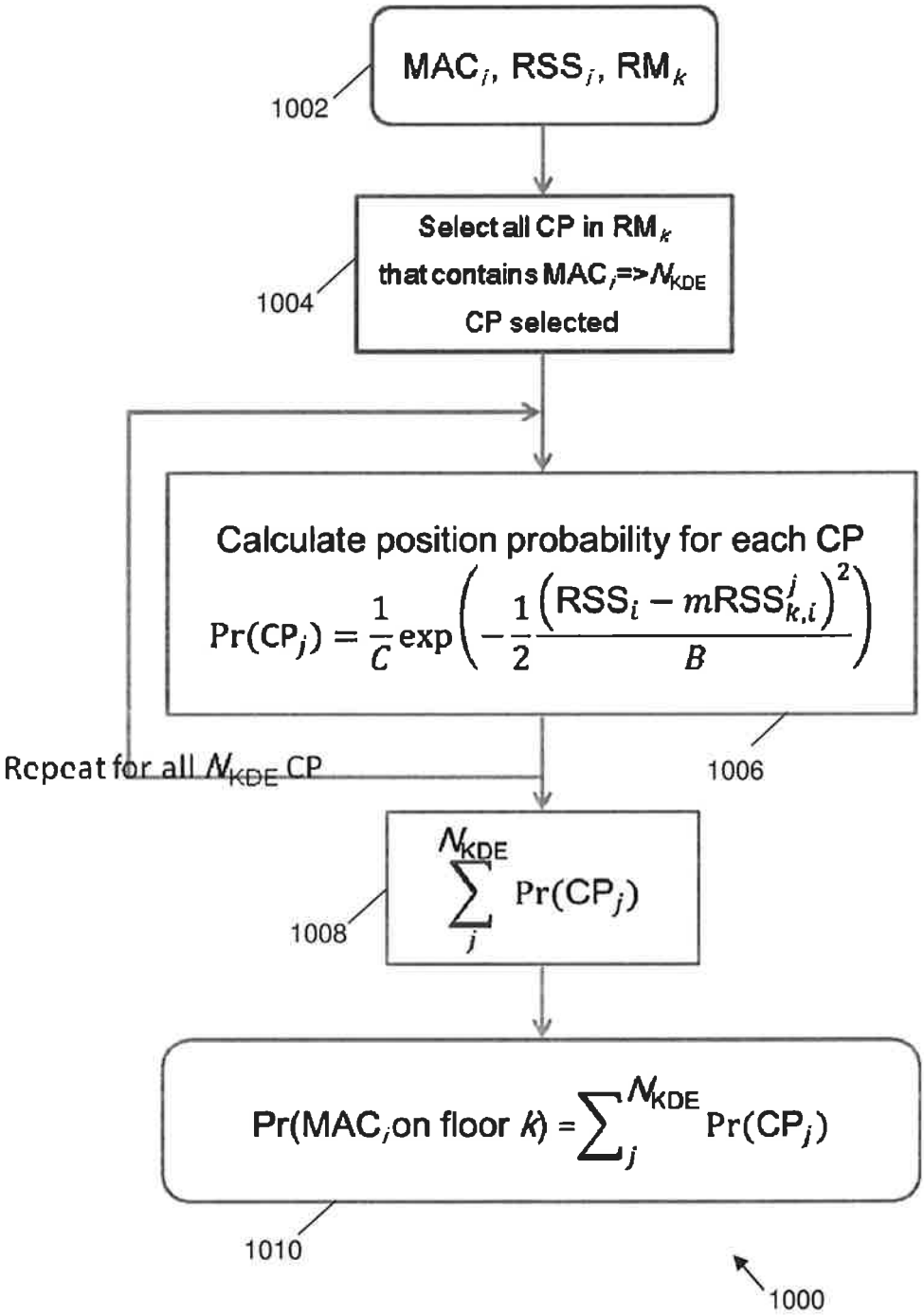

MAC_i, RSS_i, RM_k
1002
Select all CP in RM_k that contains MAC_i=>N_{KDE} CP selected
1004
Calculate position probability for each CP
$\Pr(CP_j) = \frac{1}{C}\exp\left(-\frac{1}{2}\frac{\left(RSS_i - mRSS_{k,i}^{j}\right)^2}{B}\right)$
1006
Repeat for all N_{KDE} CP
$\sum_{j}^{N_{KDE}} \Pr(CP_j)$
1008
$\Pr(MAC_i \text{ on floor } k) = \sum_{j}^{N_{KDE}} \Pr(CP_j)$
1010
1000

Figure 10

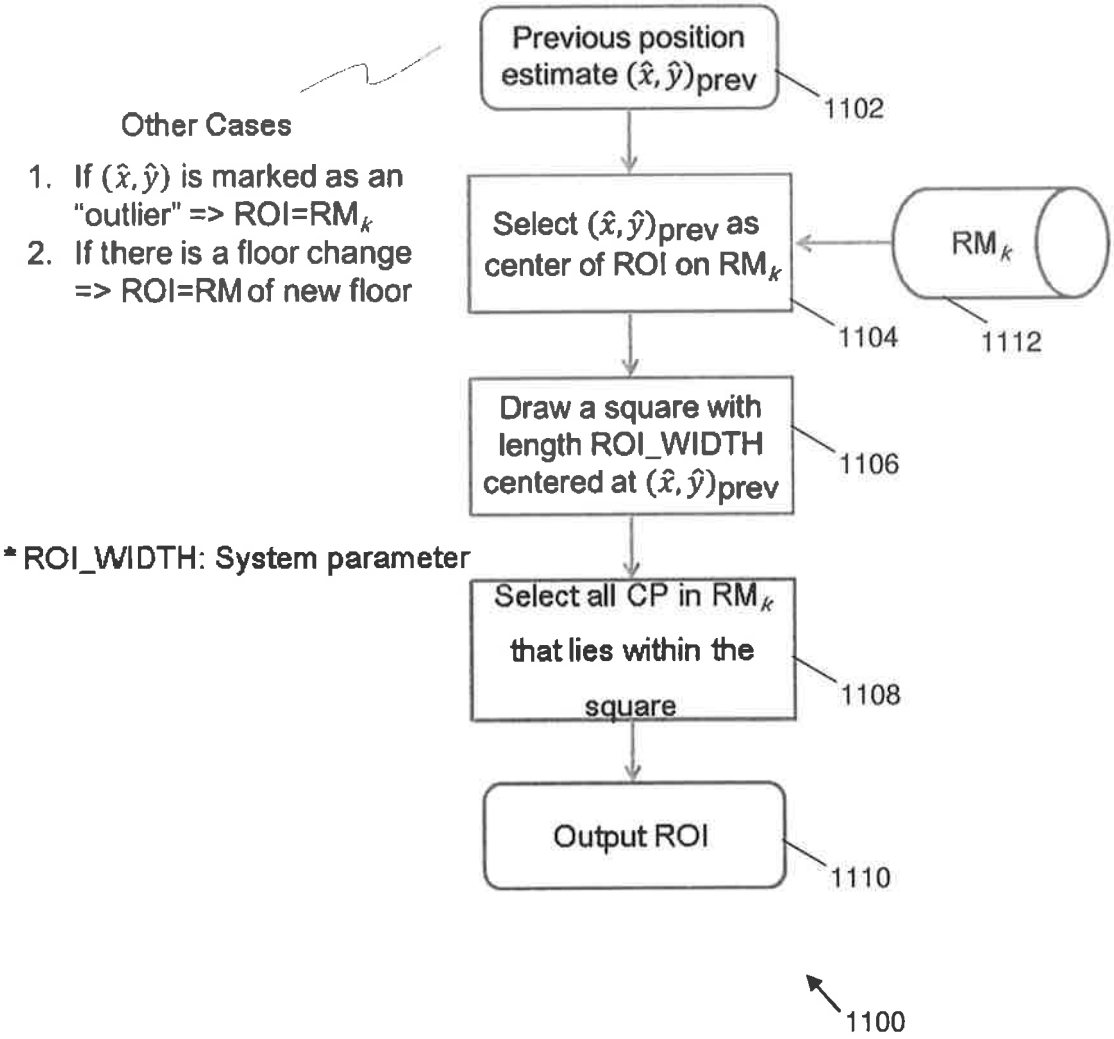

Other Cases
1. If $(\hat{x}, \hat{y})$ is marked as an "outlier" => ROI=RM_k
2. If there is a floor change => ROI=RM of new floor
* ROI_WIDTH: System parameter
Previous position estimate $(\hat{x}, \hat{y})_{prev}$
1102
Select $(\hat{x}, \hat{y})_{prev}$ as center of ROI on RM_k
RM_k
1104
1112
Draw a square with length ROI_WIDTH centered at $(\hat{x}, \hat{y})_{prev}$
1106
Select all CP in RM_k that lies within the square
1108
Output ROI
1110
1100

Figure 11

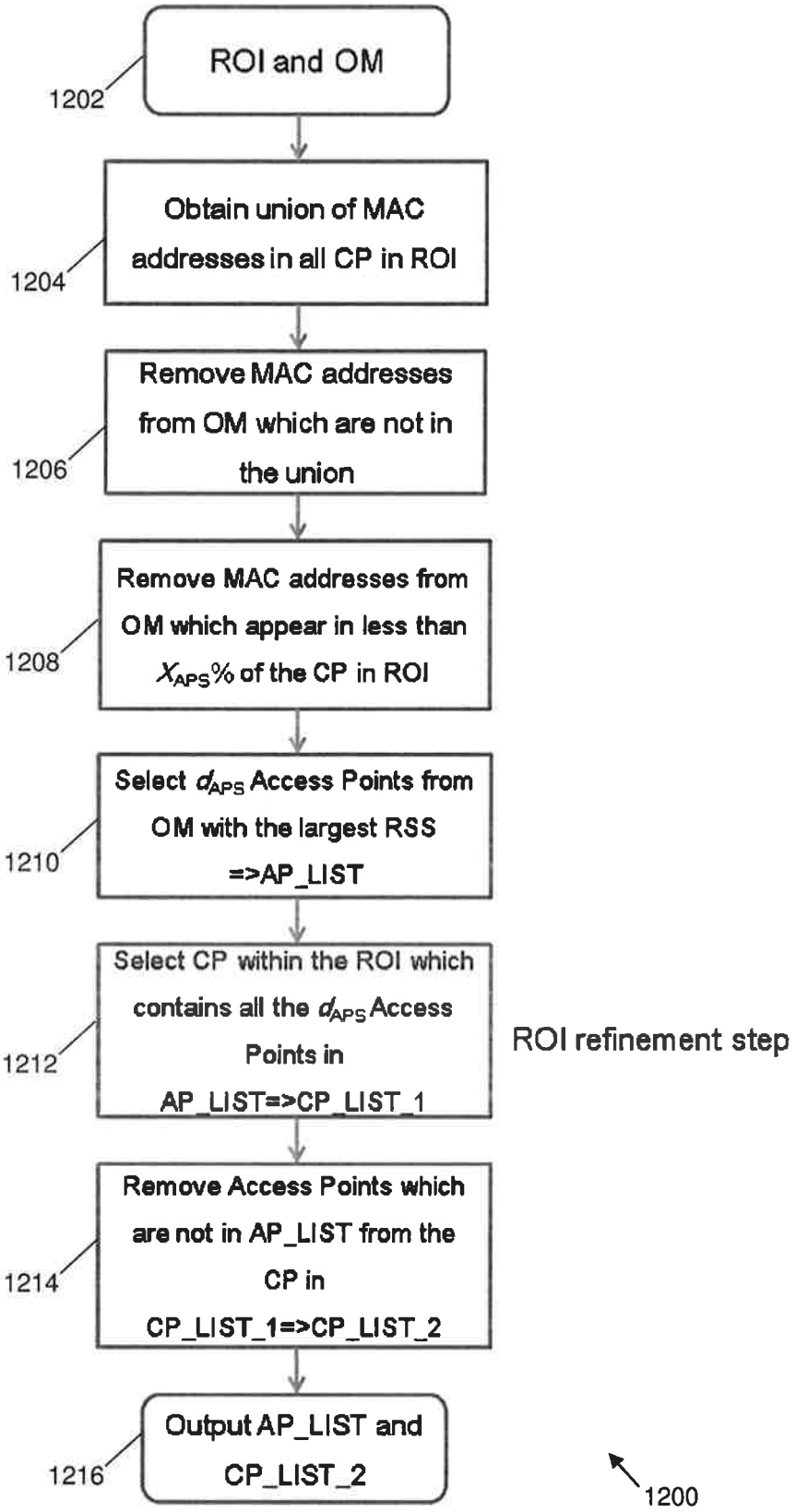

ROI and OM
1202
Obtain union of MAC addresses in all CP in ROI
1204
Remove MAC addresses from OM which are not in the union
1206
Remove MAC addresses from OM which appear in less than X_{APS}% of the CP in ROI
1208
Select d_{APS} Access Points from OM with the largest RSS =>AP_LIST
1210
Select CP within the ROI which contains all the d_{APS} Access Points in AP_LIST=>CP_LIST_1
1212
ROI refinement step
Remove Access Points which are not in AP_LIST from the CP in CP_LIST_1=>CP_LIST_2
1214
Output AP_LIST and CP_LIST_2
1216
1200

Figure 12

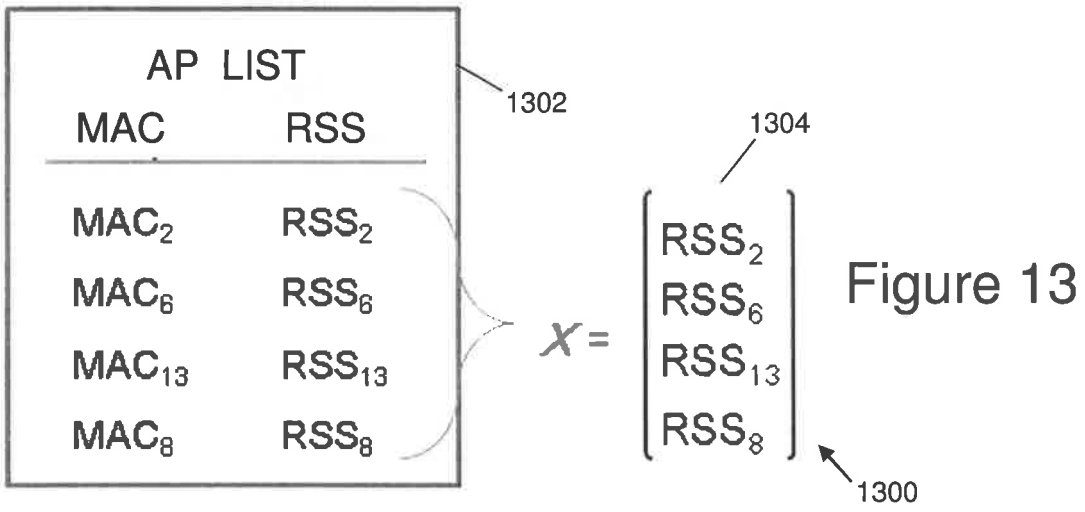


Figure 13

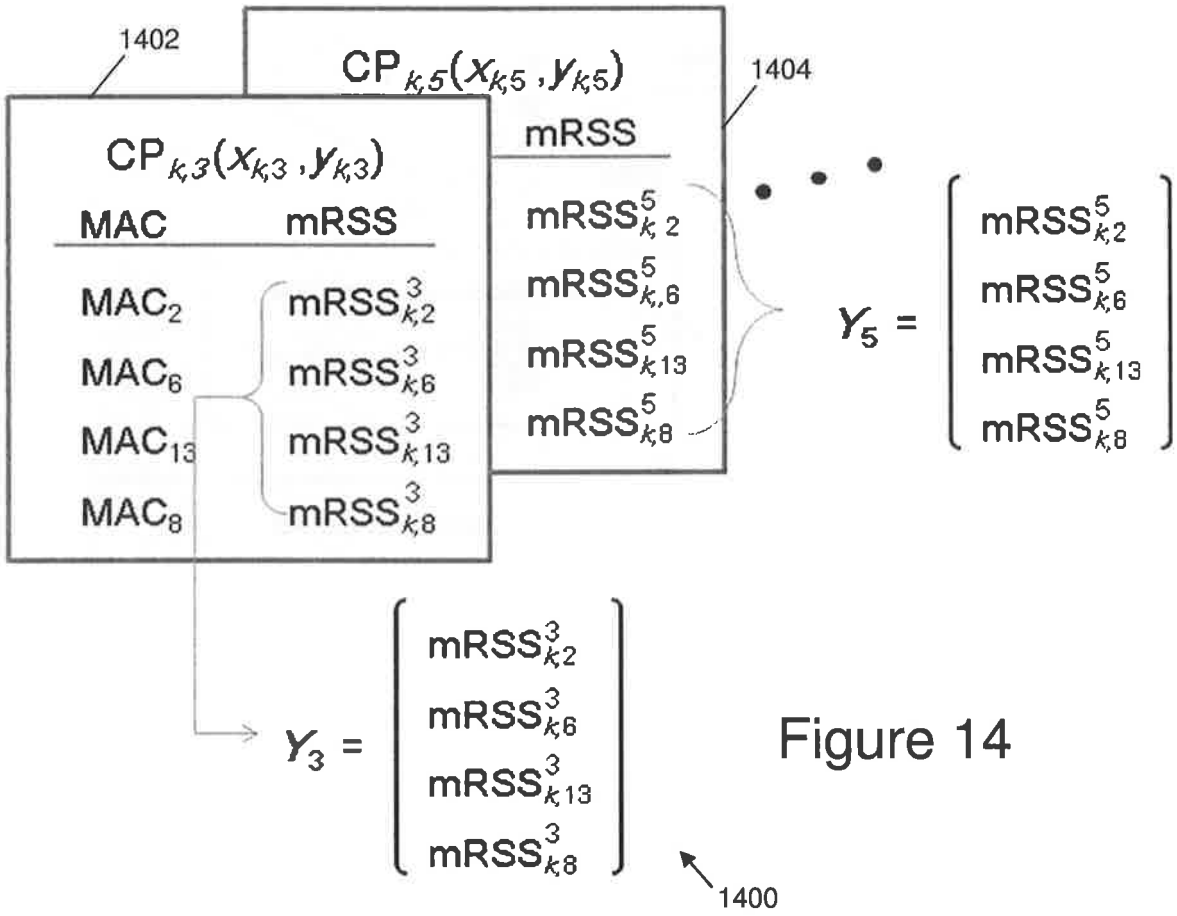


Figure 14

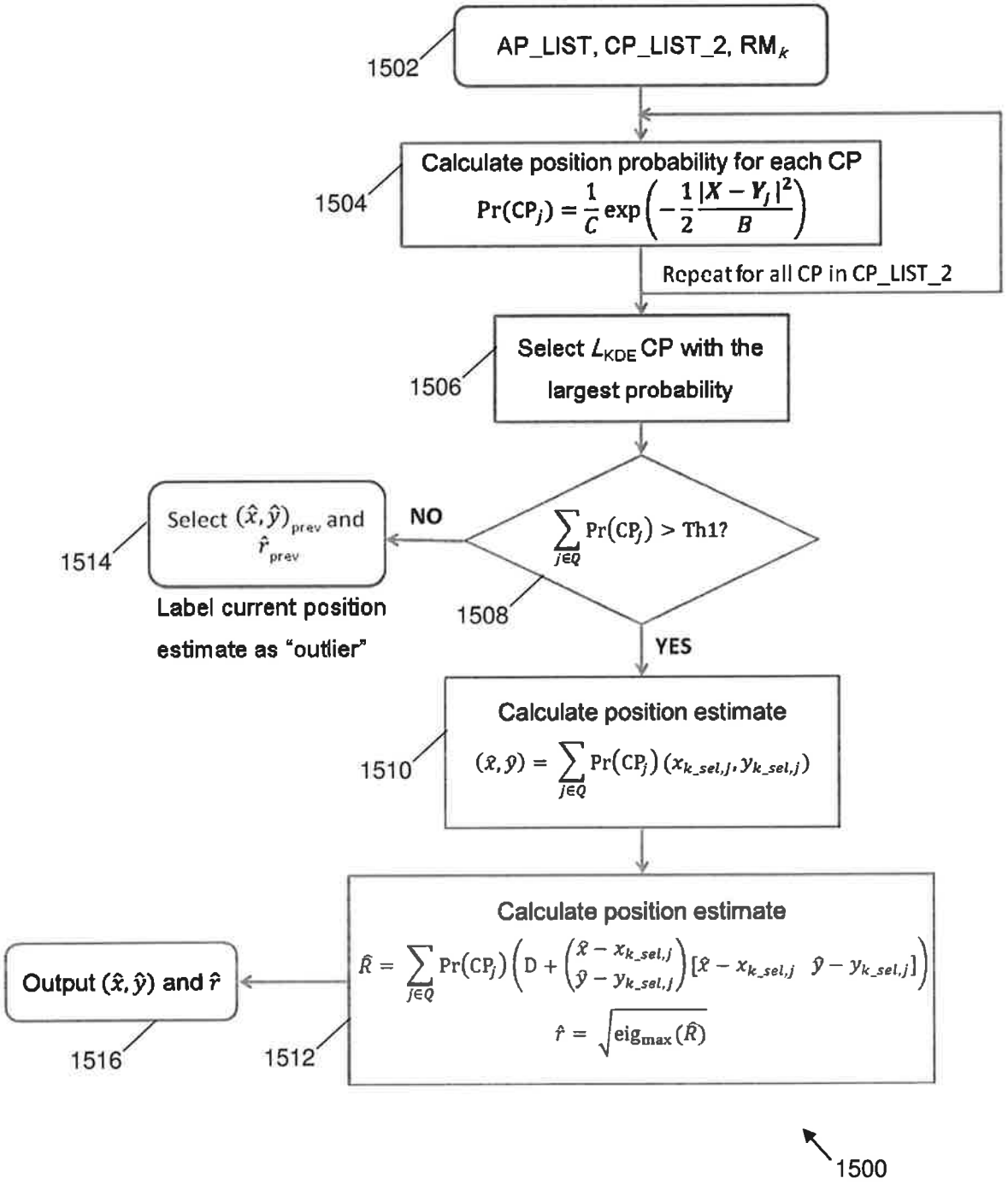

1502
AP_LIST, CP_LIST_2, RM_k
1504
Calculate position probability for each CP
$\Pr(CP_j) = \frac{1}{C}\exp\left(-\frac{1}{2}\frac{|X - Y_j|^2}{B}\right)$
Repeat for all CP in CP_LIST_2
1506
Select L_{KDE} CP with the largest probability
1508
$\sum_{j\in Q}\Pr(CP_j) > Th1?$
NO
1514
Select $(\hat{x},\hat{y})_{prev}$ and $\hat{r}_{prev}$
Label current position estimate as "outlier"
YES
1510
Calculate position estimate
$(\hat{x},\hat{y}) = \sum_{j\in Q}\Pr(CP_j)\,(x_{k_sel,j}, y_{k_sel,j})$
1512
Calculate position estimate
$\hat{R} = \sum_{j\in Q}\Pr(CP_j)\left(D + \begin{pmatrix}\hat{x}-x_{k_sel,j}\\ \hat{y}-y_{k_sel,j}\end{pmatrix}[\hat{x}-x_{k_sel,j} \quad \hat{y}-y_{k_sel,j}]\right)$
$\hat{r} = \sqrt{eig_{max}(\hat{R})}$
1516
Output $(\hat{x},\hat{y})$ and $\hat{r}$
1500

Figure 15