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Title: Comparison of Time Aligned IPDL and IPDL Positioning Techniques Using Common Simulation Parameters

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Introduction

At present there are three main proposals for downlink location in UMTS: TA-IPDL [1], IPDL [2]and downlink measurements without idle periods [3]. However, comparison of the performance achievable by different location techniques is not a simple task. To this end, basic system scenarios have been agreed, and some initial results have been presented [4 ,5]. These appeared to show relatively little difference between systems. However, additional work has been carried out since the last TSG-RAN Working Group 1 meeting towards defining scenarios and examining assumptions.

This document presents an updated set of results, which suggest that there are significant differences in the levels of performance between techniques. In particularly, it illustrates and explains the difference in performance between TA-IPDL and IPDL.

The network simulator results are presented as the radial error of the position estimate of a mobile compared to the true position of the mobile. These results have been generated by a network level simulator, using common parameters that have been agreed upon since the last TSG-RAN Working Group 1 meeting.

Also presented is a C/I+N analysis of the pilot signals received by a MS within the network whilst performing location measurements for standard UMTS operation, IPDL and TA-IPDL. Single link time of arrival (TOA) results under such C/I+N conditions are also analysed in order to understand the relative performance of the different location techniques.

Given the short time frame for release 99, we feel that it would be sensible to enable different operation modes for downlink measurements under a common framework. We note that all methods require the mobile to schedule measurements of the common pilot from multiple BTSs and to make time of arrival estimates on those measurements. This suggests that the signaling to the UE and the operation required by the UE could be made common, allowing the network operator to deploy whichever location solution they require. It is also our opinion that all three solutions can co-exist in a single network – perhaps with the enhanced techniques being deployed in specific areas only. This document does not explore this possibility, and concentrates on the performance aspects.

Network Simulator

The network simulator used to generate the results in this document incorporates a regular hexagonal layout of Base Stations (BS) sites as illustrated in figure 1.

A target mobile is repeatedly dropped in sector 0 of site 0 at regularly spaced points until all areas of the cell have been covered. At each point the position of the mobile is estimated for a number of independent draws. In the results presented in this document the number of regularly spaced positions is 279, and 5 independent draws are made at each position.

Position estimation is performed by making relative time of arrival (TOA) estimates of signals from visible BSs at the MS and passing these measurements to a fixing algorithm. In time aligned IP-DL, measurements are made from all cells during the common idle period.

The network simulator incorporates the common simulation parameters that are described in Table 1. In addition the following assumptions have been made:

- TOA estimates from the serving site are available outside of the idle period. It is assumed that 10 TOA estimates are available from the serving site during normal operation of the MS. Although implemented in these simulations for both techniques, in TA-IPDL this is not necessary as measurements can be collected from all sites during the common idle period.
- No Round Trip Time (RTT) information has been assumed, as it is not certain whether this measurement will be available. Also, mobiles in the idle state would not be able to use this information anyway.
- No detailed knowledge of the antenna gain profile of the different sectors has been assumed (this would provide angle of arrival information). Where antennas are mounted on buildings or other similar irregular deployment sites (i.e. not a tower) the gain profile must be measured directly. Also any modifications to the deployment of the antennas (tilt etc.) would require new measurements to be made.
- No mobiles are considered to be in handover. Mobiles in handover can potentially make better TOA estimates from the participating BTSs and improve overall location performance. However, this will be true for all techniques with the improvement dependent on implementation of handover in the simulator. As there has been no common simulation parameters discussed for the treatment of handover, it has been ignored.
- When it is not possible to locate the mobile (e.g. not enough TOAs, fixing algorithm divergence etc.) the position of the mobile is estimated to be at the centre of the sector
- For TA-IPDL the assumption is that one complete symbol is lost through the synchronisation process and one complete symbol is lost through geographical factors. The net effect of this is that only three symbols are used in the common idle period. This is a worst case scenario but has been applied to all results.

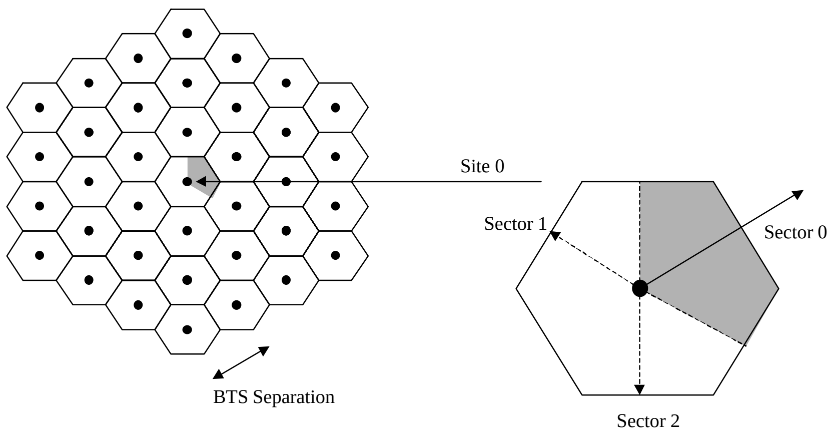


Figure 1 Network Simulator

Idle Period Length	5 * 256 chips
Guard Period Length	256 chips
Average Frequency of Idle Periods	10 Hz
Number of Idle Periods	10
Transmit Probability of TA	0.3
Channel Model	T1P1.5 Models : Rural, Suburban, Urban B, Urban A, Bad Urban
BTS Separation: Urban, Suburban, Rural	1 km, 3 km, 20 km
Pathloss Model	beta + alpha * 10*log(range in metres)
Urban :	alpha = 3.52; beta = 29.03
Suburban :	alpha = 3.48; beta = 22.2
Rural :	alpha = 3.41; beta = 0.34
Signal Used	Common Pilot
Chip Rate	3.84 Mbits/s
Vehicle Speed	50 km/hr
Sampling	1 bit resolution
AGC tuning	N/A
BS Total PA Power	43 dBm
Common Pilot Transmit Power	33 dBm
Maximum Antenna Gain	17 dB
Cable losses	4 dB
Body Losses	3 dB
Lognormal Fading Sigma	8 dB Shadow fading between different sites is considered to be uncorrelated. During the measurement collection period the shadow fading is considered constant for each site
Number of Sectors	3 per site

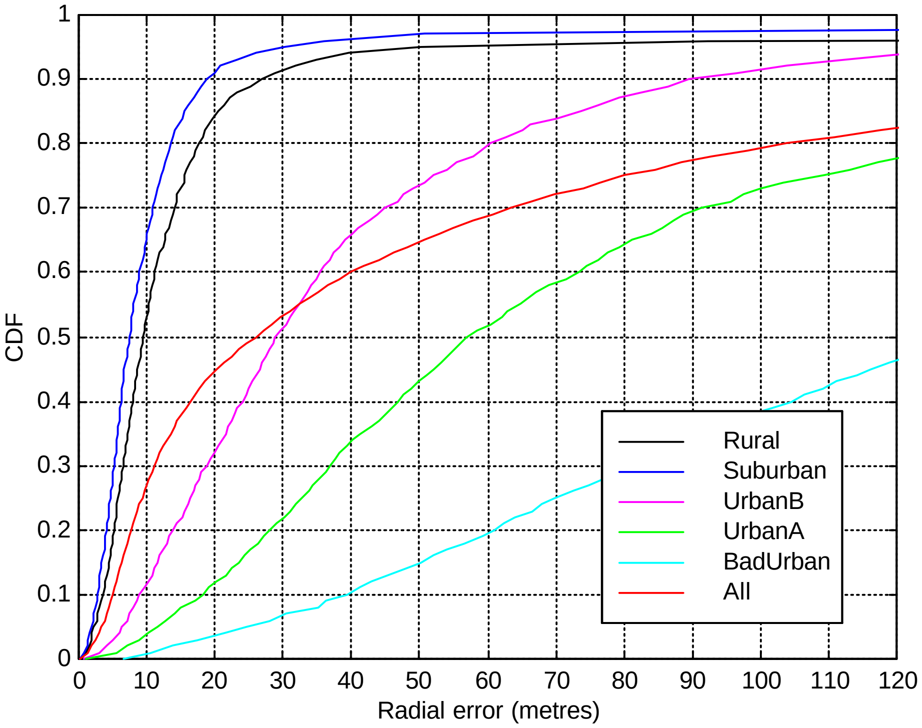
Table 1 Common simulation parameters

Simulation Results

TA-IPDL

The results from the network simulator for TA-IPDL are illustrated below.

Figure 2 illustrates the CDFs of radial error for each of the five environments for TA-IPDL. The 67% error and 95% errors for all measurements are listed in table 2. The pilot power during the common idle period in these simulations is 10% of the transmitted power from the BTS.



	67%	95% error
Rural	13 metres	48 metres
Suburban	10 metres	30 metres
UrbanB	40 metres	131 metres
UrbanA	80 metres	251 metres
Bad Urban	180 metres	440 metres
All environments	54 metres	295 metres

Table 2 67% and 95% radial error for CDFs in Figure 2

IPDL

The results from the network simulator for IPDL are illustrated below.

Figures 3 and 4 illustrate the CDFs of radial error for each of the five environments for IPDL, with a pilot power of 10% of the BTS ERP. Figure 3 shows the performance of IPDL for cases where the location estimate converged to a solution, whereas figure 4 includes all results for the simulation. The 67% error and 95% errors and the percentage of location estimates that gave a result that converged to a solution are listed in table 3.

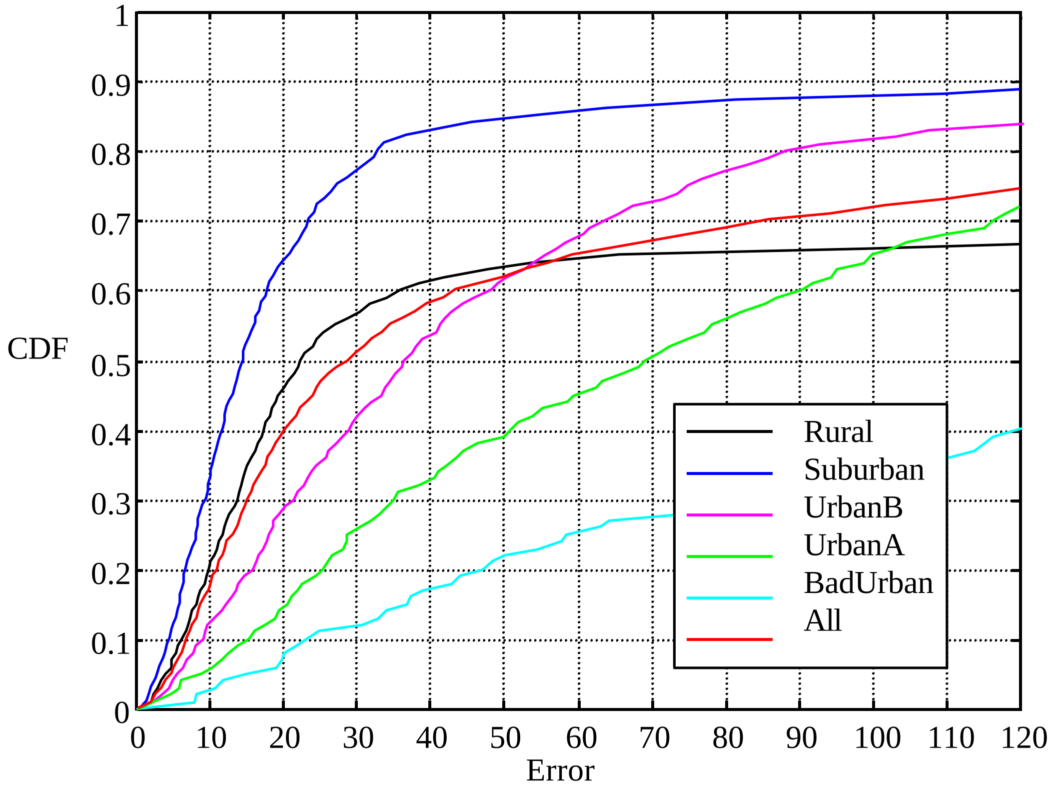


Figure 3 CDFs of radial error for IPDL, 10% pilot power, converged results only

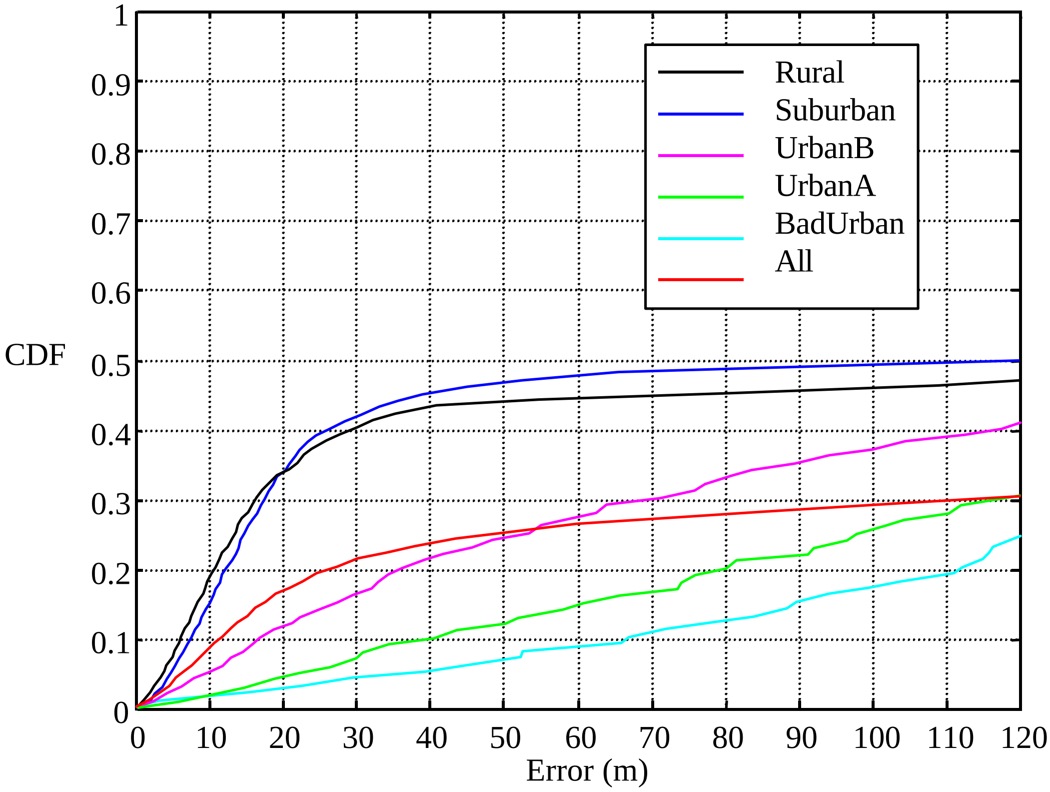


Figure 4 CDFs of radial error for IPDL, 10% pilot power, all results

	Percentage of results that converged	67% error: converged results	67% error: all results	95% error: converged results	95% error: all results
Rural	74%	141 metres	2212 metres	5525 metres	6819 metres
Suburban	51%	22 metres	586 metres	1164 metres	1155 metres
UrbanB	36%	59 metres	217 metres	227 metres	375 metres
UrbanA	25%	108 metres	242 metres	551 metres	385 metres
Bad Urban	13%	264 metres	261 metres	936 metres	388 metres
All	40%	67 metres	551 metres	3456 metres	3370 metres

Table 3 Convergence, 67% and 95% radial errors for CDFs in Figures 6 nd

Analysis of Results

In this section we consider the factors leading to the comparatively poor performance of IPDL under the conditions described in this document, with a view to establishing confidence in the results.

C/I+N Analysis of Network Simulator

The main reason that the performance of the two techniques varies so much lies in the C/(I+N) statistics of the measurements collected by the mobile for location (i.e. the pilot signals from each of the neighbour BTSs collected during the idle period). When the C/(I+N) ratio is too low, it is not possible to estimate an accurate TOA for a link. In order to get a location estimate it is necessary to have relatively accurate TOA measurements from 3+ BTS sites. Therefore, the impact of the C/(I+N) statistics of the second highest neighbour BTS will be investigated.

In figures 5 to 7, CDFs of the C/(I+N) of pilot signals received by the mobile during measurement collection are illustrated for the best three neighbours. Both IPDL and TA-IPDL are considered as well as standard UMTS operation. The environment is urban. For TA-IPDL, as the C/(I+N) is constantly changing during the measurement collection process, the best C/(I+N) from each site is used.

Figure 6 shows that in IPDL the mobile receives location signals from the second 'best' neighbour site which typically has a C/(I+N) between –15 dB and –25 dB. The impact that this has on the TOA estimation process (and therefore location performance) is discussed in the next section.

Another interesting observation from the C/(I+N) statistics is the approximate increase in sensitivity required to:

1. Make the C/(I+N) statistics of standard UMTS operation comparable to IPDL in these simulations. An increase of approximately 13dB would shift the C/(I+N) statistics of standard UMTS operation to become comparable to the C/(I+N) statistics of IPDL. In real terms, this indicates that if the idle period is removed then an increase in measurement time of 20 times is required to achieve a similar baseline performance. Therefore, measurement collection over 10 complete frames (a total time of 62.5ms would be required).
2. Make the C/(I+N) statistics of IPDL operation comparable to TA-IPDL in these simulations. Similarly, an increase of approximately 15dB would shift the C/(I+N) statistics of IPDL to become comparable to the C/(I+N) statistics of TA-IPDL. Taking into account the duty cycle of pilot transmission in TA-IPDL and the total C/(I+N) statistics for TA-IPDL (n.b. in figure 7 only the best C/(I+N) statistics are shown) the increase required is at least 7dB. In real terms, this indicates that the idle period would need to be 5 times longer or 5 times more frequent. Continuing with this analysis back to standard UMTS, a total measurement time of 5 times 62.5ms (i.e. 300ms) would be required to gain the increase in sensitivity to allow for the differences in C/(I+N) statistics.

Admittedly, these are only observations from our simulator but give an important insight into the comparative performance between the different techniques.

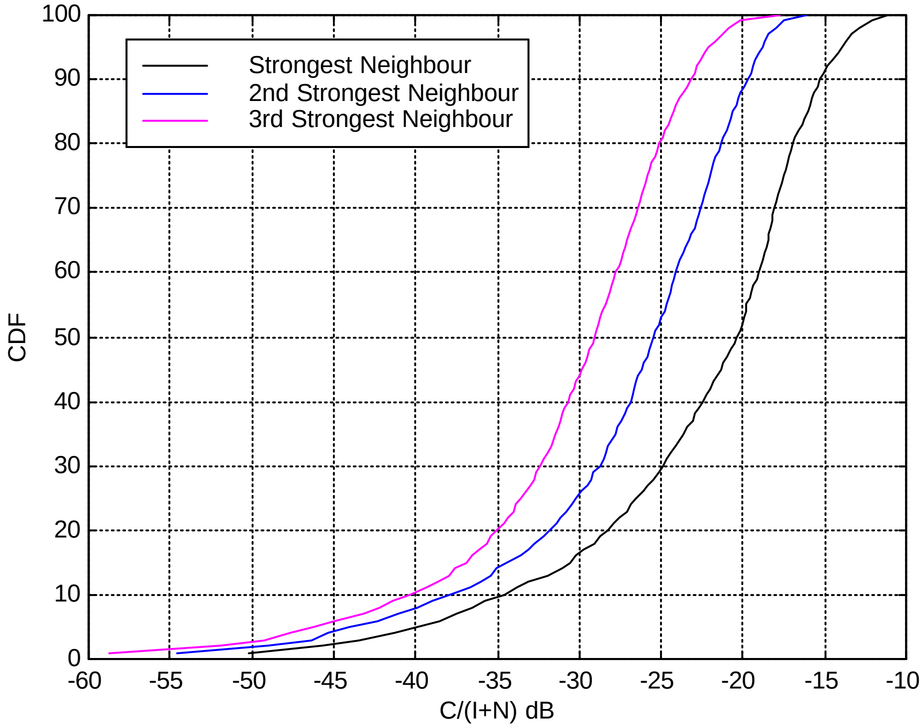


Figure 5 CDFs of C/(I+N) for best three neighbour sites for standard UMTS

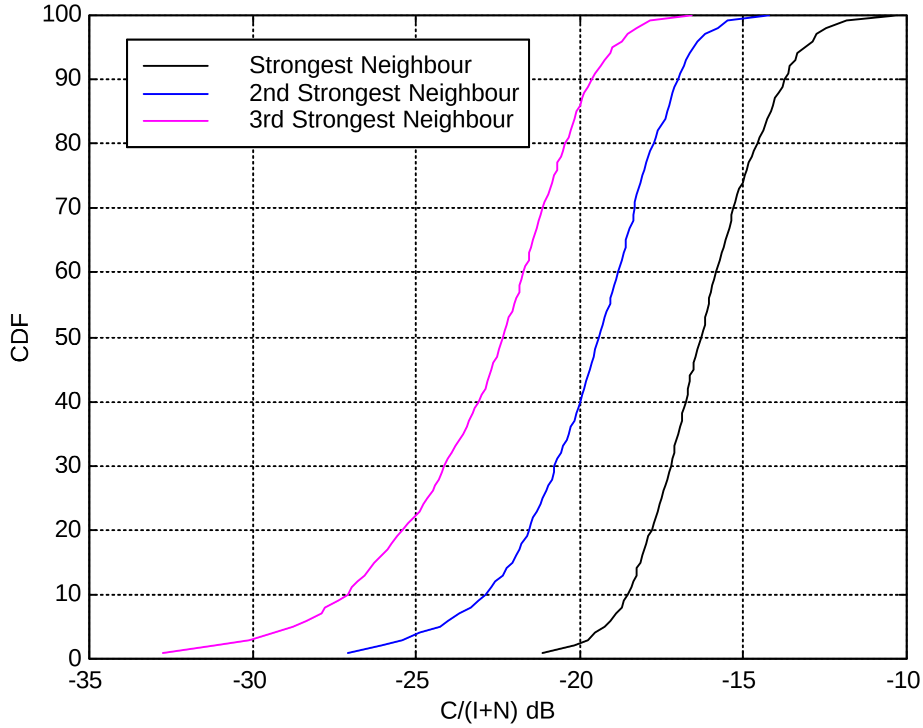


Figure 6 CDFs of C/(I+N) for best three neighbour sites for IPDL

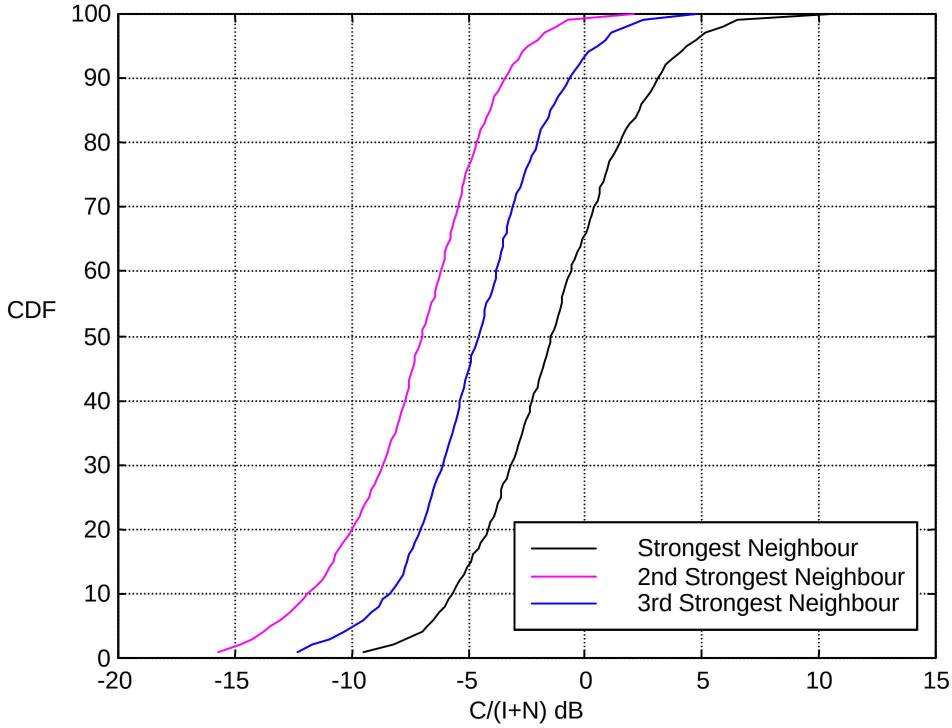


Figure 7 CDFs of C/(I+N) for best three neighbour sites for TA-IPDL

TOA estimators in varying C/I+N conditions

In the previous section it was shown that signals received from the second 'best' neighbour site typically has C/(I+N) values in the range –15dB to –25dB for IPDL. It is this third site (serving site plus two neighbour sites) that is essential for position estimation in a Time Difference Of Arrival (TDOA) based location system.

In order to show the impact of the above result, 'single link' TOA estimation simulations were performed to show the link level performance under varying C/(I+N) conditions. The TOA estimation process is as follows:

1. Signal generated.
2. Signal passed through channel model.
3. Interference is added to give correct C/I.
4. Signal is sampled and correlation is performed.
5. This process is repeated for the 10 'half slots' and the individual correlator outputs are non-coherently integrated.
6. The peak of the combined correlation curve is taken to be the TOA estimate.

The parameters used in the link layer simulation were kept in line with the common simulation parameters as far possible and are listed in table 4.

Idle Period Length	5 * 256 chips (1/2 slot)
Average Frequency of Idle Periods	10 Hz
Number of Idle Periods	10
Channel Model	T1P1.5 Model : Urban A (range in channel model set to 500m) and Line of Sight
Signal Used	Common Pilot
Chip Rate	3.84 Mbits/s
Vehicle Speed	50 km/hr
C/(I+N) Values considered	0, -5, -10, -15, -20, -25 dB
Sampling	16 bit resolution

Table 4 Link layer simulation parameters

The results illustrated in figures 8 and 9 show that the TOA process begins to fail at a C/I values between –10 dB and –15 dB for the UrbanA channel (becoming catastophic by –25 dB) and begins to fail between –15 dB and –20 dB for the line of sight channel.

Given the C/(I+N) analysis of the network for IPDL, it is not surprising that it performs badly under these conditions. In order to gain improvement, more and/or longer idle periods and/or longer measurement collection times would be required.

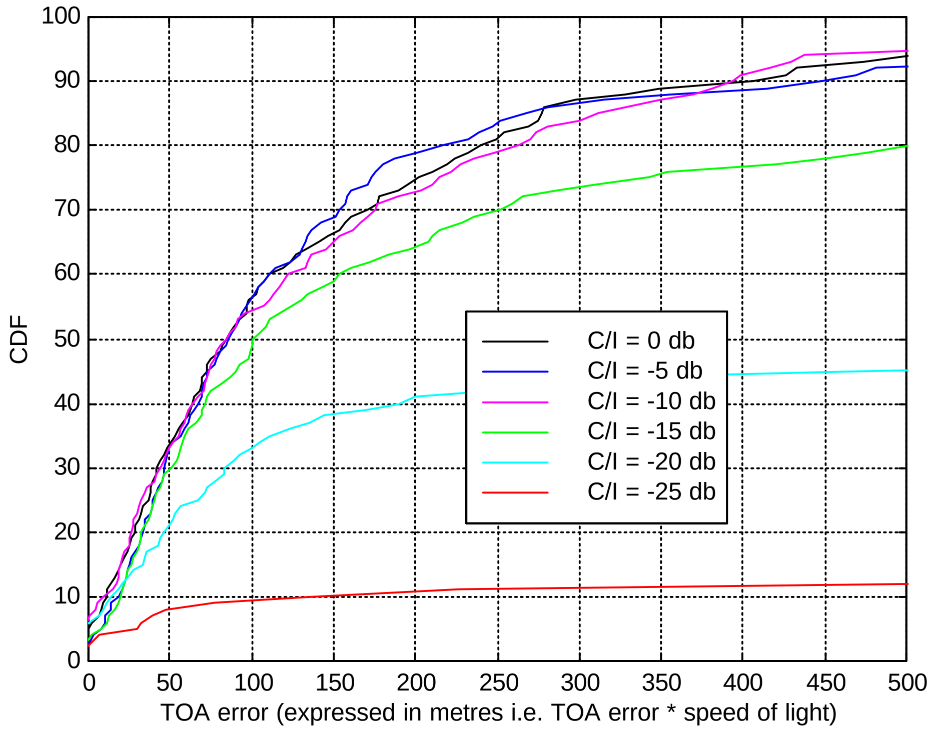


Figure 8 CDFs of TOA estimate (expressed as an error in metres) for a single link in UrbanA environment for C/(I+N) values –25dB to 0dB

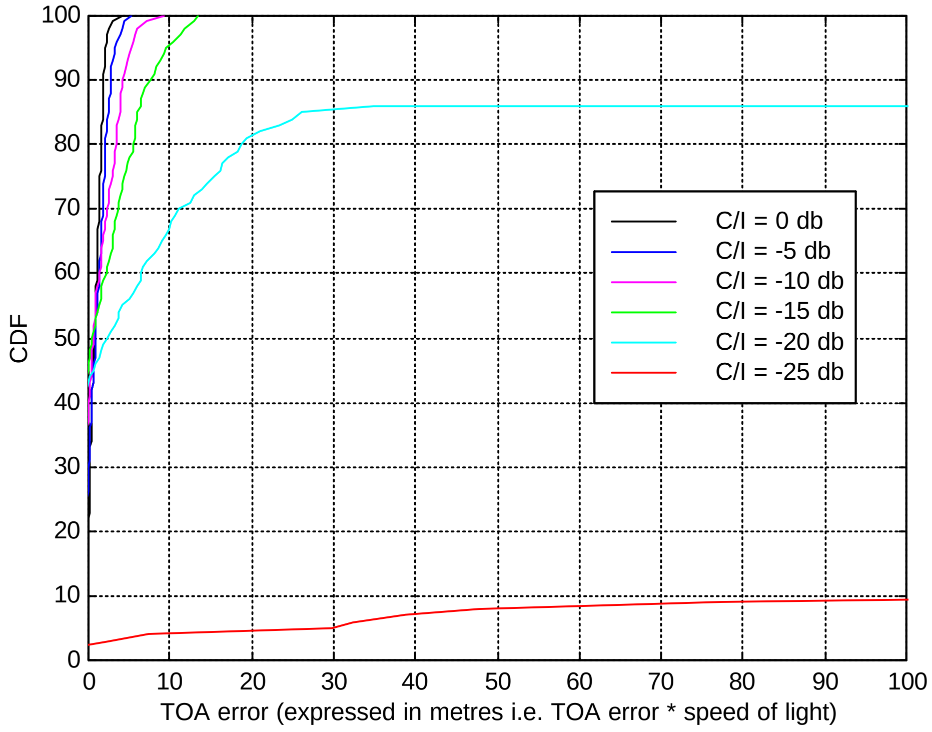


Figure 9 CDFs of TOA estimate (expressed as an error in metres) for a single link in a Line of Sight channel for C/(I+N) values –25dB to 0dB

False TOA Peak Rejection

It is not only the TOA error that is important. It is also important to unambiguously detect whether the peak from the correlation process is a true TOA or not.

In the Motorola system we consider the peak value of the combined output of the correlation process and the number of measurements that were combined to get the results. This in turn is compared to a threshold value that is chosen to reject false TOA peaks.

However, at low C/(I+N) levels it is impossible to successfully identify all true TOA estimates whilst rejecting all false estimates. The net effect of this is that a lower yield of usable TOA estimates is available than is actually there. An example of this is illustrated in Figure 10 for an UrbanA link with C/(I+N) set at –20dB. Here the peak output of the correlator is plotted against the TOA error (expressed in metres for convenience). In order to reject all false TOA estimates the threshold value must be set to 0.5. This gives a yield of 25% of useable measurements. In fact in this case the threshold here has been optimised for C/(I+N) = -20dB. In practice it will be optimised for the complete dynamic range of expected C/(I+N) and the true yield may be lower.

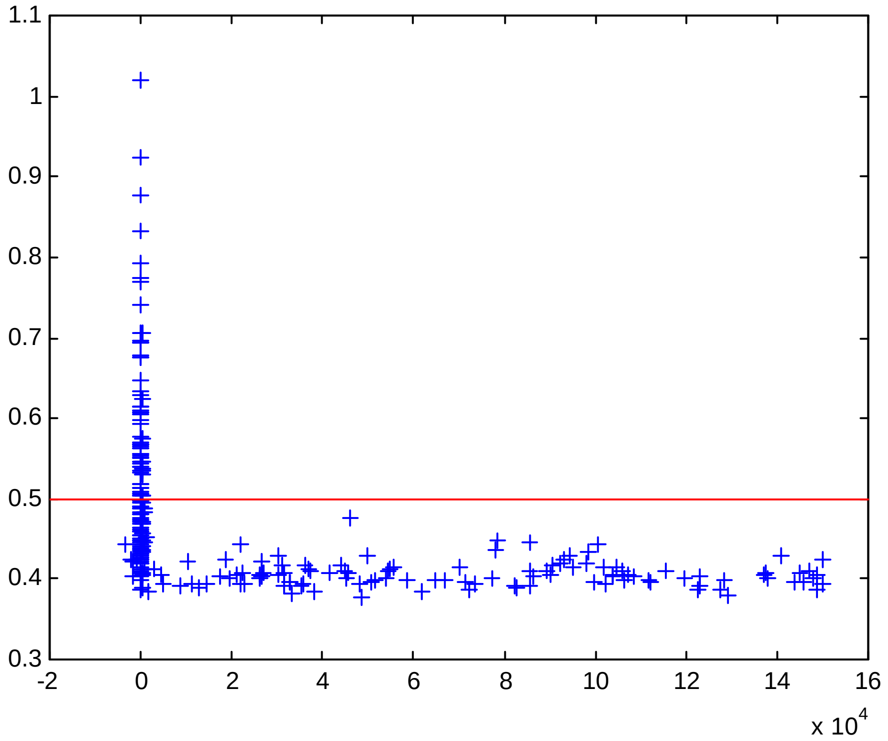


Figure 10 Peak of integrated correlator ouputs plotted against TOA error for an UrbanA link at C/(I+N) = -20dB. The red line shows the peak rejection threshold to needed to umambiguously detect a true TOA estimate.

Multipath Rejection (MPR)

Perhaps the simplest method of MPR is the successful detection of secondary TOA peaks that occur earlier than the highest peak from the correlation process. In poor C/(I+N) conditions (IPDL) this will be difficult, whilst the chances of successful detection will improve at higher C/(I+N) ratios (TA-IPDL).

Another method of MPR is to collect multiple snapshots of the channel spread over the measurement collection time. This allows multiple TOA estimates to be collected, subsets of which can be used to mitigate multipath. This is the case in TA-IPDL and has been applied successfully. However, in IPDL, for the agreed common simulation conditions, the C/(I+N) ratios are such that typically all measurements need to be combined to get one single TOA estimate. This is no help in mitigating multipath.

Adaptive Pilot Power in TA-IPDL

In TA-IPDL it is possible to change the pilot power in the common idle period without having any further impact on the network performance [6]. For example, some of the resources that have been dedicated to traffic channels during normal UMTS operation can be momentarily shifted to the pilot during the common idle period. This will enable a mobile to make location measurements at a greater range from a BTS. This aspect of TA-IPDL will certainly be beneficial in a sparse base site population - the likely scenario in initial deployment of UMTS and in many rural areas. Also, it will increase the number of BTSs visible to a mobile in an indoor environment.

Another relevant aspect is that the pilot optimisation for communication purposes can in this way be separated from the pilot power optimisation during the common idle period. As a result, the two requirements can be handled independently.

In figure 11 the improvement made by increasing the pilot power from 10% to 40% during the common idle period for an extended rural cell (BTS separation = 40km) is illustrated. This is shown to demonstrate the power of this technique. In practice, such BTS separations will result from a non-homogeneous layout in rural areas.

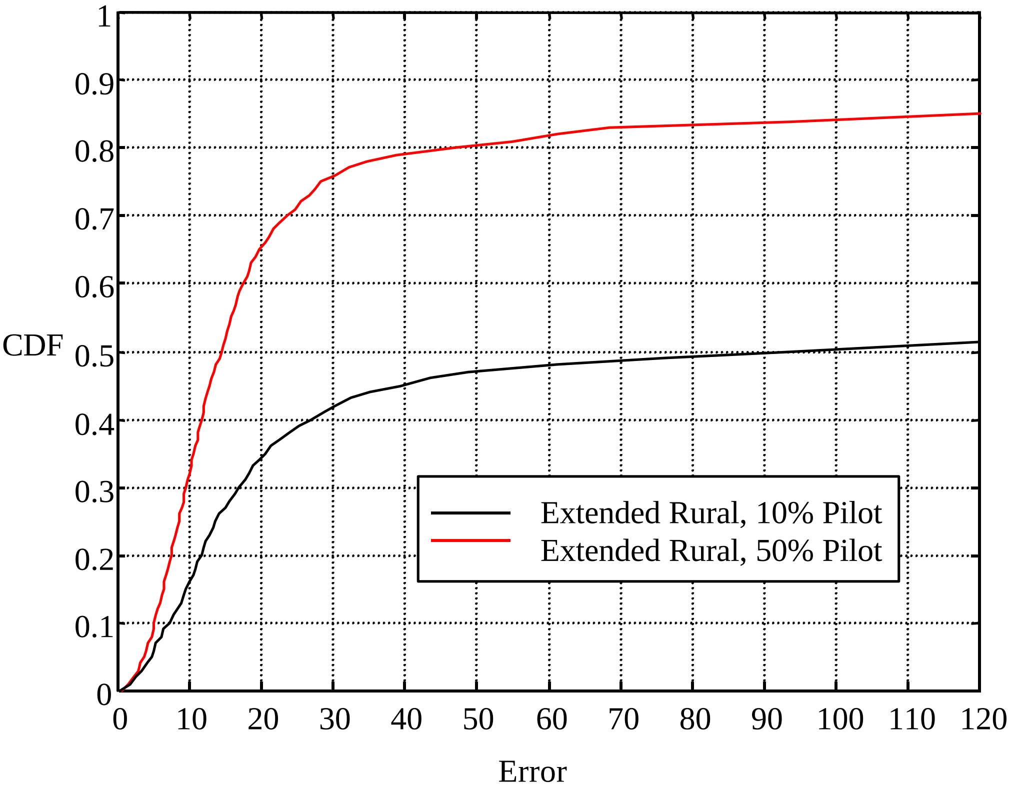


Figure 11 CDFs of radial error for TA-IPDL in an extended rural cell for 10% and 50% pilot powers

Conclusions

It has been shown that IPDL performs poorly under the described simulation conditions. Methods of improving its performance include more idle slots, longer idle slots and longer measurement times.

In addition, it is possible in practice to improve all techniques (including not using idle periods at all) by employing RTT and detailed knowledge of antenna gain profiles (angular information in a sectorised site). Further, mobiles in soft handover may be able to use multiple idle periods when these are available. Here we have not considered any of these enhancements to enable a direct comparison of the performance between TA-IPDL and IPDL, and to avoid excessive assumptions.

On the other hand, some of the issues regarding the provision of synchronisation of the idle slots for TA-IPDL still require further study. In practice, it is reasonable to enable the operator to decide whether to use idle slots (and their span and frequency), and also whether to synchronise these in all or part of the network. Since all methods require the mobile to schedule TDOA measurements of the common pilot from multiple BTSs, it appears sensible to standardise a common framework for signaling to the UE (the actual operation required by the UE is virtually identical). This will allow the network operator to configure the system to their requirements, including the possibility of having different configurations in different geographical areas.

[1] TSGR1#7(99)b79, Time Aligned IPDL positioning technique, Motorola.
[2] TSGR1#4(99)346, Recapitulation of the IPDL positioning method, Ericsson.
[3] TSGR1#7(99)c36, Pilot signal coverage for Location Services, Nortel Networks.
[4] TSGR1#8(99)g88, Evaluation of IPDL positioning techniques.
[5] TSGR1#8(99)g15, Evaluation of time aligned IPDL positioning technique using common simulation parameters.
[6] TSGR1#8,(99)f51, Pilot channel structure for location services, Samsung.