

# PRECISE UE POSITIONING IN UMTS USING CUMULATIVE VIRTUAL BLANKING

P J Duffett-Smith & M D Macnaughtan

Cambridge Positioning Systems Ltd., UK

## ABSTRACT

The current Observed Time Difference of Arrival technique for finding the position of a mobile in a UMTS network suffers from a severe near-far problem when the UE is close to a Node B. We describe a new technique, called Cumulative Virtual Blanking, for overcoming this problem efficiently, without disrupting the normal operation of the network. Early results from a network-based trial indicate positioning accuracy of the order of 20 m in a rural environment.

## INTRODUCTION

There is broad agreement that location will play a central role in enabling value-added services in third-generation (3G) networks, and that these services require high accuracy at low cost. There are several techniques by which the position of a mobile terminal operating in a radio communications network may be determined. These include using signals from transmitters not connected with the network, such as the Global Positioning System (GPS) satellites. Others make use of the signals radiated by the mobile terminal and picked up by remote receivers, such as the Time Of Arrival (TOA) and so-called "Radio Finger Printing" techniques or, *vice versa*, using the signals radiated by the network itself and picked up by the mobile terminal. Chief amongst the last category is the Enhanced Observed Time Difference (E-OTD) technique.

The E-OTD technique, although generally applicable to many different communication technologies, has been particularly applied to the Global System for Mobiles (GSM). Signals are measured both by the mobile terminal and by a fixed receiver at a known position. The instantaneous transmission time offsets of each transmitter relative to its neighbours are calculated from the values measured at the fixed receiver using the known positions of the fixed receiver and the transmitters. The timing offsets measured by the mobile terminal can then be used in a calculation based on well-known standard techniques in which the points of intersection of two or more hyperbolic position lines predict the position of the mobile terminal.

The E-OTD technique has been adopted as a mandatory element of the current 3G Universal

Mobile Telephone System (UMTS) standard [ref 1]. Here, E-OTD has been re-named Observed Time Difference of Arrival (OTDOA), but it suffers from a major problem, the so-called "hearability" problem. In Code Division Multiplexed (CDMA) networks generally, the same radio frequency (RF) channel can be shared between multiple neighbouring network transmitters. In UMTS this channel is about 5 MHz wide. The downlink signals from each transmitter (Node B) are scrambled using a different "scrambling code" which allows a mobile terminal (known in 3G as the User Equipment, UE) to recover the required signal provided that (a) it knows the scrambling code used by that Node B, and (b) its internal clock is synchronized with the transmitted signals. To assist with the latter, each Node B also radiates a "pilot code" on the Common Pilot Channel (CPICH) within the same RF channel whose coding and other characteristics make it easily distinguishable. The UE first detects and locks on to the pilot signal, determines the scrambling code used by that transmitter, and then is able to decode the main transmissions. In the OTDOA technique, the relative timing offsets of the CPICH associated with different Node Bs are measured by the UE, and are translated into the corresponding differences between Super Frame Numbers (SFN).

The hearability problem arises when the UE is near to a Node B. E-OTD systems (and therefore OTDOA systems) require the measurements of the time offsets associated with at least three geographically-distinct transmitters, but when the UE is too close to a transmitter, the signals from the more-distant transmitters are drowned out by the local signals to the extent that their time offsets cannot be measured. The application of the OTDOA technique is therefore limited in practice without the assistance of a secondary service such as Idle Period on the Down Link (IP-DL) [ref 2] in which the transmissions from the local transmitter are turned off periodically in a so-called "idle period" during which the signals from the distant transmitters may be received. The problem facing network equipment suppliers, terminal manufacturers and operators alike is that IP-DL adds complexity, reduces communications efficiency, and suffers from major flaws making it unworkable in some situations. The result is that IP-DL may not be deployed widely, if at all, in 3G networks. Some 3G operators have therefore

adopted a wait-and-see position based on an expectation that Assisted GPS (AGPS) will eventually provide ubiquitous positioning.

Cambridge Positioning Systems Ltd. has developed a variant of its E-OTD solution for 3G (Bartlett et al, ref 3). The new technique does not need IP-DL nor any similar supporting technique, but overcomes the hearability problems of OTDOA by (a) making use of the all the energy radiated by a Node B, not just the fraction within the common pilot channel, and (b) removing the interference from the brightest signals in turn in a software process called Cumulative Virtual Blanking (CVB) which resides in the network-based calculation node, the Serving Mobile Location Centre (SMLC). The implementation is particularly simple involving the addition of only a minor software element to the handsets and Node Bs. (A time-stamping function is also needed in the Node B.) This solution does not require the handset to perform additional timing functions of its own

This paper describes the CVB technique and presents some early results from a network-based trial.

## THE CVB TECHNIQUE

### How it works

CVB uses signal processing in the SMLC to remove stronger Node B interferers successively instead of requiring the Node Bs to be physically turned off for blanking periods as in IP-DL.

The SMLC needs the following measurements to be made in order to implement the technique: a "snapshot" of the signal received by the UE, and time co-incident snapshots of the transmitted signals from each Node B. Each snapshot is typically 1 to 2 Kbytes at the UE and 4 Kbytes at the Node B, and nominally represents the base band I-Q signals.

CVB does not require the UE to do any additional processing of the captured snapshot. This is simply buffered and transferred to the SMLC.

The SMLC pre-processes the co-incident snapshots from the UE and each relevant Node B by successively cross-correlating the UE snapshot with the Node B snapshots and removing the strongest Node B signal from the UE signal by estimation and subtraction. The output of this pre-processing stage is a set of Observed Time Difference (OTD) measurements which are transferred to the standard location algorithms instead of the SFN-SFN measurements that

would have been obtained using the standard OTDOA measurement procedure.

## Implementation

**In the UE:** A block diagram of the basic elements of a UE is shown in Figure 1, and it illustrates how the CVB function might be integrated. It is represented as the two shaded blocks. In practise it is anticipated that 3G architectures for the UE

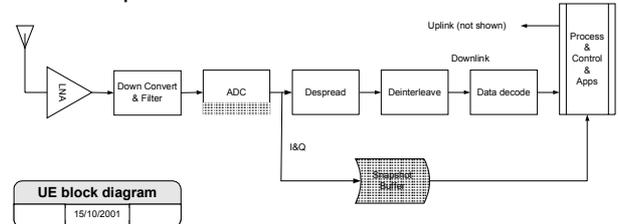


Figure 1 - UE block diagram with CVB elements.

will already incorporate the Sampler Function (using the existing Analogue to Digital Converter, ADC), since it is likely that Digital Signal Processing (DSP) and software radio techniques would be used in their design. It is also anticipated that the memory requirements of the Snapshot Buffer (typically around a kByte or two) will be easily accommodated. Thus we envisage that the addition of the CVB functions in the UE will require only software modifications.

**In the Node B:** Figure 2 illustrates how the CVB function can be implemented in the basic elements of a Node B.

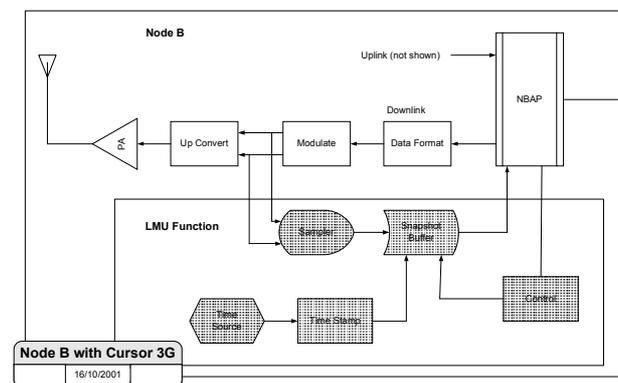


Figure 2 - Node B with integrated CVB function.

The CVB elements are the Sampling Device, the Snapshot Buffer, a Time Source and associated method of accurately time stamping the snapshot measurement, and a method of coordinating the collecting of snapshots between Node Bs.

In this configuration, the downlink signal is sampled before being up-converted and transmitted. Typically the base-band I-Q signals would be sampled here, although other sampling

points could be used. In order that there is complete overlap between the UE snapshot and the Node B snapshots, the Node B snapshot needs to be long enough to take account of measurement timing uncertainty, Node B synchronisation errors, and signal time of flight. It is expected to be around 4 Kbytes in length.

The time stamp is an important element in the Node B CVB function. It is necessary to time stamp the snapshot accurately. Time stamp errors translate directly into position errors at the speed of propagation of radio waves - 3m per 10ns. There are several ways to achieve accurate time stamping, the most obvious being the use of GPS time, but it is possible that future processing algorithms in the SMLC could lead to the elimination of the need for any external time source.

It is important to note that the time stamp requirement is just that, there being no need to synchronise actual operation of the Node Bs. Indeed the snapshot may be captured completely asynchronously from Node B operation. It is not necessary for the snapshot to be captured coincidentally with network operations or data structures such as framing or CPICH. It is, however, important that all Node B snapshots completely overlap with the UE snapshot. All snapshots need to be taken at the same time.

**In the SMLC:** A standard E-OTD position calculation function may be used in the SMLC. However, a pre-processor is also required to extract the OTDs from the Node B and UE snapshots.

### Operation

It is envisaged that the Node B function will be configured to capture regular snapshots and send them to the SMLC at a repetition rate appropriate for the applications supported by the network. This can be done through the network management function using the Node B Application Protocol (NBAP). A typical repetition rate may be once every few seconds. However, the UE only captures a snapshot when requested to do so as follows:

- A position request from the core network is routed to the UE. The request includes timing information instructing the UE when to capture the snapshot.
- The UE captures the data and sends it to the SMLC using standard signalling functions.
- The SMLC cross-correlates the snapshot made at the UE with each of the snapshots from the relevant Node Bs. The time offset for the strongest Node B correlation is measured.

- An estimate of the signal received by the UE from the strongest Node B is made and subtracted from the UE snapshot.
- The cross-correlation and signal subtraction, steps c) and d), iterate until no further signals can be extracted.
- The time offsets gathered are transferred to the standard E-OTD position calculation function which calculates the UE position and responds to the original measurement request with the result.

### THE HEARABILITY PROBLEM

Macnaughtan and Bartlett (4) have described the hearability problem in some detail and have simulated the three cases (i) in which the CPICH signals are used in OTDOA unsupported by any other service, (ii) in which IP-DL is added to support the first case, and (iii) in which CVB is used. The results of their simulations are shown in Figures 3, 4, and 5 respectively.

The upper panel in each figure is a differential probability distribution of the number of Node B

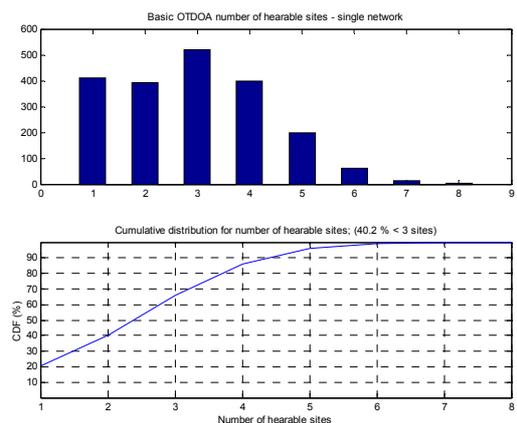


Figure 3 – simulation results for case (i).

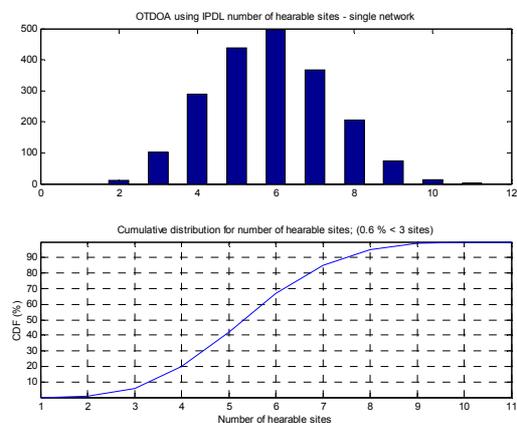


Figure 4 – simulation results for case (ii).

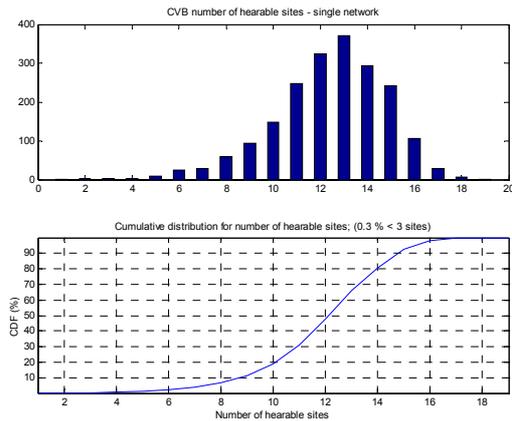


Figure 5 – simulation results for case (iii).

measurements available for passing to the positioning function represented as a histogram. The lower panel shows the cumulative probability distribution. Please refer to the reference (4) for details of the simulations. Here it is sufficient to note that unsupported OTDOA will fail in approximately 40 per cent of the cases (Figure 3), but with the support of IP-DL the median value of the number of Node B measurements available for positioning rises to 6 (Figure 4). CVB performs best (Figure 5) with a median value of 13.

## A FIRST TRIAL OF CVB

### Aims

Our two principal aims were (i) to perform some OTDOA location measurements on a UMTS network, unsupported by IP-DL, and (ii) to demonstrate the effectiveness of CVB in mitigating the hearability problem.

### Experimental procedure

We installed a receiver at each of three Node B sites of an operating UMTS network as illustrated in Figure 6. The receiver input was connected to a downlink transmission test point in the Node B for a particular sector. Each receiver has the ability to capture a signal segment up to one UMTS frame in duration. A fourth, identical, receiver was installed in a vehicle to emulate a UE moving around in the test area. Each of the four receivers was also equipped with a GPS time reference to enable near-simultaneous capture of the snapshots at the Node Bs and the simulated UE.

Measurements were made at a variety of locations around a test area enclosed by the three monitored sectors. GPS position measurements were also recorded at each of the test locations for comparison with the calculated OTDOA positions.

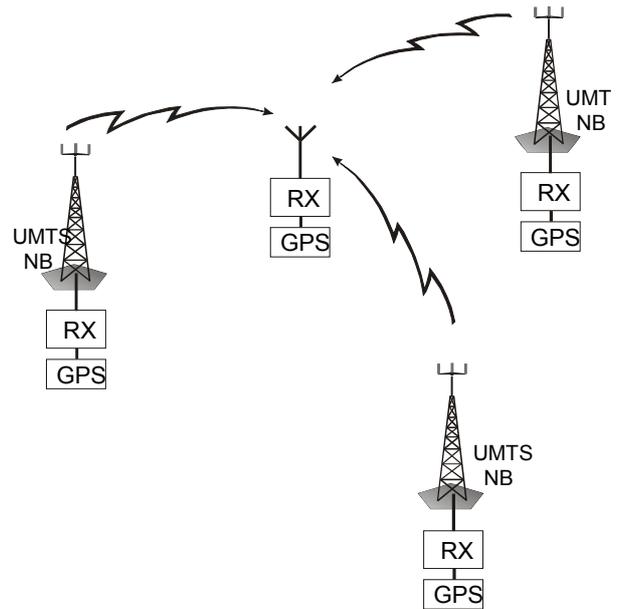


Figure 6 – the experimental configuration

For convenience, all the UE measurements were made with the vehicle stationary. This will not be a limitation of the method in practice since the actual snapshot duration used is a few hundred microseconds. All four receivers were configured to capture data at the beginning of a specific GPS second. After the recordings were completed, the signals were cropped to a few CPICH symbols duration, quantized, and then collected at a central site for position calculation.

### Results

The trial was conducted just a few days before the deadline for submission of this paper. As a result we can present here only a preliminary analysis of the data.

Table 1 - Preliminary results

Site	Time	Error / m
1	16:26	22.8
2	16:43	27.6
3	17:11	16.9
4	17:13	5.7
5	17:16	26.2
6	17:40	13.3
7	17:58	28.9
8	17:59	43.7
9	18:58	30.5
10	19:53	11.7

Table 1 shows the error between our calculated position and the 'ground truth' as given by non-differential GPS at 10 sites distributed across the test area. Figure 7 shows the relative positions of

the Node Bs and the measurement sites (crosses), as well as the orientation of the Node B sectors. These position calculations were made using only the snapshots from the three chosen sectors, i.e. only three OTDOA measurements were used, the minimum necessary to compute a two-dimensional OTDOA position fix.

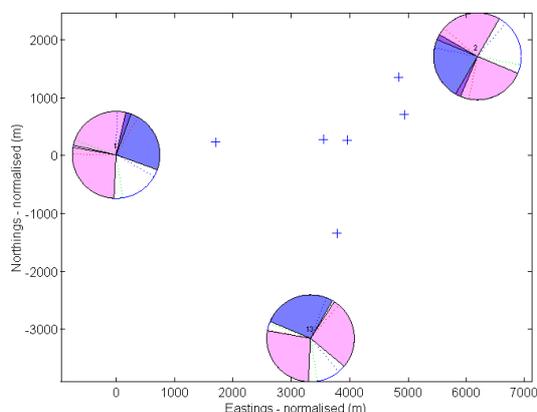


Figure 7 - The relative positions of the sites

## Analysis

The test conditions of this first trial did not provide an ideal showcase for the CVB method. This was partly due to the conditions and partly due to the limitations of our experimental setup. Whilst the CVB algorithm was used for computing the time offsets used to derive the positions listed in Table 1, the real strength of the method lies in its ability to attenuate successively relatively strong signals contained in a snapshot from the UE, enabling weaker ones to be measured. Simulations and laboratory measurements have shown that attenuations of up to several tens of dB can be achieved, depending on the conditions. However, in the environment for this trial the observable interference reduction was limited to about 10 dB.

In some cases, the fact that we only installed a receiver at a single sector of a tri-sector site proved to be the problem. For instance at sites chosen to be very close to a Node B in order to present a severe hearability problem, whilst the strongest signal was able to be attenuated significantly, there was often another signal from a sector which was not being monitored which was only 10 dB or so weaker. In this case, although the CVB method removed a very significant proportion of this signal's energy from the UE snapshot, the overall carrier to interference ratio for the signals of interest from the other two sites was only improved by about 10 dB since the interference from the sectors not being monitored became dominant. This would not be a problem in a full-scale deployment because those signals

would also have been recorded and could be removed in the same way as the strongest signal. At other test sites the UE was more equally separated from the 3 sites. In these cases we observed the strongest received signal at levels of -90 dBm or lower. This was at best 10 dB above the noise floor of our receiver. Once again, although the CVB method achieved a significant attenuation of the strongest signals, the net improvement in the carrier to noise ratio for the weaker signals could never have been greater than 10dB since the receiver noise floor became the limiting factor. This was a limitation imposed by a flaw in our experimental arrangement.

Despite the above problems, however, the overall accuracy is pleasing and within range of our expectations from simulations and calculations. Accuracy will be improved further in practice by using more than three sectors in each position calculation.

A striking aspect of this trial was the fact that it was completed within a single day. We visited the three Node B sites in the morning and installed our equipment at each of them. We made measurements within the test area in the afternoon, and we took away our equipment in the evening. All this was achieved without disruption to the normal operation of the network, and it demonstrates the simplicity of the CVB technique.

## CONCLUSION

The OTDOA positioning technique in UMTS suffers from a hearability problem which is likely to prevent measurement of position in as much as 40 percent of the geographical area served by the network. The new CVB technique ameliorates this problem by cancelling successively the interference from the strongest signals, enabling the otherwise undetectable weaker signals to be measured. A recent trial on a UMTS network in a rural setting indicates that OTDOA with the assistance of CVB will yield accuracies of the order of 20 meters.

## References

- 1 3GPP; Technical Specification Group Radio Access Network; Functional Specification of UE Positioning in UTRAN, 3GPP TS 25.305.
- 2 TSGR1#4(99)346, Recapitulation of the IPDL positioning method, Ericsson, 18-20 April 1999.
- 3 "Cumulative Virtual Blanking", D Bartlett, P Morris, M Macnaughtan, & P Duffett-Smith, white paper submitted to 3GPP, October 2001.
- 4 "UMTS hearability for OTDOA", M Macnaughtan & D Bartlett, white paper submitted to 3GPP, October 2001.

## ADDENDUM: ADDITIONAL RESULTS

### BACKGROUND

The paper submitted for the IEE 3G 2002 conference contained results from a preliminary trial of OTDOA using Cumulative Virtual Blanking (CVB) in a live UMTS network. This addendum presents the results of a subsequent, more detailed series of trials completed in the same network after submission of the original paper.

### TEST SETUP

CVB employs short snapshots of the downlink transmissions recorded at the NBs (Node Bs) to mitigate the hearability problem. For these trials, downlink monitoring receivers were installed at 3 NB sites enclosing a test area of approximately 10 km<sup>2</sup> (the same sites as used for the initial trials reported in the paper). The configuration of the downlink monitoring equipment is illustrated in Figure 8.

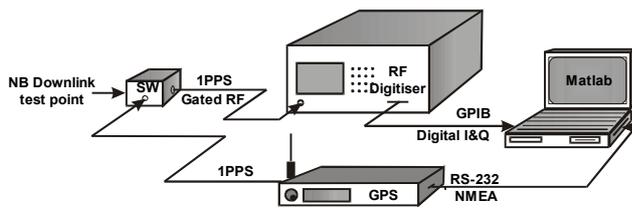


Figure 8 – Downlink monitoring equipment.

Each receiver was connected to the NB downlink test point for the sector received most strongly in the test area.

An identical receiver was installed in a vehicle and driven to different locations in the test area. Position measurements were made at 25 different sites chosen randomly across the test area. At each test site, 5 separate position measurements were made at intervals of 1 metre. Figure 9 shows the relative locations of the NBs and the test sites. The monitoring receivers were installed at the sites labelled 1, 2 and 3. It should be noted that this significantly limits the positioning performance compared to a full-scale deployment where many more signals would be used. A sample rate of 2 samples per chip was used together with a resolution of up to 4 bits per sample with a total UE snapshot size of the order of 1 kByte.

To make a position measurement, all NB monitoring receivers record a segment of the downlink signal starting at a specified GPS second. The snapshots are stored on disk for later processing. A GPS receiver was used to record a reference position for comparison with the position computed using CVB.

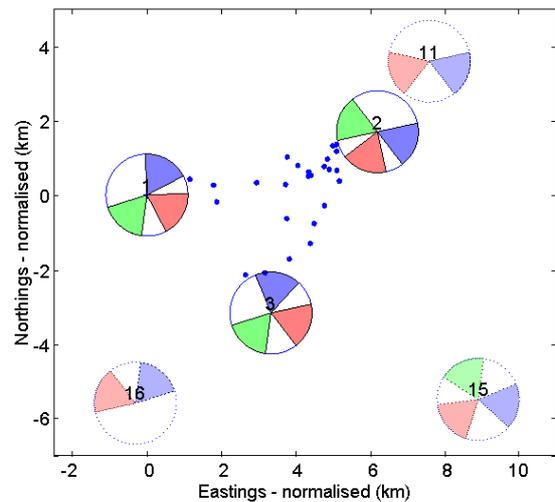


Figure 9 – Relative locations of NBs and test sites

### RESULTS

The test area consists of two distinct types of environment which could be described as rural and suburban. The former consisting mainly of farmland while the latter is a small town with relatively narrow streets and typically 2 storey houses on either side of the street. The signals measured in the two areas are significantly different and therefore the results are presented separately in Table 2.

Area	67%	95%
Rural	28.6	57.6
Suburban	54.2	81.1

Table 2: Position Accuracy

Analysis of the correlation profiles for the rural data shows little time dispersion. In fact in these measurements, the experimental error, which we estimate to be of the order of 15 to 20 metres, represents a significant fraction of the overall error. The suburban data by contrast shows significantly more time dispersion. Figure 10 illustrates this, showing the cross correlation profiles for the 3 monitored NB signals received by the UE at one particular site. The profiles have been aligned in time using the reference GPS position fix. In the ideal case, the peak of each profile should occur at a delay of zero. In this case however none of the profiles shows a peak at zero although lower peaks at zero are evident in the upper and lower plots.

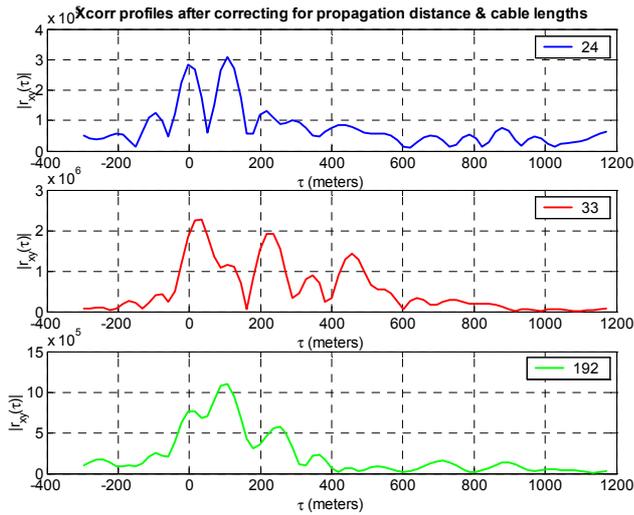


Figure 10: cross correlation profiles for 3 monitored Node Bs

## CONCLUSION

These initial trials yielded good accuracy given that only 3 NB sites were monitored. In the rural areas the experimental uncertainties of 15 to 20 metres represent a significant fraction of the overall error. The significant difference between the rural and the suburban areas is due to the greater multipath time dispersion in the suburban areas and the fact that only one sector from each of only three sites were monitored. Since 3 is the minimum number of sites required to compute an OTDOA position fix, there is no redundancy available in the data to support multipath mitigation measures to be applied in the position calculation or even to provide the averaging benefit that arises when extra measurements are available.

With the larger number of sectors and sites available in a full system deployment, we expect to achieve accuracies between 15 and 20 metres in a suburban environment.