Software-only TDOA/RTT positioning for 3G WCDMA Wireless Network

Sanem Kabadayi and Ibrahim Tekin

Sabanci University

Faculty of Engineering and Natural Sciences

Orhanli, Tuzla, Istanbul, 81474, Turkey

kabadayi@su.sabanciuniv.edu, tekin@sabanciuniv.edu

Phone: +90 (216) 483-95, Fax: +90 (216) 483-9550

Summary

A hybrid location finding technique based on time difference of arrival (TDOA) with round trip time (RTT) measurements is proposed for a WCDMA (Wideband Code Division Multiple Access) network. In this technique, a mobile station measures timing from at least three base stations using User Equipment Receive-Transmit (UE Tx-Rx) time difference and at least three base stations measure timing from the mobile station using round trip time (RTT). The timing measurements of mobile and base stations are then combined to solve for both the location of the mobile and the synchronization offset between base stations. A software-only geolocation system based on the above mobile/base stations timing measurements is implemented in Matlab platform and the performance of the system is investigated using the large-scale propagation models.

Keywords: Mobile geolocation, E911, WCDMA, TDOA, RTT

I. Introduction

In this paper, we will describe and analyze a software-only geolocation system for a third generation WCDMA network. The increase in cellular phone usage has resulted in an increase in the number of emergency calls originating from cellular phones. In such applications, the location must be accurate to within a few hundred meters and it must be calculated within a few seconds after the initiation of the call. In USA, the FCC mandated an E-911 location accuracy of 50 meters 67 % of the time and 150 meters 95 % of the time for mobile based location methods, [1]. From the service providers' point of view, position location offers many commercial applications. The service providers can offer additional services such as mobile yellow pages, equipment tracking, location specific advertising, navigation assistance, and zone-based billing [2].

For WCDMA networks, there are techniques reported for mobile location with accuracies in the range of a few meters. In [3], Idle-Period Downlink (IP-DL) method is specified where a mobile station measures only the downlink signals based on TOA or TDOA for WCDMA and CDMA 2000. For WCDMA, location errors less than 100 meters are reported using a correlation length of 13 msec and with the assumption that the mobile station can ''hear'' sufficient number of base stations. In [4], another down link-only measurements technique is reported, which does not use idle periods. There are also techniques that use TOA technique where graph theory is employed as a different way of solution of the DL TOA equations, [5] for WCDMA. An interference cancellation IPDL is introduced in [6] to increase hearability of BSs. The reported location error is in the order of 100 meters for 90 % of the time. All the techniques in [3], [4] and [6] rely on the assumption that the transmission time offsets of the BSs are measured and known at the serving mobile location center (SMLC). This assumption also implies a Location Monitoring Unit (LMU) network deployment for availability of these time offsets. In [7], a hybrid technique of using forward link pilot signals for TDOA and reverse link AOA by the BS's is proposed, and generates location accuracies much higher than a TDOA only solution. The hybrid technique in [7] relies on AOA information that will require deployment of antenna arrays at the BSs. Further, the hybrid TDOA/AOA technique is also applied to UWB systems with Kalman filtering to improve location accuracy, [8].

This paper evaluates a simple hybrid technique, which uses only TDOA measurements at the mobile station, and RTT measurements at least at three base stations to estimate the location of a mobile station in a WCDMA network. Location finding in a WCDMA network is one of the challenging problems since the network is asynchronous. In order to utilize timing information from a WCDMA network for the purpose of location finding, the time offsets between base stations are required, which may necessitate a large investment in a monitoring equipment network such as LMU. Our hybrid technique yields both the location of the mobile and the time offsets between the three base stations, which can replace an LMU network. In addition, our technique involves very simple algebraic equations to solve for the location of the mobile and the time offsets, hence, involved complexity is very low. However, these are advantages which result from timing measurements at the mobile as well as at the three base stations, which may not be possible at all the times because of the hearability problem both at the mobile and base stations.

For our hybrid technique, the mobile station makes signal arrival-time measurements (UE Rx-Tx) from the common pilot channel (CPICH channel for WCDMA, [9]) from each of the three base stations. In addition, the mobile station is locked on to one of the base stations (primary base station) and at the request of this base station, the mobile station transmits a response, and this transmission is picked up by all the three base stations, resulting in a round-trip time measurement available at each base station. The RTT measurement for the primary BS corresponds to the real round trip distance between the UE and the MS. However, the other two RTT measurements are not one-to-one correspondent to the round trip distance between the UE and BS's, however, these measurements can be still used to find the mobile distances. By combining all available timing measurements both from the base stations and the mobile, an estimate for each propagation time from mobile station to base station can be obtained. It should be mentioned that this technique does not need any synchronization, or any additional hardware such as LMU.

The rest of the paper is organized as follows: In Section II, the algorithm of the geolocation system will be explained in detail, i.e., a diagram will be introduced for timing measurements, and finding the mobile’s location and time offsets between base stations will be derived using the timing measurements. The simulation scenarios and models will be illustrated in Section III, where the performance of the proposed technique will be investigated. In Section IV, the numerical results on the accuracy of the hybrid technique will be presented, and finally the paper will conclude with section V.

II. Geolocation System

In most geolocation systems, synchronization between base stations is a requirement. However, WCDMA is designed as an asynchronous network. Therefore, different measurements and techniques should be employed to locate a mobile station in such a network. One method is to employ many LMUs to obtain the synchronization offsets between the base stations, and let mobile measure the time-of-arrival of at least three different base stations and hence obtain enough timing information to calculate its location, [3], [4] and [6]. Such a method might be costly due to the need of an LMU network. As an alternative solution, we propose a time measurement technique both at the mobile station and base station and hence elimination of an LMU network deployment. In the proposed technique, the MS makes time of arrival measurement of the downlink pilot signal transmitted from each of the base stations with respect to mobile’s local reference time just as a mobile station would do for a geolocation network with LMUs. However, instead of deploying LMUs, if the mobile's uplink signal could be measured at least by three base stations with respect to their local reference times, a solution can be achieved for the location of the mobile. When these measurements are combined with mobile measured timings, both the location of the mobile and the time offsets of the base stations with respect to each other can be obtained. These timing measurements are already defined in WCDMA standards as UE Rx-Tx and RTT measurements, [16]. In order to better understand the involved timings and the algorithms, one can use a timing diagram where three BSs to MS uplink/downlink transmissions are shown in Figures 1.a, b and c. Let t be absolute reference time, which may be taken as GPS or UTC time, and let t_s^n represent different base stations clocks with respect to the absolute time t. According to timing diagrams in Figure 1, BS1 transmits its pilot signal synchronized at $t+t_s^1$, BS2 transmits its pilot signal synchronized at $t+t_s^2$ and BS3 transmits its pilot signal synchronized at $t+t_s^3$. Let t_p^n be the actual propagation time from BSn to the mobile station, where $n=1,2,3$ for the three base stations. So, the transmitted pilot signals from BSs will reach the MS at absolute times given by

$$t_{abs,mobile}^n = t + t_s^n + t_p^n \quad \text{for} \qquad n=1,2,3 \qquad (1)$$

Equation 1 simply states that if a BS transmits at absolute time t with an offset t_s^n, this will reach mobile station with an additional delay of one way propagation t_p^n between that base station and the mobile station. Assuming that the MS is synchronized with BS 1 (primary base station), mobile local time is $t+t_s^1+t_p^1$.

All the timings are given with respect to the antenna reference of both mobile and the base stations. In Figure 1, the sum of the hardware Tx-Rx chain delay is denoted as UE Rx-Tx time difference. Note that each mobile might have different hardware delay (turn around time can also include some processing delay as well) depending on specific models, however, it is assumed that these delays can be measured and can be stored in a mobile and mobile can convey this information to the network when requested. Actually, this time difference is already defined as a message in WCDMA standards as UE Receive-Transmit time difference type 2, which takes the first detected path in time as Rx path reference and also a measurement of this time difference with a higher chip accuracy of ± 1 chip, [16]. Also, note that this discussion holds for other techniques which use timing measurements. For example, in GSM standards, the mobile station will transmit three time slots before its reception of the downlink signal defined at the antenna of mobile [10], and when BSs receive the mobile uplink signal and measures the round trip time, this predetermined time offset at the mobile station will be calibrated. In IS-95 CDMA systems, round trip delay is measured at the serving cell for hand-off purposes and also in GSM systems, TA (timing advance) that can be related to round trip time can be easily measured.

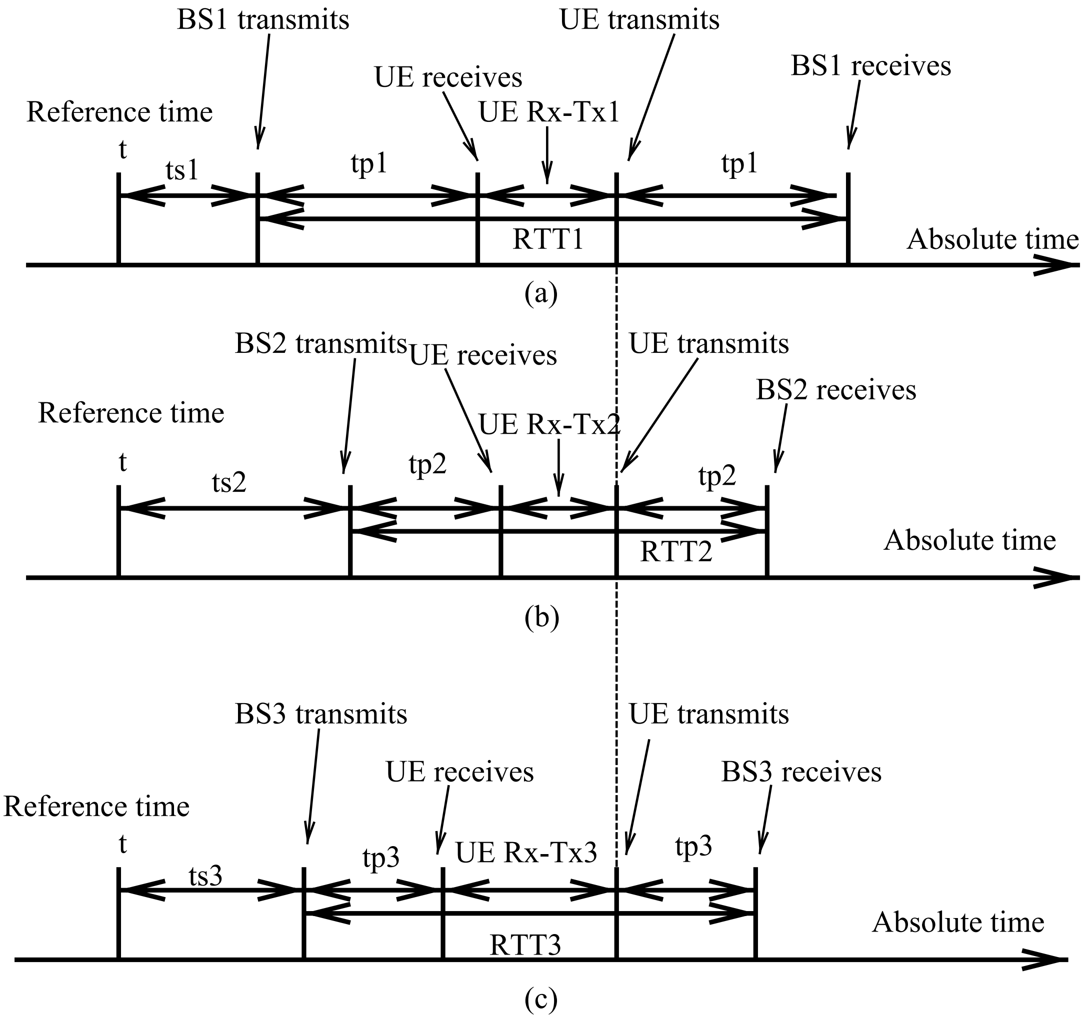

Figure 1: Base stations and mobile station transmit and receive timing diagrams for a) Base Station 1 b) Base Station 2 c) Base Station 3.

When the mobile local time is synchronized with $t+t_s^1+t_p^1$, the mobile station will measure TDOA measurements of BS2 and BS3 stations as,

$$t+t_s^2+t_p^2-(t+t_s^1+t_p^1)=UERx\_Tx1-UERx\_Tx2=c_2 \qquad \text{for BS 2} \qquad (2)$$

$$t+t_s^3+t_p^3-(t+t_s^1+t_p^1)=UERx\_Tx1-UERx\_Tx3=c_3 \qquad \text{for BS 3} \qquad (3)$$

where c_2, c_3 are the constants that are the differences of UE Rx-Tx time differences as shown in Figure 1. When the mobile station transmits at absolute time of $t+t_s^1+t_p^1$, the mobile uplink signal will be picked up at three base stations at absolute times given by,

$$t_{abs,BS}^{n} = t + t_s^1 + t_p^1 + UERx\_Tx1 + t_p^n \qquad \text{for } n = 1,2,3 \tag{4}$$

where mobile uplink signal is delayed by one way propagation time of each base station. Each base station synchronized with respect to their own transmission time ($t + t_s^n$) will measure three round trip times (RTTn) from the mobile uplink signal given as,

$$t + t_s^1 + 2 * t_p^1 - (t + t_s^1) = RTT1 - UERx\_Tx1 = c_4 \qquad \text{for BS 1} \tag{5}$$

$$t + t_s^1 + t_p^1 + t_p^2 - (t + t_s^2) = RTT2 - UERx\_Tx1 = c_5 \qquad \text{for BS 2} \tag{6}$$

$$t + t_s^1 + t_p^1 + t_p^3 - (t + t_s^3) = RTT3 - UERx\_Tx1 = c_6 \qquad \text{for BS 3} \tag{7}$$

where c_4, c_5, c_6 are the RTT measurements of each base stations minus UE Rx-Tx delay of the BS1, respectively. Using Equation 5, we can solve for the one way propagation delay from the first base station which is given by

$$t_p^1 = c_4 / 2 = (RTT1 - UERx\_Tx1) / 2 \tag{8}$$

By manipulating Equations 2 and 6, we can obtain the solution for t_p^2 and Equations 3 and 7 for t_p^3 as,

$$t_p^2 = (c_2 + c_5) / 2 = (RTT2 - UERx\_Tx2) / 2 \tag{9}$$

$$t_p^3 = (c_3 + c_6) / 2 = (RTT3 - UERx\_Tx3) / 2 \tag{10}$$

Similarly, we can also solve the relative time offsets of the base stations with respect to first base station. Using Equations 2, 8 and 9, we can obtain the relative time offset of BS2 and BS1 as,

$$\begin{aligned} t_s^2 - t_s^1 &= c_2 - (t_p^2 - t_p^1) = (c_2 + c_4 - c_5) / 2 \\ &= (RTT1 - RTT2) / 2 + (UERx\_Tx1 - UERx\_Tx2) / 2 \end{aligned} \tag{11}$$

and using Equations 3,8 and 10 the time offset between BS3 and BS1 is given by,

$$\begin{aligned} t_s^3 - t_s^1 &= c_3 - (t_p^3 - t_p^1) = (c_3 + c_4 - c_6)/2 \\ &= (RTT1 - RTT3)/2 + (UERx\_Tx1 - UERx\_Tx3)/2 \end{aligned} \tag{12}$$

Mobile station measures UE Rx-Tx time difference (type 2) for three different base stations and then forms the difference of these measurements by taking the measurement of the primary base station as the reference measurement, and these measurements are given as c_2, c_3 in Equations 2 and 3. The base stations measure RTTs with respect to their own transmission times and form the difference between RTTs and UERx-Tx1, and these measurements are given as c_4, c_5, c_6 in Equations 4, 5 and 6. Given these mobile and base station time measurements, Equations 11 and 12 define the algorithms which result in the relative time offsets of the base stations with respect to the first base station. Further, Equations 8 to 10 are the defining algorithms for the estimation of propagation delays between MS and BS's.

If the distances of a mobile station to three BSs are given, one may calculate the location of the mobile in various ways. One of the techniques is such that three distances from the mobile station define three circles passing through location of the mobile station. Intersection of any two of these circles will generate two intersection points as possible locations of the mobile station. Third circle can be used to resolve the ambiguity between the two solutions. This may be the simplest algorithm. However, in case of multipath error, two circles may not intersect at a point, or may generate very large errors. The third circle can also be incorporated into the solutions using a technique such as TDOA. TDOA technique may eliminate common timing errors, as well as some of the multipath caused error for the first base station. In this case, rather than using Equations 8-10 which define BS's centered circles which also passes through from mobile location, the time-difference equations can be used to calculate the mobile position. TDOA equations are formed by taking the difference of Equations 9, 10 with 8 and then exact solution is obtained which is proposed in [2]. The TDOA equations can be easily obtained as,

$$t_p^2 - t_p^1 = (c_2 + c_5 - c_4)/2 = (RTT2 - UERx\_Tx2)/2 - (RTT1 - UERx\_Tx1)/2 \tag{13}$$

$$t_p^3 - t_p^1 = (c_3 + c_6 - c_4)/2 = (RTT3 - UERx\_Tx3)/2 - (RTT1 - UERx\_Tx1)/2 \qquad (14)$$

Note that the right hand side of the Equations 13 and 14 are known measurements from both MS (UE Rx-Tx) and BSs (RTT) including the multipath error. These equations define two hyperbolas with the base station coordinates being at the foci of the hyperbolas. In the case of multipath free propagation, the solution of these equations will yield the exact solutions for the location of the mobile and also synchronization offsets between the base stations. However, multipath environment will induce timing errors and deteriorate the performance of the mobile location network.

The location finding technique has simple algorithms to solve both the location of the mobiles and the time offsets between base stations, however, there may be decisions or problems associated with the technique which should be taken into consideration. One of these decisions is to determine where the location calculations will be performed. If the location is calculated at the mobile (which can be done since the TDOA equations are solved exactly which do not require much processing power), the timing measurements performed at the BSs should be transferred to the mobile station as well as BSs coordinates, which may require new message definitions. On the contrary, primary BS may request the timing information from the mobile station as well as other BSs to calculate the location of the mobile. It is also possible using other measurement messages defined in [15] for location calculation. For example, pilot signal timing difference measurements (SFN-SFN and SFN-CFN observed time differences type 1 and type 2, CFN: connection frame number, SFN: system frame number) that are sent to the network for handover purposes can also be used in location calculations. However, one should note that these messages would be used only when location calculation is needed and will not use a large bandwidth since the message will contain only pilot signal measurements. The required messaging can be done on the WCDMA data channel if the mobile is in active call mode, however, for idle mode positioning, messaging should be performed on one of the control channels.

One of the major challenge of the hybrid location finding technique is the hearability problem, i.e., the MS should be able to receive and make timing measurements on three BSs downlink signal and also three BSs should be able to detect the MS uplink signal and perform the required time measurements. This may not be possible at all the times and all the locations in a network. However, for a 2G IS-95a CDMA network, it is the author's field measurement experience that in a typical field drive test, percentage of locations that mobile can detect more than three BSs pilot signals could be as high as 20 to 30 %. In addition, for the various channels simulated in our paper, the success rate of seeing at least three BSs to calculate locations was around 30 % for COST 231 Rural model, and was low as high as 10 % in the Urban model. This ratio could be higher for the number of BSs that could see the MS since the BS hardware is made of better quality, and also processing power at the BS will be more powerful than at the MS. In order to solve the hearability problem, mobile integration time for detection can also be increased or interference cancellation techniques can also be employed, [6]. Also, IPDL which is proposed for downlink location finding, can also be used with our technique to increase the likelihood of 'hearing' at least three base stations. It is beyond the scope of this paper to discuss further the hearability problem in detail.

Another challenge with the hybrid location finding technique could be the ill-conditioned TDOA equations when the mobile station is very close to a BS, or due to deployment geometry of BSs such as three BSs are deployed in a straight line, which might be the case on a highway. One of the advantages of the using TDOA exact solution in our hybrid technique is that geometrical dilution of precision (GDOP) is also calculated, and ill-conditioned cases can be determined and eliminated from the solution easily. For the locations with bad GDOP number, a fall back solution such as Cell-ID/RTT can be used instead. In a practical implementation of the hybrid location finding technique, it is important to note that for a specific three BSs in a network, if one of the mobile can hear three BSs, then the timing offsets between BSs can be calculated based on this mobile, and then the calculated values can be broadcasted to the rest of the mobiles using the same three BSs, and for those mobiles, the network does not have to measure the time offsets again and mobile stations will measure only the three BSs timing to employ the TDOA technique.

Now, given the TDOA/RTT measurements and TDOA algorithms for the location of the mobile, the performance of the location finding technique will be investigated using a realistic simulation of the overall system. The solution of the Equations 13 and 14 will be simulated in a multipath propagation environment to assess the performance of the geolocation system The details of the system simulation parameters which include the network parameters, propagation models, channel parameters, fading, receiver characteristics, etc will be explained in the next section.

III. Simulation Model

The simulation model of the TDOA/RTT technique can be separated into two parts: the first part which describes the overall network model which includes number of base stations, slow and fast fading models, propagation models, shadowing and the second part is about the link model where one MS to one BS's point to point communications parameters, such as filters, spreading, correlation integration time and related parameters are specified.

As a system model, the geolocation system simulated in this paper has a 19-cell 3-tier, 3-sector hexagonal cell topology with three directional antennas at each base station. The directional antenna of each sector of the BS has a 120-degree beamwidth. The path loss, shadowing, and fading models were analyzed for a 5-km cell radius, using lognormal shadowing with a standard deviation of 8 dB. The path loss model used in evaluating the downlink performance is the COST-231 model (extended HATA model) at a carrier frequency of 2 GHz and the fast fading is modeled using Rayleigh fading for a maximum Doppler spread of 175.92 Hz, corresponding to a mobile speed of 95 km/h at the carrier frequency, [10]. Rayleigh fading is a worst-case scenario where no direct line of sight path exists and is most perceptible in urban areas. Then, a simulink end-to-end model was created according to WCDMA system specifications, where the pilot signal (CPICH channel) was scrambled using 38400-chip complex Gold spreading and shaped using a square-root raised cosine transmit filter, [9], [12]. The effects of multipath fading and noise were also introduced to the simulations. The link model includes a BS transmitter/receiver, mobile fading channel, and a MS receiver/transmitter. The simulations are implemented in Matlab simulink, and the blocks from the Communications Blockset, DSP Blockset, and the CDMA demo were used extensively [11]. Also, the link model is assumed to be symmetric, and the same models are applied both at the uplink and downlink. For the link model, the transmitter section includes quadrature spreading with the long code and filtering to reduce the interference to adjacent channels. Rayleigh fading and additive white Gaussian noise (AWGN) blocks model the effects of the channel between the transmitter and the receiver. The receiver section includes filtering, despreading with the long code, and correlation for detection of the BSs pilot signal.

In the transmitter section, the pilot channel is a constant symbol. The channel coding operations in the WCDMA system use 10 ms frames for all channels. The WCDMA system requires spreading of the spectrum using a PN sequence. In WCDMA, the rate of this PN sequence is 3.84 Mchips/s which results in a bandwidth of the spread signals to be about 4.6848 MHz. The spreading is achieved using the long codes used in WCDMA, which is a pair of periodic binary PN sequences with a period of 2^{18}-1. These sequences are used for spreading and despreading signals into in-phase and quadrature components. Multiple base stations use different masks in the PN sequence generator to obtain different codes for identification. The pilot signals are transmitted continuously for coherent detection, and the timing measurement for the proposed mobile location technique is based on this WCDMA CPICH channel. There are techniques like IP-DL to increase hearability where BSs transmit in specified intervals, however, here continuous pilot transmission is assumed.

The role of the transmitter section is to generate the spreading signal that contains the pilot channel. The transmitter components are the pilot signal, the spreading code, and the transmit filter. The code generator block generates the complex spreading code. The pilot signal is spread with the in-phase and quadrature components of the PN sequence. The signal generated is then processed by the pulse shaping transmit filter block. The transmit filter consists of upsampling by a factor of 8 and filtering by using a square-root raised cosine filter which is defined by 3GPP documents as a square-root raised cosine filter (with a roll-off factor of 0.22, [9]), which generates the modulated I and Q waveforms. Mobile channel is assumed to be a Rayleigh fading channel for a mobile speed of 95 km/h and also AWGN noise is added to simulate the intracell interference. Power allocated to pilot signal was assumed to be 10 % of the total transmitted power from the BS.

The receiver section of the system is responsible for the detection of the time delay, which corresponds to c_n's in Equations 2 to 7. The receive filter consists of filtering using the same square-root raised cosine filter that is used in the transmit filter and then downsampling by a factor of 8. The square-root raised cosine filter again has a roll-off factor of 0.22. The positions of the correlation peaks are estimated as the timing measurements. The correlation integration time is set to 10 msec, which is the frame duration for WCDMA. The coherence time of the channel is around 6 msec for the chosen Rayleigh model, so we have integrated two 5 msec parts of the pilot signal coherently and then combined the two correlated outputs incoherently to stay with in the coherence time of the channel.

The simulation is performed as follows: time delay estimation is based on correlation of 10 msec pilot signal, and then 10 such correlation samples are generated for simulation of Rayleigh fading channel, and 10 set of such samples for shadowing, so for one point simulation, 100 location estimation is calculated and overall 2000 different such points are chosen to obtain distribution of the overall network location performance. Correlation involves only processing of 10 msec of the pilot signal, which corresponds to one frame integration. Note that the performance of the algorithms could be increased by integration of location estimations, or increasing the correlation time.

For the detection of the correlation peak, we used a threshold based detection. First, an average signal plus noise level is determined as an average of the different lags of the correlation of the signal and then this is set as the threshold. As a time delay estimate of the signal, the left most time at which a peak above the threshold is taken as the estimate of the BS pilot signal time since it is the first incoming multipath above the set threshold. The effect of the moving mobile is seen in the signal levels as the mobile station moves which will deteriorate the timing measurements. When correlation of the incoming pilot signal with the locally generated pilot signal is performed, we take the first most left peak as our desired solution since it is the earliest arrival incoming path, which has the least multipath timing error.

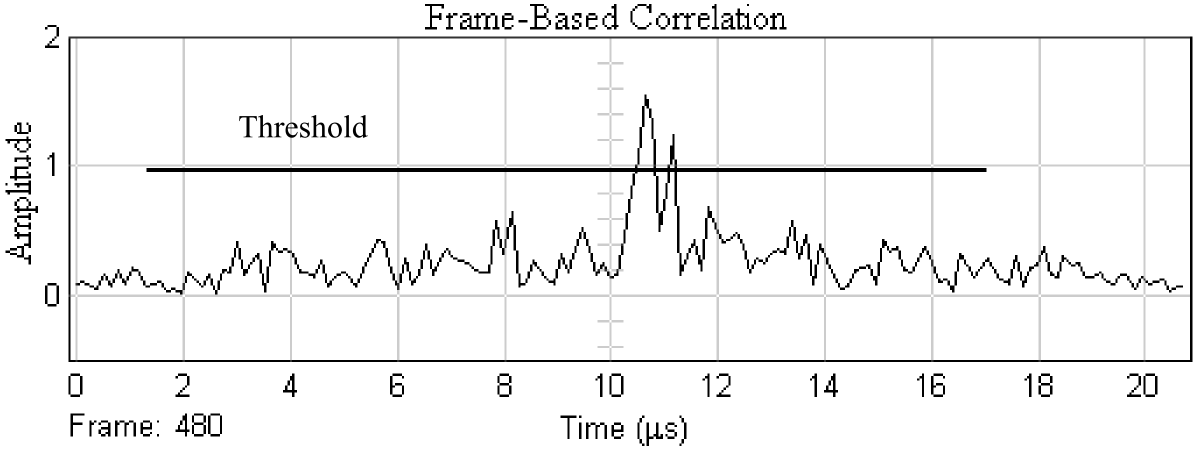

Figure 2: Correlation of the incoming signal with the locally generated long code

A sample correlated signal can be seen in Figure 2 where there are two peaks above the set threshold, and the location of the most left one is chosen as our time delay estimate. All the transmit and receive filters are performed by sampling the BS pilot signals 8 times the chip rate, and before taking the correlation of the signal with the locally generated codes, the peaks could be resolved with 1/8 of a chip duration. However, we have taken the correlation with one chip resolution to decrease the number of samples and hence save processing power that would be a more realistic case when mobile calculates the correlation of the pilot signals. Also, for the multipath delay profiles we have chosen, the duration between multipaths were already larger than a chip period. For this purpose, correlation is calculated in terms of one chip resolution without sacrificing from the accuracy of the technique. Results are also obtained without truncating the time measurements to one-chip, i.e., 8 times chip rate timing is also applied to see the effect of truncation.

For multipath free propagation, the location of the signal arrival time will only be deteriorated by the internal noise of the receiver, which can be modeled as AWGN. However, when the multipath components are considered, the performance of the mobile location algorithm based on the timing measurement will be affected considerably. If the multipath components construct destructively, the first incoming path, sometimes will not be detected, and this will induce a large timing error and hence a location error. To assess the performance of the TDOA/RTT algorithms for multipath propagation, different scenarios are considered and following multipath delay profile models are used: ATDMA Macro, CODIT Macro, ITU Vehicular A, and ITU Vehicular Bin, [12] and [13]. Further details on simulation environment and channel models can be found in [14].

We have chosen 4 multipath models specified by WCDMA and ITU documents for the performance of the location algorithms. Two of them are ATDMA and CODIT that are wideband models. ATDMA is chosen as the wideband model in which the delay spread is much wider than the CODIT model. The ATDMA channel is lossier since the second path is attenuated by 10 dB. However, this is a better channel condition as far as the location finding is concerned since the second multipath will not affect the correlator output and the timing estimated will be better on channels based on ATDMA. For ITU vehicular models, both models have two strong first incoming paths, and hence an optimistic environment for a geolocation network. ITU vehicular Model A is a better channel model for a geolocation network than Model B since it has the first incoming path with the strongest power. Model B represents an environment with a large delay spread, and also a stronger second incoming path that will result in an error for timing estimates. At all locations included in the simulation results, the number of ‘’hearable’’ BSs was greater than three, i.e., at least three BSs could hear the mobile as well as the mobile could detect at least three BSs signals. The method does not apply if the number of BSs involved is less than three. In that case, no location was calculated.

IV. Numerical Results

In this section, numerical results are presented for the accuracy of the TDOA/RTT technique for different propagation environment such as Rural, Suburban and Urban (mainly propagation path loss different environments) for different multipath delay profile distribution, namely ATDMA, CODIT, ITU vehicular A and B models.

For the ATDMA Macro model, the multipath delays starting with the first major component at 380 nsec, and have all less than -10 dB relative gain. This causes the correlator to detect the peak at 0 sec. most of the time. This model assumes that the first incoming path is strongest, and the multipath components are weaker than the first multipath. Note that 1 chip resolution will be sufficient for this case. As for the ITU Vehicular Model A, the correlation peaks are detected mostly at 0 sec. and at 1 chip offset corresponding to the multipath at 310 nsec. since this multipath has a relative gain of −1 dB quite close to the peak at 0 sec., but the later multipaths are already attenuated by more than 9 dB. This model assumes that the first incoming path is strong, but the second incoming path is as strong as the first incoming path. In the ITU Vehicular Model B, the relative gain of the peak at 300 nsec, corresponding to approximately 1 chip delay, is higher than the delay of the peak at 0 sec. So, peaks are detected at mostly at 0 and at 1 chip offset, since the later multipaths are already attenuated by more than 12 dB. In this model, the strongest path is the second incoming path. The CODIT Macro model is by far the most interesting model, since it has many multipath components at delays close to each other and having similar relative gains. Peaks are detected at 0, 1, 2, 3, 4, 5, and 6 chip offsets. It is the model where a geolocation would be expected to be most erroneous. As expected, there are 0, 1, 2, 3, 4, 5, and 6 chip delays and the occurrence of 0 chip delays are rare, compared to the other possible delays. Figure 3 shows an example of delays obtained from this model.

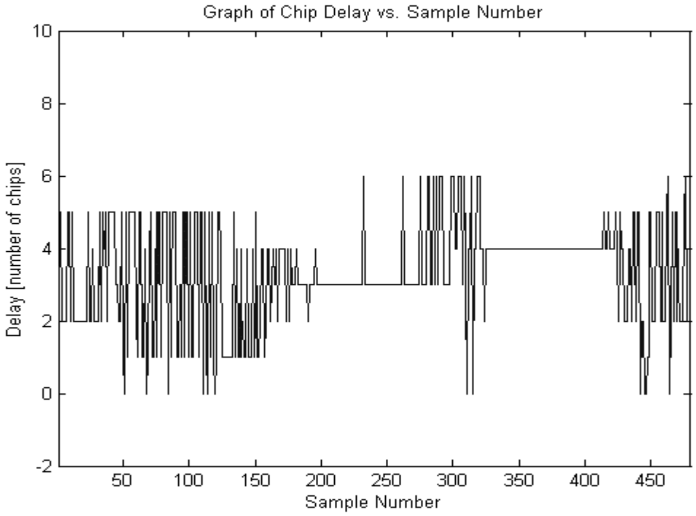

Figure 3: Chip delay versus sample number for CODIT Macro model

Note that the resolution time was taken as one chip time, 260 nsec, for the considered multipath models. Taking more samples can increase the resolution, and in general, it can increase the accuracy of the timing measurement. In a typical application, a long time integration of pilot signals such as 10 msec with finer resolution will consume much more processing power. However, the results are also obtained with 1/8 chip resolution to see the effect of 1 chip resolution. In Figures 4-7, the staircase curve is obtained for the one-chip resolution time measurements, and the solid curve is obtained with the 1/8 chip resolution time measurements. For the CODIT Channel Model, the cumulative distribution function (CDF) of the distance error is plotted in Figure 4 for a COST 231 Suburban environment.

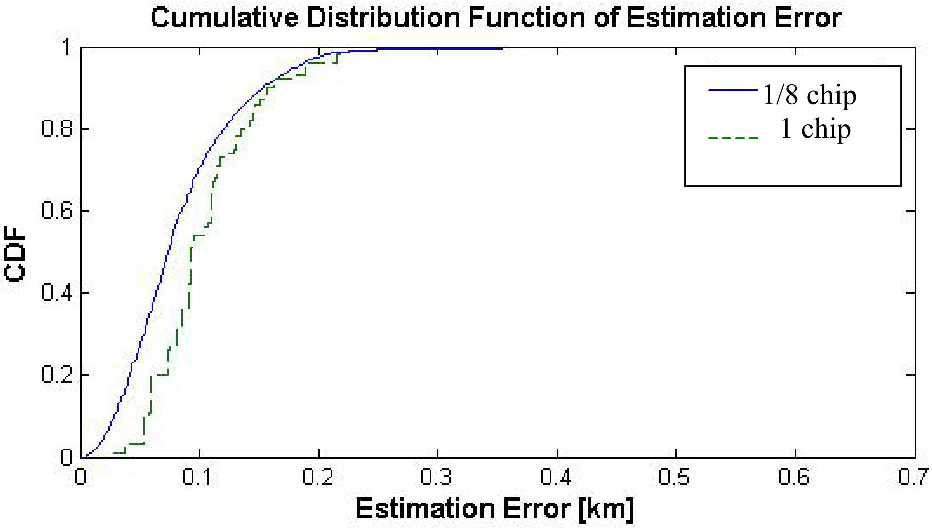

Figure 4: CDF of estimation error for suburban CODIT model

For the exact time measurements, the error is below 95 meters 67 % of the time and below 160 meters 90 % of the time. The overall error is decreased for the 1/8 chip resolution compared to 1 chip resolution. In Figure 5, the performance of the TDOA/RTT algorithm is obtained for suburban ATDMA channel model in terms of the cumulative distribution function of location error. For ATDMA channel, the first incoming path is at least 10 dB stronger than the other multipath components, the error is within 59 meters 67 % of the time, and 92 meters, 90% of the time, mainly caused by the AWGN contribution.

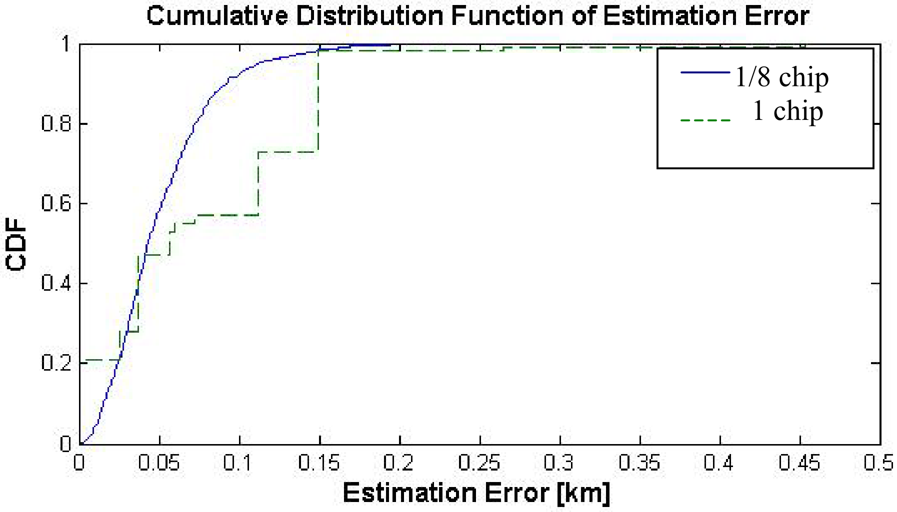

Figure 5: CDF of estimation error for suburban ATDMA model

In Figure 6, the result of the TDOA/RTT algorithm is plotted for ITU Vehicular A channel model in suburban environment. The location error is within 55 meters 67 % of the time and 104 meters, 90% of the time. The ITU Vehicular A model has a better multipath distribution than the CODIT model, but multipath components are much widely distributed than the ATDMA channel model and the location error variance is larger than the ATDMA channel model.

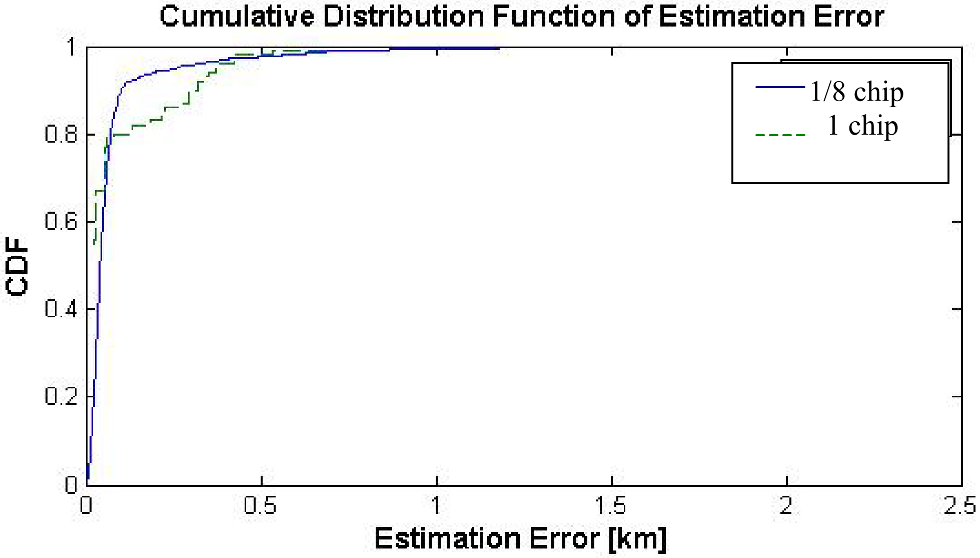

Figure 6: CDF of estimation error for suburban ITU Vehicular A

Finally, the CDF of the location error for ITU Vehicular B Channel model is plotted in Figure 7. From the CDF distribution, the location error is within 53 m 67 % of the time, 91m, 90% of the time, which is the second best channel model. In this channel model, the strongest incoming path is offset but this induces a small amount of timing error (300 nsec).

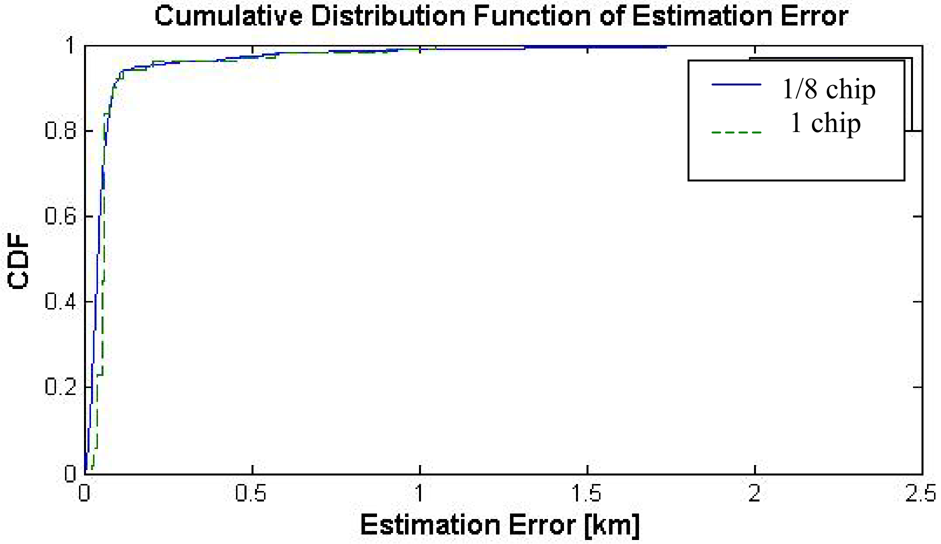

Figure 7: CDF of estimation error for suburban ITU Vehicular B

We have also obtained overall error for different propagation environments and different multipath models in the location estimates of mobile station. These are tabulated as 90 % estimation errors in Table 1 for Suburban, Urban and Rural environments using COST 231 propagation models. It can be seen from the table that The CODIT Macro model, simulates the worst multipath conditions, yields the largest error for the urban environment type (161 meters). ATDMA model yields the largest error for the urban environment type while the location errors in Vehicular A and Vehicular B models do not seem to depend on the environment type. The simulated results are fairly reasonable for some of the location based services such as location based billing, location specific advertising, considering that one chip time corresponds to 78 m resolution.

Table 1: 90% estimation errors for various environments and channels –1/8 chip resolution

Estimation Error [m]				
	CODIT	ATDMA	ITU Vehicular A	ITU Vehicular B
Suburban	160	92	104	91
Urban	161	168	106	98
Rural	150	130	98	81

V. Conclusion

In this paper, a hybrid TDOA/RTT mobile location finding technique is introduced for a WCDMA network. The input to the algorithms is provided by both mobile and base stations time of arrival measurements. The mobile station measures TDOA at least from three BSs downlink CPICH channel, and at least three BSs measure RTT on MS uplink signal. As solution from the algorithms, mobile location and synchronization time offsets between base stations are obtained. The effect of multipath propagation is investigated on the performance of these algorithms for ATDMA Macro, CODIT Macro, ITU Vehicular A, and ITU Vehicular B channel models, and the assumed propagation model is the COST231 model with 8 dB lognormal shadowing as well as Rayleigh fading for a mobile speed of 95 km/h. The proposed algorithms do not need any special hardware for the measurement of synchronization time offsets between BSs. Implementation of the technique may require new messages on WCDMA standards or can use some of the messages that are already in standards and hence the TDOA/RTT technique is a software-only solution.

References

1. FCC docket no CC-94-102, FCC ruling on E911 phase II, http://wireless.fcc.gov/releases/e911reconFinalPR.doc
2. Sunay MO and Tekin I, Mobile location tracking for IS-95 networks using the forward link time difference of arrival and its application to zone-based billing, *Proc. IEEE Glob. Telecom. Conf.*, Dec. 5-9, 1999.
3. Wang SS, Green M, and Malkawi M, Analysis of downlink location methods for WCDMA and cdma2000, *IEEE Vehicular Technology Conference*, vol. 4, pp. 2580 – 2584, May 2001.
4. Grosicki E et. al., Comparison of downlink mobile positioning methods for the UMTS FDD mode without using IPDL periods**,** *Proceedings of Seventh International*

Symposium on Signal Processing and Its Applications, vol. 2, pp. 347–350, July 2003.

5. Jung-Chieh C, Ching-Shyang M, Yeong-Cheng W and Jiunn-Tsair C, Mobile position location using factor graphs, *IEEE Communications Letters*, Vol. 7, Issue 9, pp. 431 – 433, Sept. 2003.
6. Sangheon K, Yangseok J, Chungyong L, Interference-cancellation-based IPDL method for position location in WCDMA systems, *IEEE Trans. On Vehicular Technology*, vol. 54, Issue 1, pp.117 – 126, Jan. 2005.
7. L. Cong and W. Zhuang ''Hybrid TDOA/AOA mobile user location for wideband CDMA cellular systems'', IEEE Trans. on Wireless Comm., vol. 1, no. 3, pp. 439-447, July 2002.
8. Chin-Der Wann, Yi-Jing Yeh and Chih-Sheng Hsueh, ''Hybrid TDOA/AOA Indoor Positioning and Tracking Using Extended Kalman Filters'', *IEEE Vehicular Technology Conference*, vol.3, pp.1058-1062, 2006.
9. Technical Specification Group Radio Access Networks, UE Radio transmission and reception (FDD) (Release 5), *3GPP, Technical Specification* 3G TS 25.101 v. 5.3.0, Jun. 2002.
10. Rappaport TS, Wireless Communications, Principles and Practice, *Prentice Hall*, NJ, 2002.
11. CDMA Reference Blockset User's Guide, *The Mathworks*, Inc., 2001.
12. Ojanpera T, WCDMA for third generation mobile communications, Artech House, 1998.
13. ITU-R M.1225, Guidelines for evaluations of radio transmission technologies for IMT-2000, 1997.
14. Kabadayı S, System Level Simulation of a third generation WCDMA wireless geolocation network, *MS Thesis*, Sabancı University, Istanbul, 2002.
15. Technical Specification Group Radio Access Networks, Requirements for support of radio resource management'' (FDD) (Release 7), *3GPP, Technical Specification* 3G TS 25.133 v. 7.2.0, Dec. 2005.
16. Technical Specification Group Radio Access Networks, Physical layer - measurements'' (FDD) (Release 6), *3GPP, Technical Specification* 3G TS 25.215 v. 6.4.0, Sept. 2005.
17. Technical Specification Group Radio Access Networks, Physical channels and mapping of transport channels onto physical channels, (FDD) (Release 6), *3GPP, Technical Specification* 3G TS 25.211 v. 6.7.0, Dec. 2005.