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Technical Report

Universal Mobile Telecommunications System (UMTS); Evaluation of the inclusion of path loss based location technology in the UTRAN (3GPP TR 25.907 version 9.0.1 Release 9)

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Contents

Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

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1 Scope

<Editor's note: Text in this section is cited from the original text in 'Annex A.1 Overview'>

Path-loss technologies cover a broad scope of specific location technologies, including: RSSI Trilateration technologies, certain Enhanced Cell-ID technologies, and RF pattern matching technologies. For the purposes of this Study Item, individual technology groups to be evaluated will be treated independently as Annexes to the TR.

In this TR, Annex.A should:

- Describe pattern matching and outline it's benefits and challenges.
- Illustrate the required messaging to support RF pattern matching technologies, as well as the projected performance improvements associated with additional messaging/measurement support.
- Confirm the performance capability of RF pattern matching Technology on the UMTS air-interface, over all environments. Both in terms of accuracy and location result latency:
  - Dense Urban
  - In-Building
  - Rural
- Illustrate the Standardized architecture for RF pattern matching technologies as related to the UMTS and future air interfaces.
- Provide an outline of anticipated standardization requirements for improved performance and interoperability of RF pattern matching technologies.
- Provide a conclusion based on the information contained herein and a recommendation to the 3GPP regarding standardization of RF pattern matching Technologies within the RAN.

2 References

[1] Weiss, A., "On The Accuracy of A Cellular Location System Based on RSS Measurements," *IEEE Transactions on Vehicular Technology*, vol. 52, pp. 1508 – 1518, Nov 2003.

[2] Catovic, A. and Sahinoglu, Z., "The Cramer–Rao Bounds of Hybrid TOA/RSS and TDOA/RSS Location Estimation Schemes," *IEEE Communications Letters*, vol. 8, pp. 626 – 8, Oct 2004.

[3] 3GPP TR 25.942: " Universal Mobile Telecommunications System (UMTS); Radio Frequency (RF) system scenarios

[4] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[5] 3GPP TS 25.331: "Radio Resource Control (RRC); Protocol specification".

[6] 3GPP TS 25.453: "UTRAN Iupc interface Positioning Calculation Application Part (PCAP) signalling".

[7] 3GPP TS 25.215: "Physical layer; Measurements (FDD)".

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in TR 21.905 [4] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in TR 21.905 [4].

3.2 Symbols

For the purposes of the present document, the following symbols apply:

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1].

4 Overview

<Editor's note: Text in this section is cited from the original text in 'Annex A.1>

Performance in field deployments and trials of Path-loss technologies indicates potential benefits, both in terms of location accuracy and latency, in including some of these technologies in the Standards. Individual Path-loss technologies will be evaluated thoroughly and objectively in this TR to assess which, if any, of these are sufficiently promising so as to justify further consideration by the 3GPP.

5 Feasibility of path-loss technologies for location on UMTS

5.1 RF pattern matching

<Editor's note: Text in this section is cited from the original text in 'Annex A.2.1 and A.2.1.1>

pattern matching technologies represent a family of Path Loss based technologies that rely on matching the RF environment (as experienced by the UE) to the known characteristics of the larger RF System in which the UE is operating. Information from the UE, including measurements of neighbour cell signal strengths, time delay and other network parameters form the basis of the RF environment to be compared to the established System RF Database. The intent of this approach is to mitigate the negative impacts of anomalies within the RF environment that challenge the accuracy of trilateration technologies (e.g. multipath and reflection).

The RF pattern matching positioning method is based on measurements made by the UE and Node B. The essential measurement set required for this method is currently defined in [25.215] and necessary for the basic mobility functionality and hence this method will work with existing mobiles without any modification.

6 Evaluated performance of path-loss technologies on UMTS

6.1 General

<Editor's note: Text in this section is cited from the original text in 'Annex A.8, detailed simulation methodology and results are presented in Annex A >

- RF pattern matching provides a significant improvement in performance to Cell-ID with RTT
    - Average simulated improvement was 47.3%
    - Highest simulated improvement was 259%

6.2 RF pattern matching technologies on UMTS

See Annex A.6.

7 Network Architecture for Path-loss technologies on UMTS

7.1 RF pattern matching technologies on UMTS

<Editor's note: Diagram in this section is cited from the original text in 'Annex A.5.1>

- Architecture shown is the currently approved 3GPP LCS architecture (no architecture changes are needed for RF pattern matching)>

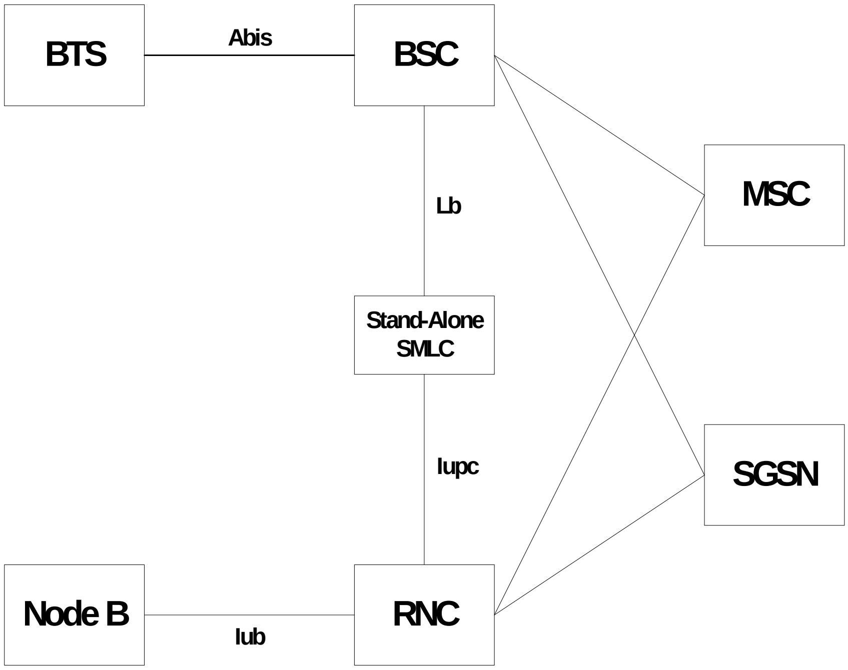

Figure A.5.1: Overlay Architecture for RF pattern matching

8 Summary comparison of path-loss technologies with currently standardized location technologies on UMTS

Refer to Clauses A.3 and 10.1.

9 Anticipated requirements for the standardization of path-loss technologies in 3GPP

9.1 RF pattern matching technologies on UMTS

<Editor's note: Diagram in this section is cited from the original text in 'Annex A.7>

9.1.1 Modifications to TS 25.331 [5] (RRC Protocol Specification) and TS 25.453 [6] include:

The changes anticipated for this specification include the definition/addition of RF pattern matching to the UE Positioning description section (8.6.7.19) and the inclusion of RF pattern matching in the defined UE positioning procedures. Additionally, a PCAP group for "RF pattern matching" will be required in TS 25.453.

9.1.2 Anticipated Change Requests

- Inter-RAT

The ability to leverage Inter-RAT measurements in an overlay network will provide significant potential improvements in location accuracy for RF pattern matching. It is anticipated that these measurements will be requested as an optional parameter (at least for use in emergency service locations).

- IPDL

IPDL offers similar advantages to RF pattern matching to those that it gives to other location technologies (e.g. OTDOA). To the extent that this capability is pursued for those technologies, it is intended that it will be used to benefit RF pattern matching as well.

- Absolute Ec (Sector TX Power)

As RF pattern matching is a path-loss, based location technology, absolute Ec will allow for better definition of the local UE environment and improved location accuracy. It is assumed that this measurement will be requested in the UE positioning report for RF pattern matching.

- Round Trip Time (RTT)

Given the dynamic power management scenarios that are being used in the UTRAN, The measure of RTT has good potential to improve the accuracy of any path-loss based location technology. Access to RTT as an optional parameter has great benefit to RF pattern matching, as well as ECID and should be and it is anticipated that this measure will be requested as an optional parameter.

10 Conclusions

<Editor's note: Text in this section is cited from the original text in 'A.8'>

10.1 RF pattern matching technologies

This section is reiterated in Annex A.8 and provides detailed information on the potential benefits, as well as the implications, of the inclusion of RF pattern matching in the UTRAN. As a result of the evaluation contained herein, it can be shown that:

- RF pattern matching provides a significant improvement in performance to Cell-ID with RTT
    - o Average simulated improvement was 47.3%
    - o Highest simulated improvement was 259%
- RF pattern matching operates with limited impact on the network or UE
    - o No network hardware requirements
    - o No UE modifications
- Anticipated Changes have benefit for other location methods
    - o IPDL – Also needed for OTDOA

- o RTT – Also benefits Cell-ID, OTDOA and UTDOA

There are growing market segments for location services that require both location accuracy and user transparency (Government Surveillance and Lawful Intercept); these services cannot be addressed with location technologies which require UE support or modification (A-GPS, GNSS, OTDOA). Additionally, Emergency Service applications require a level of location accuracy which has not been met with Cell-ID and RTT. The potential benefits of RF pattern matching and and the relative ease with which this location method can be adopted in the UTRAN would indicate that it is appropriate that the technology be included in the UTRAN in support of the services noted above, as well as for cooperatve deployment with satellite-based systems (A-GPS, GNSS, etc.) in support of "Hybrid" location technology for Location Based Services (LBS).

Annex A (Informative): RF pattern matching

A.1 Overview

RF pattern matching uses an established database of the network's RF characteristics and compares the RF parameters that are seen by the UE to this database to determine the UE's location. One type of RF Pattern matching technology (known as Wireless Location Signatures) has been widely deployed in 2G GSM networks in support of the US E-911 emergency services requirements. That RF pattern matching gas performed successfully in 2G does not necessarily imply good performance in 3G. However, as this technology is not affected by channel bandwidth or most other differences in air interfaces, it is reasonable to assume that this technology might present similar performance characteristics in 3G UMTS. The primary goal on this annex will be to test this assumption and to determine if this specific technology warrants further allocation of time and resources in the 3GPP.

This Annex should:

- Describe pattern matching and outline it's benefits and challenges.
- Illustrate the required messaging to support RF pattern matching technologies, as well as the projected performance improvements associated with additional messaging/measurement support.
- Confirm the performance capability of RF pattern matching Technology on the UMTS air-interface, over all environments. Both in terms of accuracy and location result latency:
    - o Dense Urban
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- Illustrate the Standardized architecture for RF pattern matching technologies as related to the UMTS and future air interfaces.
- Provide an outline of anticipated standardization requirements for improved performance and interoperability of RF pattern matching technologies.
- Provide a conclusion based on the information contained herein and a recommendation to the 3GPP regarding standardization of RF pattern matching Technologies within the RAN.

A.2 Feasibility of RF pattern matching technologies for location on UMTS

A.2.1 General description of RF pattern matching technologies

Pattern matching technologies represent a family of Path Loss based technologies that rely on matching the RF environment (as experienced by the UE) to the known characteristics of the larger RF System in which the UE is operating. Information from the UE, including measurements of neighbour cell signal strengths, time delay and other network parameters form the basis of the RF environment to be compared to the established System RF Database. The intent of this approach is to mitigate the negative impacts of anomalies within the RF environment that challenge the accuracy of trilateration technologies (e.g. multipath and reflection).

A.2.1.1 Data elements used in RF pattern matching location calculation

The RF pattern matching positioning method is based on measurements made by the UE and Node B. The essential measurement set required for this method is currently defined in [25.215] and necessary for the basic mobility functionality and hence this method will work with existing mobiles without any modification.

A.2.1.1.1 Data necessary for operation of RF pattern matching

The following intra-frequency signal strength measurements of the Common Pilot Channel (CPICH RSCP) for all measurable cells along with identifier of the cells in terms of either just the UCIDs and/or the Primary Scrambling Code of the CPICH is necessary for the RF pattern matching positioning method

A.2.1.1.1.1 Received Signal Code Power (RSCP) ([TS 25.215 [7] clause 5.1.1])

- Received power on one code measured on the Common Pilot Channel (CPICH)
- A downlink measurement, carried out by the UE
- Can be obtained in idle mode and active mode

A.2.1.1.2 Data that would enhance the performance of RF pattern matching

One of the strengths of the pattern matching positioning method is that it is straightforward to introduce new measurements and their corresponding uncertainty into its structure, and assuming they convey some new information, they will improve performance. The following measurements improve the performance of the method:

A.2.1.1.2.1 PRACH Propagation delay ([25.215 [7] clause 5.2.10])

- Propagation delay is defined as one-way propagation delay as measured during PRACH access.
- In principle, it is difference between the transmission time of AICH access and the time of reception of the beginning (the first detected path, in time) of the PRACH message from the UE at PRACH access slot ([25.215 clause 5.2.10]).

A.2.1.1.2.2 UTRA carrier Received Signal Strength (RSS) ([25.215 [7] clause 5.1.3])

- The received wide band power, including thermal noise and noise generated in the receiver
- RSSI describes the downlink interference level at the UE side
- Measurable by the UE
- Can be measured in active mode only

A.2.1.1.2.3 SFN-SFN observed time difference ([25.215 [7] clause 5.1.9])

- Time Difference of System Frame Numbers (SFN) between Two cells
- Measured in idle mode or active mode by the UE

A.2.1.1.2.4 Round Trip Time (RTT) ([25.215 [7] clause5.2.8])

- Corresponds to the Timing Advance Parameter in GSM
- Difference between The time of transmission of the beginning of a downlink DPCH or F-DPCH frame to a UE and the time of reception of the beginning (the first detected path, in time) of the corresponding uplink DPCCH frame from the UE.
- Measurements are possible on Downlink DPCH transmitted from NodeB and Uplink DPDCH received in the same NodeB.
- Measured in active mode only

A.2.1.1.2.5 UE Rx-Tx time difference ([25.215 [7] clause 5.1.10])

The difference in time between the UE uplink DPCCH frame transmission and the first detected path (in time), of the downlink DPCH or F-DPCH frame from the measured radio link.

Type 1 and Type 2 are defined. For Type 1, the reference Rx path shall be the first detected path (in time) amongst the paths (from the measured radio link) used in the demodulation process.

For Type 2, the reference Rx path shall be the first detected path (in time) amongst all paths (from the measured radio link) detected by the UE.

In addition to these measurements, the following additional measurements optionally supported by some networks can be used by the positioning method

- Inter-RAT signal strength measurements ([25.331 section 14.3])

Inter-frequency measurements of the Common Pilot Channel (CPICH RSCP) for all measurable cells.

A.2.1.2 Air interface ramifications on RF pattern matching technologies

A.2.1.2.1 UMTS-specific impacts on RF pattern matching

RF pattern matching Technologies are passive technologies that depend on the measurements made by the UE and the network as a regular part of their operation. There are no physical-layer impacts from this technology and the technology currently operates using existing messaging mechanisms. The technology is a SAS-centric, network-based, location technology and messages are routed to the SAS through the I_{upc} interface (see section A.5.1 for implementation architecture).

A.2.1.2.2 Confirmation of UE neutrality with RF pattern matching technologies

As RF pattern matching technologies are intended to operate with existing defined network measurements. This technology group will be completely neutral to the UE. The location method will operate with <u>all</u> UE's, inclusive of legacy terminals that do not support A-GPS, OTDOA, or other UE-assisted or UE-based location technologies. No changes to the UE are required for proper operation and performance of RF pattern matching.

A.3 Evaluated performance of RF pattern matching technologies on UMTS

A.3.1 Simulation methodology

A.3.1.1 Overview

In the following sections, a simulation methodology is provided to evaluate the location accuracy of RF pattern matching against a baseline of CELL-ID + RTT. The simulation tool also provides information on the improvements that can be achieved with the availability of RSCP measurements, in terms of increased accuracy of a location estimate. It is suggested that the simulation methodology and flows are used as the foundation of further study.

A.3.1.2 Network model

The simulation uses the standard hexagonal distribution of cellular towers shown in Figure A.3.1.2. Each tower is assumed to have the same number of sectorized cells at the same angular orientations. The user may specify the tower spacing, the number of cells per tower, the orientation of the alpha cell, and the beamwidth of each antenna.

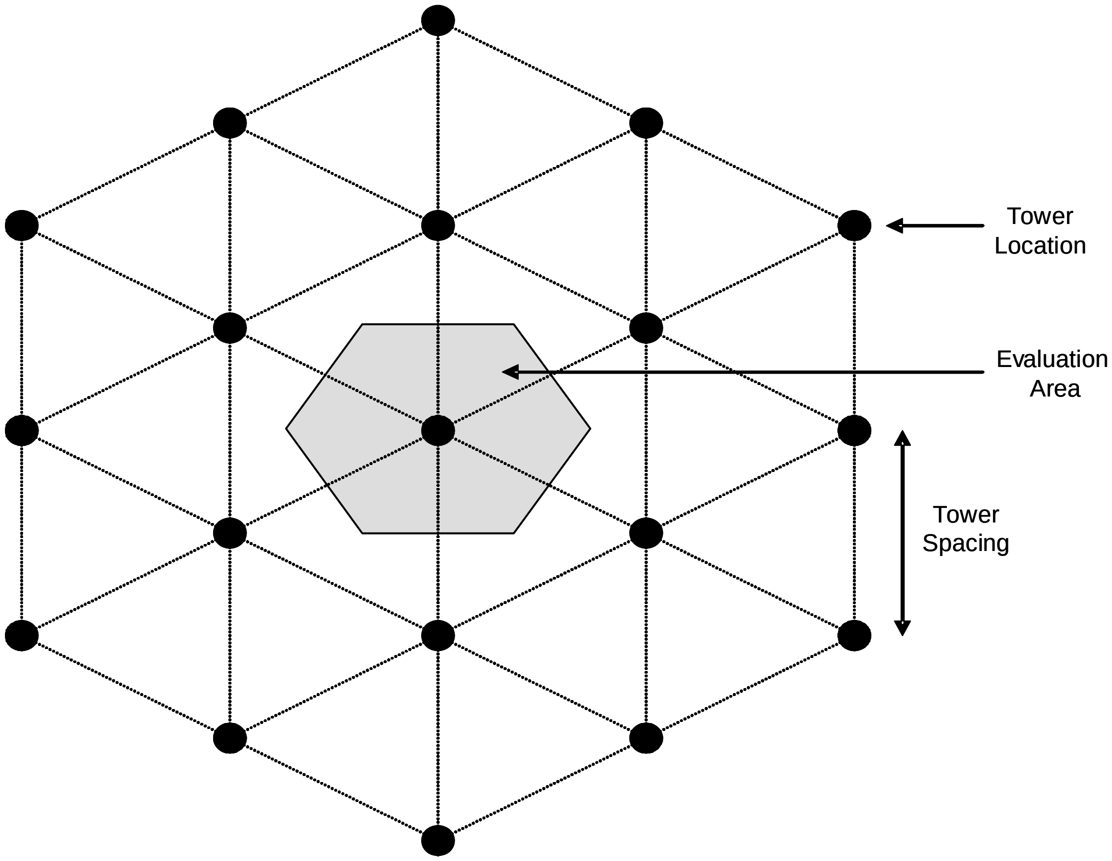

Figure A.3.1.2 - Network 'Configuration'.

The simulation models both event-based and periodic reporting by the handset. In terms of network and handset behaviour, the user may specify the maximum number of cell in the active set, the minimum E_c / I_0 needed for detection, the threshold for requesting addition to the active set, and the fraction of total channel power contributed by traffic. For periodic reporting, the user may also specify the length of the call and the time interval between measurement reports.

A.3.1.3 Location methods

The simulation models the accuracy of two general methods of calculating the location of a handset in a UMTS network:

- **CellID-RTT:** In this method, the network measures the round trip time (RTT) for each cell in the active set. This measurement is used to calculate the distance of the handset from the corresponding cell. The intersection of these RTT circles is taken to be the location of the handset. If there is only one cell in the active set, the estimate is taken to be the intersection of the RTT circle with the antenna boresite.

- **Pattern matching:** This method also uses the RTT measurements as measures of the handset's distance from the cells in the active set. But in addition, it compares the signal strengths for all reported cells (both active and monitored) with a database of predicted signal strengths to derive additional measures of the handset's location. The details of how the RTT and RSCP measurements are combined vary from implementation to implementation. Some implementations also use temporal processing to further refine the location estimate when multiple measurement reports are available (either because of multiple events or periodic reporting).

Models for the location accuracy of these two methods are given in the next Section.

A.3.1.4 Error models

The location accuracy models in this simulation are based on covariance analysis, assuming that the general location systems can be modeled as the solution to a nonlinear optimization problem. We assume that we have a vector of measurements of the form:

$$y = h(x_0) + v$$

where x_0 is the true handset location and v is a zero-mean Gaussian error vector with covariance vector R. The location estimate is the argument that minimizes:

$$J = \left\| y - h(x) \right\|^2_{R^{-1}}$$

In other words, the location estimate satisfies the nonlinear equation:

$$\frac{\partial J}{\partial x} = -2\left[y - h(x) \right]^T R^{-1} \frac{\partial h(x)}{\partial x} = 0$$

To calculate the location error, we linearize this equation about the true handset location:

$$\begin{aligned} \frac{\partial J}{\partial x} &= -2\left[y - h(x - x_0 + x_0) \right]^T R^{-1} \frac{\partial h(x)}{\partial x} \\ &\cong -2\left[y - h(x_0) - \frac{\partial h(x_0)}{\partial x}(x - x_0) \right]^T R^{-1} \frac{\partial h(x_0)}{\partial x} \end{aligned}$$

$$\begin{aligned} x - x_0 &= \left(\frac{\partial h(x_0)^T}{\partial x} R^{-1} \frac{\partial h(x_0)}{\partial x} \right)^{-1} \frac{\partial h(x_0)^T}{\partial x} R^{-1}(y - h(x_0)) \\ &= \left(\frac{\partial h(x_0)^T}{\partial x} R^{-1} \frac{\partial h(x_0)}{\partial x} \right)^{-1} \frac{\partial h(x_0)^T}{\partial x} R^{-1} v \end{aligned}$$

The error covariance associated with this estimate is then given by:

$$\begin{aligned} P &= \mathrm{cov}(x - x_0) \\ &= E((x - x_0)(x - x_0)^T) \\ &= \left(\frac{\partial h(x_0)^T}{\partial x} R^{-1} \frac{\partial h(x_0)}{\partial x} \right)^{-1} \frac{\partial h(x_0)^T}{\partial x} R^{-1} R R^{-1} \frac{\partial h(x_0)}{\partial x} \left(\frac{\partial h(x_0)^T}{\partial x} R^{-1} \frac{\partial h(x_0)}{\partial x} \right)^{-1} \\ &= \left(\frac{\partial h(x_0)^T}{\partial x} R^{-1} \frac{\partial h(x_0)}{\partial x} \right)^{-1} \end{aligned}$$

If the measurement error covariance is assumed to be diagonal, this error covariance can be re-written as the inverse of a sum of outer products:

$$P = \left(\sum_i \frac{1}{\sigma_i^2} \frac{\partial h_i(x_0)^T}{\partial x} \frac{\partial h_i(x_0)}{\partial x} \right)^{-1}$$

where σ_i is the standard deviation of the i^{th} measurement. To obtain a scalar measure of the location error, we use:

$$\sigma_{LOC} = \sqrt{trace(P)}$$

In other words, the error sigma is the root sum square of the major and minor axes of the covariance ellipse.

A.3.2 CellID-RTT method

The CellID-RTT method uses each RTT measurement to calculate the distance from the cell to the handset. Although RTT is actually reported in chips, the simulation simply assumes that it is a direct distance measurement:

$$d_{RTT} = \sqrt{(x_{HS} - x_{CELL})^T (x_{HS} - x_{CELL})}$$

where x_{HS} is the handset location and x_{CELL} is the cell location. The partial derivative of this measurement equation is:

$$\frac{\partial d_{RTT}}{\partial x_{HS}} = \frac{(x_{HS} - x_{CELL})^T}{d_{RTT}}$$

which is a unit vector in the direction from the cell to the handset. Nominally the RTT measurement has no sensitivity in the cross-range direction. However, for a sectorized cell, the width of the antenna beam provides some restrictions on the cross-range error. With this assumption, the simulation uses:

$$\left(\frac{\partial d_{RTT}}{dx_{HS}}\right)^T \frac{1}{\sigma_{RTT}^2}\left(\frac{\partial d_{RTT}}{dx_{HS}}\right) + \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}\left(\frac{\partial d_{RTT}}{dx_{HS}}\right)^T \frac{1}{(1.5 \times d_{RTT} \times 0.5BW)^2}\left(\frac{\partial d_{RTT}}{dx_{HS}}\right)\begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$$

as the contribution of one RTT measurement to the inverse of the location error covariance, where *BW* is the antenna beamwidth. This will result in an uncertainty ellipse that is very narrow in the down-range direction and very long (but not infinite) in the cross-range direction. The RTT measurement sigma and the antenna beamwidth are user-specified simulation inputs.

A.3.3 RF pattern matching method

In order to keep the simulation independent of any company's proprietary algorithms, the simulation uses Hata models to represent the RSCP signature models used by the pattern matching method. This model is given by:

$$RSCP = RSCP_{REF} - \alpha \times 10 \times \log_{10}(d / d_{REF}) - a$$

where α is the pathloss exponent and

$$d = \sqrt{(x_{HS} - x_{CELL})^T (x_{HS} - x_{CELL})}$$
$$a = 0.5 \times FBR \times (1 - \cos(\theta_{HS} - \theta_{CELL}))$$

and where x_{HS} is the handset location, x_{CELL} is the cell location, *FBR* is the front-to-back ratio, θ_{HS} is the angle to the handset, and θ_{CELL} is the angle of the antenna boresite (both angles measured positive counterclockwise from the x-axis. After some tedious algebra, we find that:

$$\frac{\partial RSCP}{\partial x_{HS}} = -\frac{10}{\ln(10)} \times \frac{\alpha}{d} \times [\cos\theta_{HS} \ \sin\theta_{HS}] - 0.5 \times FBR \times \sin(\theta_{HS} - \theta_{CELL}) \times \frac{1}{d}[-\sin\theta_{HS} \ \cos\theta_{HS}]$$

Because of the possibility of an unknown bias between the handset signal strength measurements and the predicted signal strengths, the simulation uses a relative signal strength formulation for the RSCP measurements instead of an absolute signal strength formulation. This approach is informationally equivalent to assuming a common bias in an absolute signal strength formulation, estimating that bias at every point, and substituting it back into the original cost function. The simulation uses:

$$\sigma_{RSCP}^2 + \sigma_{MDL}^2$$

as the variance of the total RSCP error, where σ_{RSCP} represents the measurement error and σ_{MDL} represents the signature modeling error.

The pattern matching method uses the same uncertainty contributions for RTT measurements as the Cellid-RTT method, so that:

$$P^{-1}_{PATTERN\_MATCHING} = P^{-1}_{CELLID\_RTT} + P^{-1}_{RSCP}$$

As a result, the CellID-RTT location error covariance forms an upper bound on the pattern matching error covariance.

A.3.3.1 Simulation tool inputs

Table A.3.3.1 – Simulation tool inputs

Input	Description
tower_spacing	distance between towers (m)
cells_per_tower	number of cells on each tower
azimuth	azimuth of boresite of alpha sector on tower (deg)
sigrssi	rssi uncertainty (measurement error and channel model error) (dB)
sigmdl	rssi modeling error
sigrtt	rtt uncertainty (m)
beamwidth	cell beamwidth (deg)
rssiref	reference signal strength at distance dref from cell on cell boresite (dBm)
dref	reference distance (m)
gamma	pathloss exponent (dB)
fbr	front-to-back ratio (dB)
loading_factor	fraction of additional power created by traffic channels
decode_threshold	EcIo needed to decode signal
soft_handoff_threshold	rssi below primary cell needed for addition to active set (dB)
max_active	maximum number of cells in active set
numcaserssi	number of rssi draws at each location
numcasedet	number of detection order draws at each location
sample_spacing	distance between samples (m)

A.3.3.2 Detailed simulation flow

The simulation evaluates the location accuracy performance of the CellID-RTT method and the pattern matching method on a uniform grid of points in the evaluation region shown in Figure 1. The grid spacing is specified by the user. At each evaluation point the simulation performs the following calculations:

1) Determine the nominal RSCP value for each of the cells in the network using the propagation model described in the Appendix. These nominal values represent the RSCP signature model used by the pattern matching method.

2) For each cell, draw a random number from a Gaussian distribution and add it to the nominal RSCP value for that cell to represent the true RSCP value for the cell at that location. The standard deviation of this RSCP error is a simulation input specified by the user. This step is performed a user-specified number of times, and the following calculations are performed each time:

   a) Calculate the total channel power I_o, including the effect of traffic at the evaluation point.

   b) Determine which cells have enough E_cI_o to be decoded by the handset. If no cells can be decoded at this point, terminate this iteration because no call can be made with this set of RSCP values.

   c) Determine which cell is strongest and designate that cell as the serving cell for this call. Restrict the list of other cells that are candidates for handset reporting to those on the serving cell's Neighbor List that can be decoded.

   d) Determine which of the reporting candidates are within the soft handoff threshold of the serving cell's RSCP. These cells are candidates for inclusion in the active set.

   e) For each cell that is a reporting candidate, draw a random number from a uniform [0, 1] distribution. Sort the cells according to these random numbers. This sorted list represents the order in which the handset detects cells on its Neighbor List on this call. This step is performed a user-specified number of times, and the following calculations are performed each time:

i) Take cells from this detection list in order until either all candidates for the active set have been selected or the maximum number of active cells has been reached, whichever comes first. The set of cells selected represents the cells whose RSCP would be reported by the handset in event-driven reporting. The network would calculate RTT for every cell is this set that was a candidate for inclusion in the active set.

ii) For the set of cells reported on this call, calculate the location accuracy for the CellID-RTT method and the pattern matching method using the error models described in the Appendix.

The simulation saves the average location accuracy for the two methods for each evaluation point. These values can be displayed geographically, as a CDF (cumulative distribution function) curve, or as a set of summary statistics.

A.3.4 Propagation models

A.3.4.1 Hata propagation model

Hata's well know model covers the frequency band between 150 MHz and 1000 MHz. It is formulated as

Equation 1

$$L = 69.55 + 26.16\log\frac{f}{Mhz} - 13.82\log(\frac{h_{BASE}}{m}) - a(h_{Mobile}) + (44.9 - 6.55\log\frac{h_{BASE}}{m})\log\frac{d}{km}$$

where

$$a(h_{Mobile}) = (1.1\log\frac{f}{MHz} - 0.7)\frac{h_{Mobile}}{m} - (1.56\log\frac{f}{MHz} - 0.8)$$

Restrictions on both model are:

h_{base}: 30 to 200m

h_{Mobile}: 1 to 10m

D:1 to 20km

A.3.4.2 COST231 propagation model

COST 231 has extended Hata´s model to the frequency band between 1500 MHz and 2000 MHz. It is formulated as:

Equation 2

$$L = 46.3 + 33.9\log\frac{f}{Mhz} - 13.82\log(\frac{h_{BASE}}{m}) - a(h_{Mobile}) + (44.9 - 6.55\log\frac{h_{BASE}}{m})\log\frac{d}{km} + C_m$$

where

$$a(h_{Mobile}) = (1.1\log\frac{f}{MHz} - 0.7)\frac{h_{Mobile}}{m} - (1.56\log\frac{f}{MHz} - 0.8)$$

and

C_m is 0 dB for medium sized city and suburban centers with medium tree density or 3 dB for metropolitan centres.

A.3.5 Cramer-Rao lower bound formulation

A.3.5.1 RSS measurement model

For the RSS-based location method, the RSS database is built from a simple propagation model, as shown in Equation 3. All control channels are predicted in the database building phase. In the real-time location phase, another set of measurements is made by the handset. Only *M* channels are measured and reported via the NMR. RSS measurements from these *M* channels are used to compare with RSS values in the database. The position of the closest match is the location estimate. For a specified location

$\mathbf{z} = [x, y]^T$, a measurement on channel *i* can be expressed as

Equation 3

$$m_i = c + P_i(z) + e_i$$

where

c is a constant offset resulting from the RF properties and propagation path

z is location vector $[x, y]^T$

$P_i(z)$ is averaged power received at location z.

e_i is measurement error and propagation variance

Because the $P_R = P_T + G_R + G_T - L + C_{dB}$

where

P_R - power received by a handset (dBm)

P_T - power transmitted by a sector (dBm)

G_R - estimated measurement equipment antenna gain (dBi)

G_T - estimated sector antenna gain (dBi)

C_{dB} - constant offset (dB)

We can separate the location related term and location unrelated term and assign them to $P_i(z)$, the location related term, or the constant c, the location unrelated term to have the following formula:

$$m_i = c + P_i(z) + e_i$$

$$P_i(z) = -(44.9 - 6.55\log\frac{h_{BASE}}{m})\log\frac{d}{m}$$

For the frequency band 150Mhz to 1000Mhz,

$$c = P_T + G_R + G_T + C_{dB} - \left(69.55 + 26.16\log\frac{f}{Mhz} - 13.82\log(\frac{h_{BASE}}{m}) - a(h_{Mobile}) - (44.9 - 6.55\log\frac{h_{BASE}}{m}) * 3\right)$$

For the frequency band 1500Mhz to 2000Mhz,

$$c = P_T + G_R + G_T + C_{dB} - \left(46.3 + 33.9\log\frac{f}{Mhz} - 13.82\log(\frac{h_{BASE}}{m}) - a(h_{Mobile}) - (44.9 - 6.55\log\frac{h_{BASE}}{m}) * 3 + C\right)$$

Considering that one handset measures M channels from all surrounding base stations in each

NMR, all measurements form a vector:

Equation 4

$$\vec{m} = c_{m1}\vec{O} + \vec{P}(z) + \vec{e}$$

where

$$\begin{array}{lll} \vec{m} & \stackrel{\Delta}{=} [m1, m2, \ldots, m_M] & \text{Measurement of channel 1 ... M} \\ c_{m1} & \stackrel{\Delta}{=} c & \text{Common bias term for all observations} \\ \vec{O} & \stackrel{\Delta}{=} [1,1,\ldots,1]^T & \text{Observation vector, length M} \\ \vec{P}(z) & \stackrel{\Delta}{=} [P_1(z), P_2(z), \ldots, P_M(z)]^T & \text{RSS in pattern database} \\ \vec{e} & \stackrel{\Delta}{=} [e_1, e_2, \ldots, e_M]^T & \text{Random Error term} \end{array}$$

A.3.5.2 RSS location algorithm – relative signal strength

In RSS location algorithm, we assume perfect knowledge of the common bias term of all observations c_{m1}. The bias is removed by subtracting a constant from reported signal strength. The location decider is:

Equation 5

$$z = \arg\left(\min\left(\left\| \vec{m} - \vec{P}(z) - c_{m1}\vec{O} \right\|^2 \right) \right)$$

In practice, the common bias term of all observations is unknown and the bias is different from handset to handset. Thus, the unknown bias must be estimated from measurements using relative signal strength method as follow:

$$\hat{c}_{m1} = \frac{1}{M}\sum_{i=1}^{M}\left(\vec{m}_i - \vec{P}_i(z) \right)$$

This is actually the same as if we use LMS method to estimate the bias constant. As an analytical result, we use the following method to estimate the unknown bias:

Equation 6

$$\hat{c}_{m1} = \left(\vec{O}^T\vec{O} \right)^{-1}\vec{O}^T\left(\vec{m} - \vec{P}(z) \right) = \frac{\vec{O}^T}{M}\left(\vec{m} - \vec{P}(z) \right)$$

Inserting **Equation 6** back into **Equation 5** forms an expression of the error term:

Equation 7

$$\begin{aligned} \vec{e} &= \vec{m} - \vec{P}(z) - \vec{O}\frac{\vec{O}^T}{M}\left(\vec{m} - \vec{P}(z) \right) \\ &= \left(I - \vec{O}\frac{\vec{O}^T}{M} \right)\left(\vec{m} - \vec{P}(z) \right) \\ &= R\left(\vec{m} - \vec{P}(z) \right) \end{aligned}$$

where

$$R = I - \vec{O}\frac{\vec{O}^T}{M}$$

Therefore, the location decider is

Equation 8

$$\mathrm{z} = \arg\left(\min\left(\left\| R\left(\vec{m} - \vec{\mathrm{P}}(\mathrm{z})\right) \right\|^2 \right) \right)$$

A.3.5.3 Derivation of the Fisher Information Matrix and Cramer Rao Lower Bound for path loss measurement

The error vector, **e**, is a normally distributed multivariate random vector with zero mean and a positive definite covariance matrix, **Ce**. The conditional probability density function of the measurement is given by

Equation 9

$$p(m \mid z) = \frac{1}{(2\pi)^{\frac{M}{2}} \left\| C_e \right\|^{\frac{1}{2}}} \exp\left(-\frac{1}{2} e^T (C_e)^{-1} e \right)$$

Inserting Equation 8 into Equation 9 yields

Equation 10

$$p(m \mid z) = \frac{1}{(2\pi)^{\frac{M}{2}} \left\| C_e \right\|^{\frac{1}{2}}} \exp\left(-\frac{1}{2} \left[R\left(\vec{m} - \vec{P}(z)\right) \right]^T (C_e)^{-1} \left[R\left(\vec{m} - \vec{P}(z)\right) \right] \right)$$

The Fisher information matrix is simplified to.

Equation 11

$$\mathrm{FIM} = -E \begin{pmatrix} \frac{\partial^2 \ln p(m \mid z)}{\partial x^2} & \frac{\partial^2 \ln p(m \mid z)}{\partial x \partial y} \\ \frac{\partial^2 \ln p(m \mid z)}{\partial y \partial x} & \frac{\partial^2 \ln p(m \mid z)}{\partial y^2} \end{pmatrix} = \begin{pmatrix} p_x{}^T C_r p_x & p_x{}^T C_r p_y \\ p_y{}^T C_r p_x & p_y{}^T C_r p_y \end{pmatrix}$$

$$\text{Where} \quad C_r = R^T C_e{}^{-1} R, \quad p_x = \frac{\partial p(z)}{\partial x}, \quad p_y = \frac{\partial p(z)}{\partial y}$$

Assume all errors are independent identically distributed (i.i.d), such as the covariance matrix $C_e = \sigma^2 (I)$, then

Equation 12

$$C_e = R^T \left(\sigma^2 (I) \right)^{-1} R = \frac{1}{\sigma^2} R^T R = \frac{1}{\sigma^2} R$$

The Cramer-Rao lower bound is given by the inverse of the Fisher matrix

Equation 13

$$Cov_{cr} = inv\begin{pmatrix} p_x{}^T Rp_x & p_x{}^T Rp_y \\ p_y{}^T Rp_x & p_y{}^T Rp_y \end{pmatrix} = \frac{\sigma^2 \begin{pmatrix} p_x{}^T Rp_x & -p_x{}^T Rp_y \\ -p_y{}^T Rp_x & p_y{}^T Rp_y \end{pmatrix}}{\left(p_x{}^T Rp_x\right)\left(p_y{}^T Rp_y\right) - \left(p_x{}^T C_r p_y\right)\left(p_y{}^T C_r p_x\right)}$$

Equation 14

$$Cov_{cr} = inv\left(\left[p_x \quad p_y\right]^T R\left[p_x \quad p_y\right]\right)$$

$$[P_x]_i = \frac{\partial\left|-\left(22.45\ -3.275\ *\log(\mathrm{hB})\ \right)\log(e)\ln\left(\left(x_i - x\right)^2 + \left(y_i - y\right)^2\right)\right|}{\partial x}$$

$$= (44.9\ -6.55\ *\log(\mathrm{hB})\ )\log(e)\frac{x_i - x}{\left(x_i - x\right)^2 + \left(y_i - y\right)^2} = K * \cos(\theta)$$

$$[P_y]_i = \frac{\partial\left|-\left(22.45\ -3.275\ *\log(\mathrm{hB})\ \right)\log(e)\ln\left(\left(x_i - x\right)^2 + \left(y_i - y\right)^2\right)\right|}{\partial y}$$

$$= (44.9\ -6.55\ *\log(\mathrm{hB})\ )\log(e)\frac{y_i - y}{\left(x_i - x\right)^2 + \left(y_i - y\right)^2} = K * \sin(\theta)$$

where xi ,yi are location of the i-th base station,

$K = (44.9 - 6.55 * \log(\mathrm{hB}))\log(e)$,

θ is the angle between [x_i-x,y_i-y] and [1,0]

A.3.5.4 Derivation of Fisher Information Matrix for RTT measurement

When we have RTT measurement, we assume the error in the RTT measurement is independent from the error in the RSS measurement. The derivation is similar with that in derivation of FIM for path loss measurement.

Equation 15

$$RTT\_\mathrm{distance} = RTT_i * c = \sqrt{\left(x - x_i\right)^2 + \left(y - y_i\right)^2} + \frac{T_{Handset-Delay}}{2} + e_{RTT-Error}$$

Because each RTT measurement is measured regarding to the active cell, we can define $\tilde{x} = x - x_i$ where x' have the same unit vector as x, and $\tilde{y} = y - y_i$ where y' have the same unit vector as y.

Equation 16

$$e_{RTT-Error} = RTT\_\mathrm{distance} - \sqrt{\left(\tilde{x}\right)^2 + \left(\tilde{y}\right)^2} - \frac{T_{Handset-Delay}}{2}$$

Where the $e_{RTT-Error}$ item is assume to be i.i.d random variable with normal distribution. Therefore

Equation 17

$$p(m \mid z) = \frac{1}{\left(2\pi\right)^{\frac{M}{2}} \left\|C_e\right\|^{\frac{1}{2}}} \exp\left(-\frac{1}{2} e_{RTT\_Error}{}^T \left(C_e\right)^{-1} e_{RTT\_Error}\right)$$

where M is the number of available RTT measurements

Because errors are i.i.d random variables, $C_e = \sigma_1^2(I)$

Equation 18

$$p(RTT\_\text{distance} \mid z) = \frac{1}{(2\pi)^{\frac{M}{2}} \sigma_1^2} \exp\left(-\frac{1}{2\sigma_1^2} e_{RTT\_Error}{}^T e_{RTT\_Error} \right)$$

The Fisher information matrix is simplified after inserting **Equation 18** into **Equation 11.**

Equation 19

$$\text{FIM} = -E\begin{pmatrix} \frac{\partial^2 \ln p(m \mid z)}{\partial \tilde{x}^2} & \frac{\partial^2 \ln p(m \mid z)}{\partial \tilde{x} \partial \tilde{y}} \\ \frac{\partial^2 \ln p(m \mid z)}{\partial \tilde{y} \partial \tilde{x}} & \frac{\partial^2 \ln p(m \mid z)}{\partial \tilde{y}^2} \end{pmatrix} = \frac{1}{\sigma_1^2} \begin{pmatrix} p_{\tilde{x}}{}^T p_{\tilde{x}} & p_{\tilde{x}}{}^T p_{\tilde{y}} \\ p_{\tilde{y}}{}^T p_{\tilde{x}} & p_{\tilde{y}}{}^T p_{\tilde{y}} \end{pmatrix}$$

$$p(z) = RTT\_\text{distance} - \sqrt{(\tilde{x})^2 + (\tilde{y})^2} - \frac{T_{Handset-Delay}}{2}$$

where

$$p_x = \frac{\partial p(z)}{\partial x} = \frac{\tilde{x}}{\sqrt{(\tilde{x})^2 + (\tilde{y})^2}} = \cos(\theta)$$

$$p_y = \frac{\partial p(z)}{\partial y} = \frac{\tilde{y}}{\sqrt{(\tilde{x})^2 + (\tilde{y})^2}} = \sin(\theta)$$

θ is the angle between vector [$x-x_i$,$y-y_i$] and vector [1,0]

This can also be thought of as the RTT measurement uncertainty has been split in to x and y direction.

A.3.5.5 Information matrix for RTT measurement from a directional sector

When the cell are sectored, there are another piece of information that the cell should be in the direction of the main beam, which gives the following,

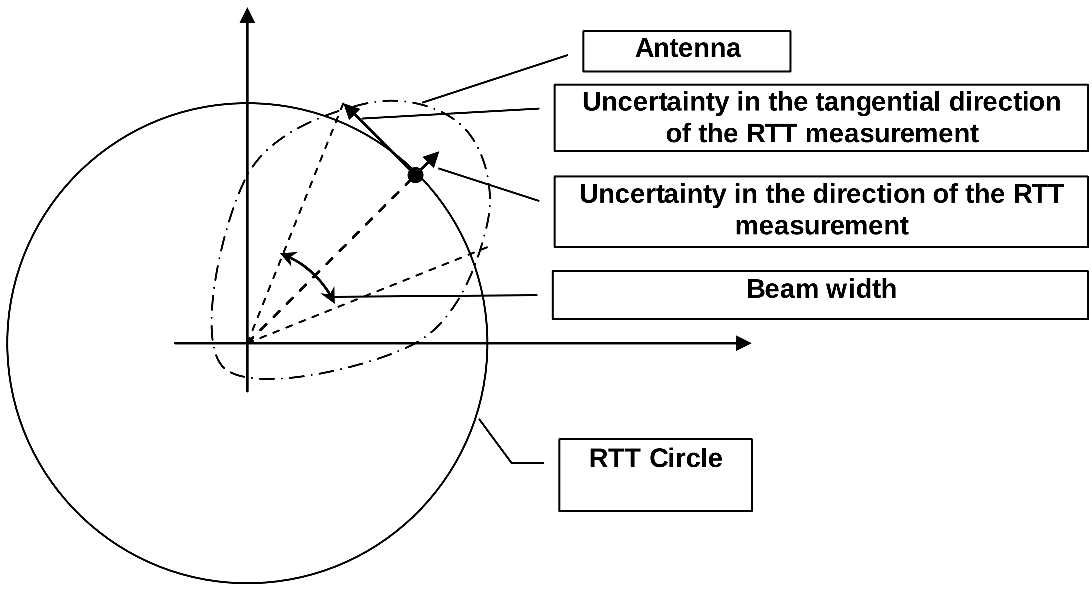

Figure A.3.5.5: Measurement from a directional sector

The uncertainty using the directional sector is given by $\sqrt{(x - x_i)^2 + (y - y_i)^2} * \tan(\frac{beamwidth}{2})$

Then we can also split this uncertainty into x and y direction by defining the following equations:

$$\text{FIM} = \frac{1}{\sigma_1^2}\begin{pmatrix} p_x{}^T p_x & p_x{}^T p_y \\ p_y{}^T p_x & p_y{}^T p_y \end{pmatrix}$$

$$\sigma_1^2 = \sqrt{(x-x_i)^2 + (y-y_i)^2} * \tan(\frac{beamwidth}{2})$$

Where

$$p_x = -\sin(\theta)$$

$$p_y = \cos(\theta)$$

A.3.5.6 The Fisher Information Matrix and the CRLB for RTT measurement + path loss measurement

When we have both Fisher Information Matrix from RTT measurement and Path Loss measurement, we can form a new Fisher Information Matrix by sum them together because we assume the measurement errors are independent between this two types of measurement.

The CRLB is the inverse of the Fisher information matrix.

If we define the location variance of the estimator to be $\sigma_d^2 = \sigma_x^2 + \sigma_y^2$.

The CRLB asserts that

$$\sigma_d^2 \geq tr\{Cov_{cr}\}$$

Therefore we can link the base station locations, measurement errors in RSS, number of NMRs with the accuracy of RSS pattern matching method. When the Location Engine perform the best the accuracy of pattern matching should approach the lower limit provided by the CRLB.

A.5 Network architecture for RF pattern matching technologies on UMTS

A.5.1 UMTS architecture for RF pattern matching technology

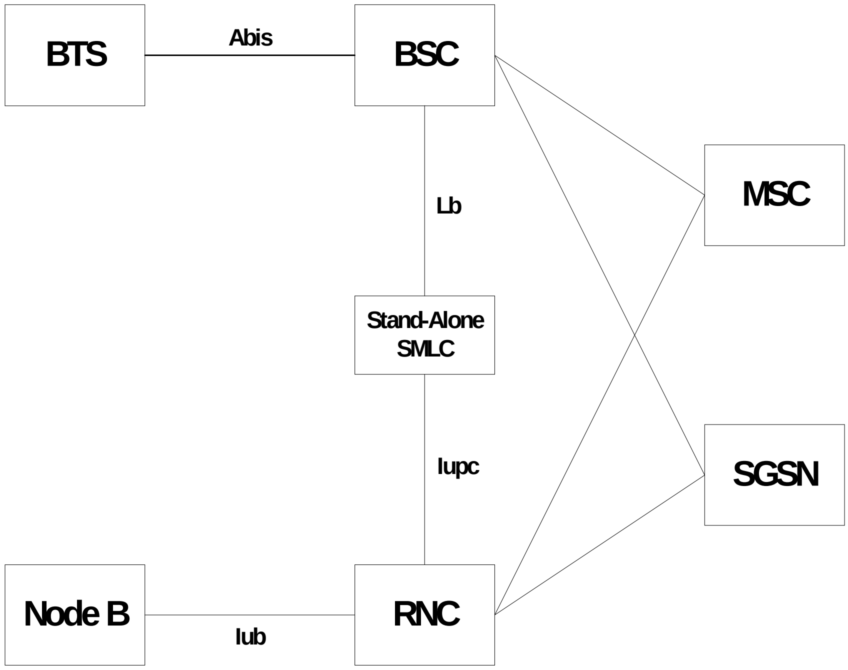

Figure A.5.1: Overlay architecture for RF pattern matching

RF pattern matching Technology is a network-based technology that is implemented through a Stand-Alone SMLC (SAS), which can be a shared element in a GSM/UMTS overlay network (as shown above). In this respect, the network architecture needed to support RF Pattern matching is similar to that currently envisioned for the support of UTDOA (although the technology itself is software-based and does not require the hardware or independent backhaul network that is needed for UTDOA). The architecture above represents a control-plane implementation of RF pattern matching; it should be noted that the technology has also been implemented in User-plane.

A.6 Evaluated performance of RF pattern matching technologies on UMTS

The following scenarios, with associated cell spacings, building and terrain assumptions, are to be evaluated in this set of simulations:

1 Dense Urban Simulation

  a. Approximate cell spacing – 500m

  b. Buildings – assume +20 story buildings with dense spacing

  c. Terrain – assume relatively small topographic diversity (flat terrain)

2 Suburban Simulation

  a. Approximate cell spacing – 2 to 3 km

  b. Buildings – assume >3 story buildings with moderate spacing (most buildings should be 1 story)

  d. Terrain – assume moderate topographic diversity (normal terrain)

3 Rural Simulation

a. Approximate cell spacing – 7 to 10 km

b. Buildings – assume no buildings

c. Terrain – assume moderate topographic diversity (normal terrain)UMTS

4 Mountain Simulation

a. Approximate cell spacing – 3 to 7 km

b. Buildings – assume no buildings

c. Terrain – use terrain data for typical market

The simulation tool provides the following input parameters with associated definitions:

Table A.6 – Simulation tool inputs

Input	Description
tower_spacing	distance between towers (m)
cells_per_tower	number of cells on each tower
azimuth	azimuth of boresite of alpha sector on tower (deg)
sigrssi	rssi uncertainty (measurement error and channel model error) (dB)
sigmdl	rssi modeling error
sigrtt	rtt uncertainty (m)
beamwidth	cell beamwidth (deg)
rssiref	reference signal strength at distance dref from cell on cell boresite (dBm)
dref	reference distance (m)
gamma	pathloss exponent (dB)
fbr	front-to-back ratio (dB)
loading_factor	fraction of additional power created by traffic channels
decode_threshold	EcIo needed to decode signal
soft_handoff_threshold	rssi below primary cell needed for addition to active set (dB)
max_active	maximum number of cells in active set
numcaserssi	number of rssi draws at each location
numcasedet	number of detection order draws at each location
sample_spacing	distance between samples (m)

Adjustment of these parameters (e.g. tower_spacing) allows the various simulation evaluation cases to be modelled.

A.6.1 RF pattern matching accuracy evaluation

A.6.1.1 Simulation results for evaluation scenarios

A.6.1.1.1 Dense urban simulation

The following simulation parameters were used for the dense urban evaluation:

Table A.6.1.1.1 – Dense urban simulation inputs

Input	Parameter
tower_spacing	500m
cells_per_tower	3
azimuth	0 (deg)
sigrssi	1 (dB)
sigmdl	6 (dB)
sigrtt	50 (m)
beamwidth	120 (deg)
rssiref	-68.7 (dBm)
dref	100m
gamma	3.57 (dB)
fbr	30 (dB)
loading_factor	0
decode_threshold	-20 (dB)
soft_handoff_threshold	6(dB)
max_active	3
numcaserssi	3
numcasedet	3
sample_spacing	10 (m)

noise floor = -127 dBm

The simulation results for the urban evaluation case comparing pattern matching to Cell-ID/RTT are as follows.

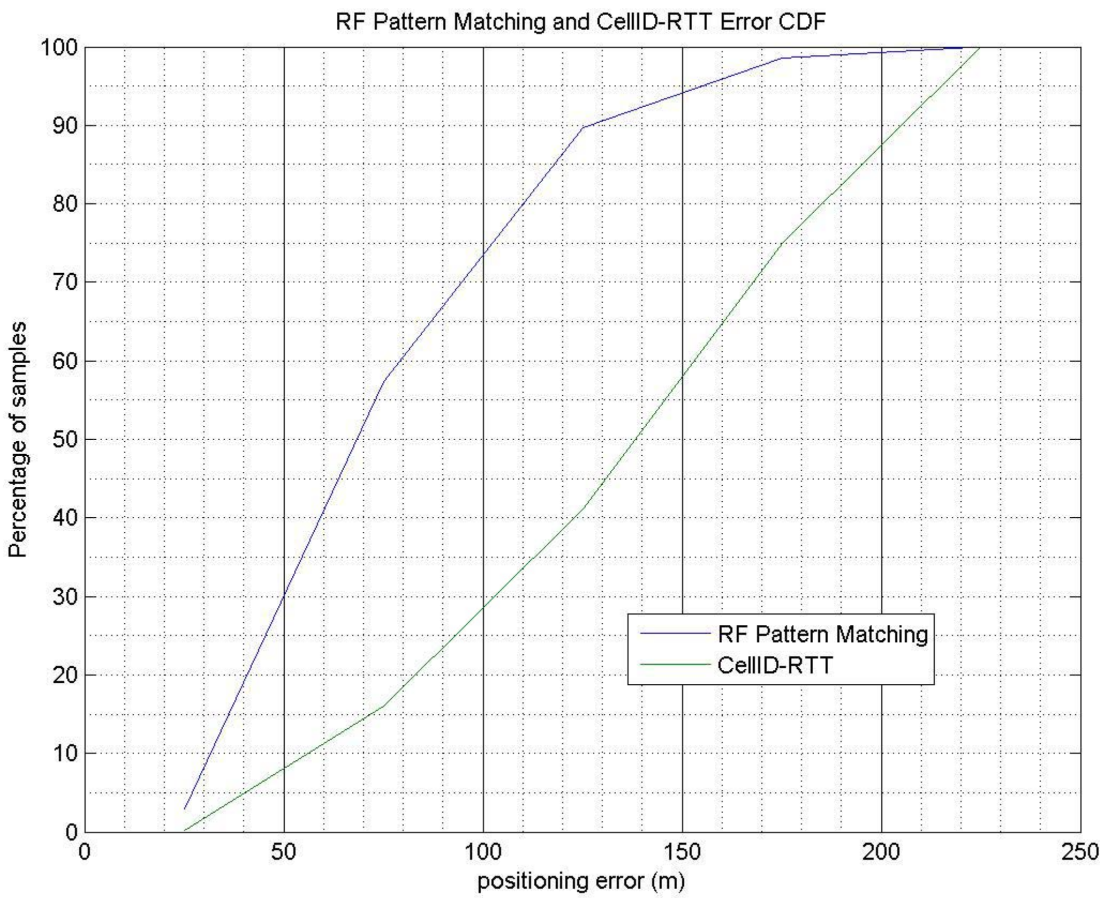

Figure A.6.1.1.1. Position error Cumulative Distribution Function (CDF) from simulations for dense urban evaluation case comparing pattern matching versus Cell-ID/RTT.

Note from the simulation results in Figure A.6.1.2 that RF pattern matching provides performance vs. Cell-ID/RTT of a factor of approximately (1.8X) and a factor of approximately (1.64X) in the location errors at the 67th and 95th

percentiles, respectively. These simulation results demonstrate significant dense urban improvements from RF pattern matching compared to Cell-ID/RTT.

A.6.1.2.1 Suburban simulation

The following simulation parameters were used for the suburban evaluation:

Table A.6.1.2.1 – Suburban simulation inputs

Input	Parameter
tower_spacing	3000m
cells_per_tower	3
azimuth	0 (deg)
sigrssi	1 (dB)
sigmdl	6 (dB)
sigrtt	50 (m)
beamwidth	120 (deg)
rssiref	-56.4 (dBm)
dref	100m
gamma	3.57 (dB)
fbr	30 (dB)
loading_factor	0
decode_threshold	-20 (dB)
soft_handoff_threshold	6(dB)
max_active	3
numcaserssi	3
numcasedet	3
sample_spacing	50 (m)

noise floor = -127 dBm

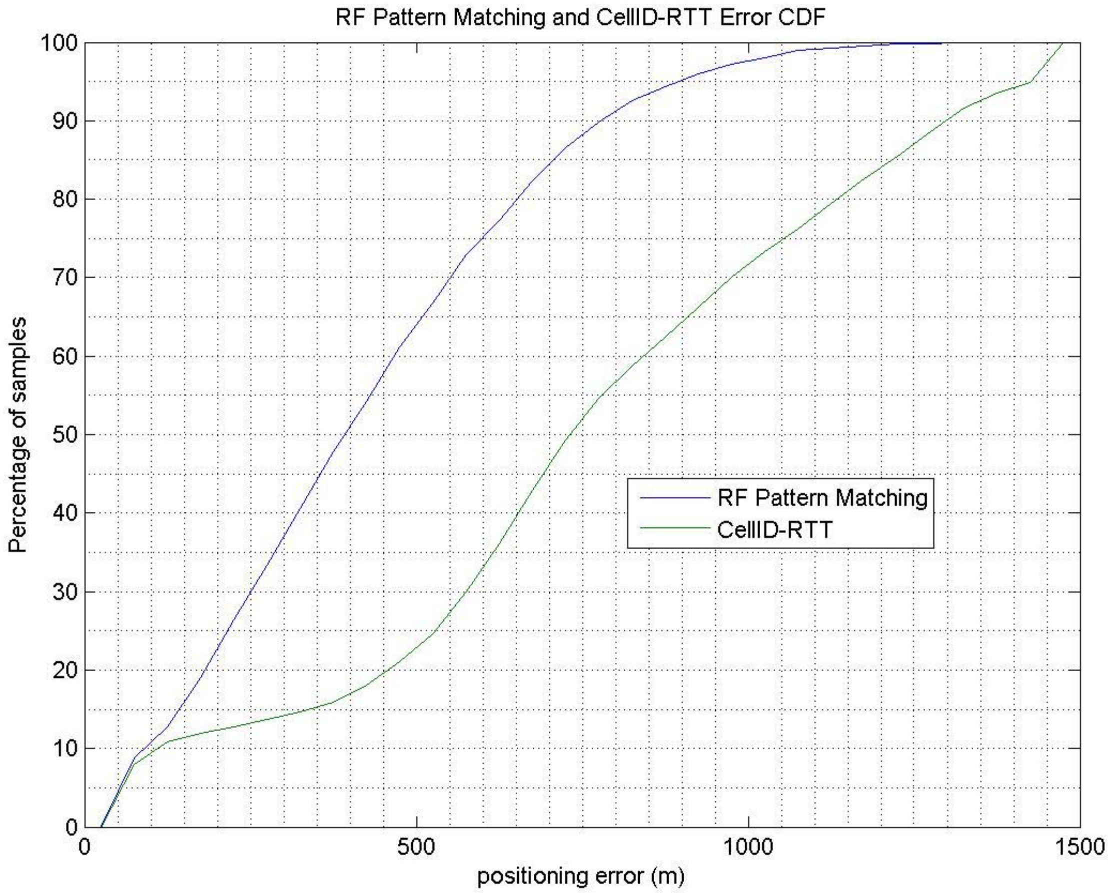

Figure A.6.1.2.1 - Position error Cumulative Distribution Function (CDF) from simulations for suburban evaluation case comparing pattern matching versus Cell-ID/RTT.

Note from the simulation results in Figure A.6.1.3 that pattern matching provides performance vs Cell-ID/RTT of a factor of approximately (1.77X) and a factor of approximately (1.65X) in the location errors at the 67th and 95th percentiles, respectively. These simulation results demonstrate significant suburban improvements from pattern matching compared to Cell-ID/RTT.

A.6.1.2.2 Rural simulation

Table A.6.1.2.2 – Rural simulation inputs

Input	Parameter
tower_spacing	10000m
cells_per_tower	3
azimuth	0 (deg)
sigrssi	1 (dB)
sigmdl	6 (dB)
sigrtt	50 (m)
beamwidth	120 (deg)
rssiref	-36.2 (dBm)
dref	100m
gamma	3.57 (dB)
fbr	30 (dB)
loading_factor	0
decode_threshold	-20 (dB)
soft_handoff_threshold	6(dB)
max_active	3
Numcaserssi	3
Numcasedet	3
sample_spacing	100 (m)

noise floor = -127 dBm

Figure A.6.1.4 - Position error Cumulative Distribution Function (CDF) from simulations for rural evaluation case comparing pattern matching versus Cell-ID/RTT.

Note from the simulation results in Figure A.6.1.4 that pattern matching provides performance vs Cell-ID/RTT of a factor of approximately (1.83X) and a factor of approximately (1.58X) in the location errors at the 67th and 95th percentiles, respectively. These simulation results demonstrate significant dense urban improvements from pattern matching compared to Cell-ID/RTT.

A.6.1.2.3 Mountain simulation

Table A.6.1.2.3 – Mountain simulation inputs

Input	Parameter
tower_spacing	5000m
cells_per_tower	3
azimuth	0 (deg)
sigrssi	3(dB)
sigmdl	6 (dB)
sigrtt	50 (m)
beamwidth	120 (deg)
rssiref	-56.2 (dBm)
dref	100m
gamma	3.57 (dB)
fbr	30 (dB)
loading_factor	0
decode_threshold	-20 (dB)
soft_handoff_threshold	6(dB)
max_active	3
Numcaserssi	3
Numcasedet	3
sample_spacing	100 (m)

noise floor = -127 dBm

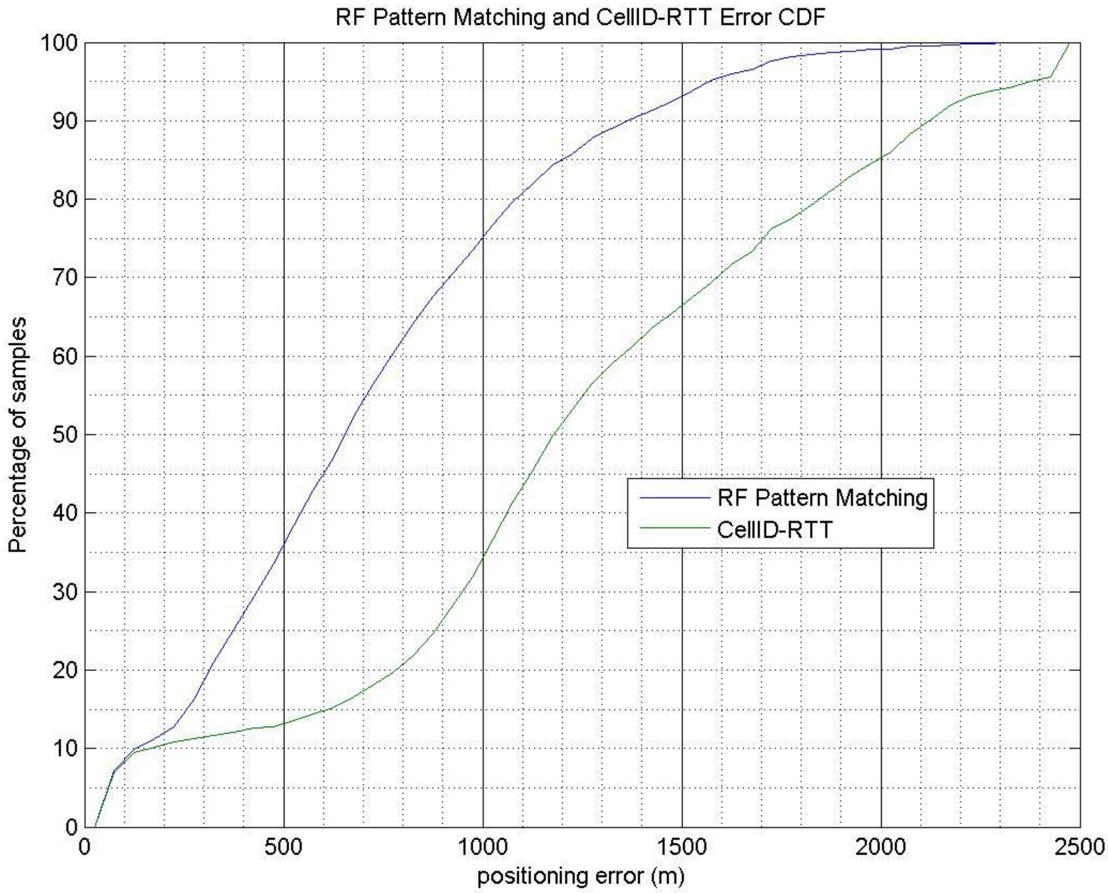

Figure A.6.1.2.3 - Position error Cumulative Distribution Function (CDF) from simulations for mountainous evaluation case comparing pattern matching versus Cell-ID/RTT.

Note from the simulation results in Figure A.6.1.5 that pattern matching provides improvements over Cell-ID/RTT of a factor of approximately (2.59X) and a factor of approximately (1.56X) in the location errors at the 67th and 95th percentiles, respectively. These simulation results demonstrate significant dense urban improvements from pattern matching compared to Cell-ID/RTT.

A.6.2.1 Additional independent simulations - TeleCommunication Systems (TCS)

A.6.2.1.1 Overview

The results presented in this section were completed using the methodology described in section A.3 of this TR. These results were obtained for the various environments listed in the following section, in terms of site spacing and system characteristics. TCS warrants the veracity of these results, based on the model provided.

A.6.2.1.2 Simulation results

Table 6.2.1.2: TCS simulation parameters

Parameter	Dense Urban	Urban	Suburban	Rural
Tower Spacing (m)	500	1000	3000	10000
Cells Per Tower	3	3	3	3
Azimuth of Alpha Sector	0	0	0	0
Sigma of RSSI (dB)	4	4	4	4
Sigma of RSSI Model (dB)	6	6	6	6
Sigma of RTT (m)	70	70	50	50
Reference RSSI (dBm)	-30	-30	-30	-30
Reference Distance (m)	100	100	100	100
P.L. Exponent	4	4	3.5	3.25
Front to Back Ratio	20	20	20	20
Loading Factor	0	0	0	0
Soft Handoff Factor (dB)	6	6	6	6
Decode Threshold (dB)	-20	-20	-20	-20
Sample Spacing	10	20	20	60
Beam Width	120	120	120	120
Active Set Max Size	3	3	3	3
Number of RSSI Cases	3	3	3	3
Number of Det Case	3	3	3	3

Table 6.2.1.2.a: TCS results

		Pathloss	CellID-RTT	Pathloss Improvement
Dense Urban	67^{th} % (m)	128	200	36%
	95^{th} % (m)	176	265	34%
Urban	67^{th} % (m)	224	362	38%
	95^{th} % (m)	334	509	34%
Suburban	67^{th} % (m)	573	934	39%
	95^{th} % (m)	910	1412	35%
Rural	67^{th} % (m)	1682	2739	39%
	95^{th} % (m)	5421	7653	29%

A.6.2.2 Additional independent simulations - AT&T

A.6.2.2.1 Overview

The results presented in this section were completed using the methodology described in section A.3 of this TR. These results were obtained for the various environments listed in the following section, in terms of site spacing and system characteristics. AT&T warrants the veracity of these results, based on the model provided.

A.6.2.2.2 Simulation results

Table 6.2.2.2: ATT simulation parameters

Parameter	Dense Urban	Urban	Suburban	Rural
Tower Spacing (m)	500	1000	3000	10000
Cells Per Tower	3	3	3	3
Azimuth of Alpha Sector	0	0	0	0
Sigma of RSSI (dB)	5	5	5	5
Sigma of RSSI Model (dB)	4	4	4	4
Sigma of RTT (m)	62	125	375	1000
Reference RSSI (dBm)	-68.7	-68.7	-56.4	-36.2
Reference Distance (m)	100	100	100	100
P.L. Exponent	5	4	3	2
Front to Back Ratio	30	30	30	30
Loading Factor	6	4	2	0
Soft Handoff Factor (dB)	6	6	6	6
Decode Threshold (dB)	-20	-20	-20	-20
Sample Spacing	10	25	50	100
Beam Width	120	120	120	120
Active Set Max Size	3	3	3	3
Number of RSSI Cases	3	3	3	3
Number of Det Case	3	3	3	3

Table 6.2.2.2.a: ATT results

		Pathloss	CellID-RTT	Pathloss Improvement
Dense Urban	67^{th} % (m)	185	221	16%
	95^{th} % (m)	258	280	8%
Urban	67^{th} % (m)	330	415	20%
	95^{th} % (m)	476	544	13%
Suburban	67^{th} % (m)	810	1115	27%
	95^{th} % (m)	1180	1518	22%
Rural	67^{th} % (m)	1784	2867	38%
	95^{th} % (m)	2725	4398	38%

A.7 Anticipated requirements for the standardization of RF pattern matching technologies in 3GPP

A.7.1 Modifications to TS 25.331 [5] (RRC Protocol Specification) include:

- Addition of a pattern matching to UE Positioning description section
- Inclusion of pattern matching in the defined procedures

A.7.2 Anticipated Change Requests

- Inter-RAT
  - Access measurements from both UMTS and underlying GSM networks
  - Increase measurements used for location estimation
    - Suggested only for Emergency Service Applications
- IPDL
  - Increase pilot Ec measurement diversity due to reduction of near-far effect
    - Suggested only for Emergency Service Applications
- Absolute Ec (Sector TX Power)
  - Additional measurement to allow absolute Ec calculation from measured Ec/No ratio
- Round Trip Time (RTT)
  - Increased ability to use RTT in location estimation
  - Provides additional temporal measurements to increase location accuracy

A.8 Conclusions (RF pattern matching)

This Appendix provides detailed information on the potential benefits, as well as the implications, of the inclusion of RF pattern matching in the UTRAN. As a result of the evaluation contained herein, it can be shown that:

- RF pattern matching provides a significant improvement in performance to Cell-ID with RTT
  - Average simulated improvement was 47.3%
  - Highest simulated improvement was 259%
- RF pattern matching operates with limited impact on the network or UE
  - No network hardware requirements
  - No UE modifications
- Anticipated Changes have benefit for other location methods
  - IPDL – Also needed for OTDOA
  - RTT – Also benefits Cell-ID, OTDOA and UTDOA

There are growing market segments for location services that require both location accuracy and user transparency (Government Surveillance and Lawful Intercept); these services cannot be addressed with location technologies which require UE support or modification (A-GPS, GNSS, OTDOA). Additionally, Emergency Service applications require a level of location accuracy which has not been met with Cell-ID and RTT. The potential benefits of RF pattern matching and and the relative ease with which this location method can be adopted in the UTRAN would indicate that it is appropriate that the technology be included in the UTRAN in support of the services noted above, as well as for cooperatve deployment with satellite-based systems (A-GPS, GNSS, etc.) in support of "Hybrid" location technology for Location Based Services (LBS).

Annex B: Change history

Change history							
Date	**TSG #**	**TSG Doc.**	**CR**	**Rev**	**Subject/Comment**	**Old**	**New**
2008-09	3GPPRAN4#48	R4-082416			Baseline TR skeleton with Overview and Verbiage addition to sections A.1 and A.5 of the Study Item.	0.0.0	0.0.1
2009-01	3GPPRAN4#48	R4-090056			Verbiage addition to section A.2.1 and A.3 of the Study Item		
2009-02	3GPPRAN4#50	R4-090788			Verbiage addition to section A.2.1.1 of the Study Item		
2009-03	3GPPRAN4#50bis	R4-091341			Verbiage addition to section A.6 of the Study Item		
2009-08	3GPPRAN4#52	R4-093432			Presentation to plenary for information	0.4.0	0.5.0
2009-08	3GPPRAN4#52	R4-09xxx			Editorial modifications on section 1 to 10.	0.5.0	0.5.1
2009-09	3GPPRAN#45	RP-090763			TR submitted to Plenary as Informational pending final approval of citings in RAN4	0.5.1	1.0.0
2009-09	3GPPRAN4#52bis	R4-093955			Text Proposal to add citings from Annex A into sections 1, 4, 5.1, 6.1, 7.1, 9.1, and 10	1.0.0	1.1.0
2009-09	3GPPRAN4#52bis	R4-094079			Text Proposal to add verbiage into section 9.1	1.1.0	1.2.0
2009-11	3GPPRAN4#53	R4-094692			Final Approval of TR by RAN 4	1.2.0	1.2.0
2009-12	RAN#46	RP-091144			Final Approval of TR by RAN	2.0.0	9.0.0
2010-01					Editorial clean up	9.0.0	9.0.1

History

Document history		
V9.0.1	February 2010	Publication