TERMINAL POSITIONING IN WCDMA

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ABSTRACT

This paper provides an overview of the terminal positioning capabilities in Wideband CDMA (WCDMA). The current situation in standardization is covered and the basic terminal positioning methods applicable in WCDMA are discussed. Performance evaluations by simulations of the selected solutions are provided at the end of the paper.

1 INTRODUCTION

LoCation Services (LCS) are a new segment of value-added services that will be introduced in future wireless communications systems. The interest towards LCS was initiated when the FCC[1] ruled in 1996 that in USA the emergency calls from mobile cellular terminals should be positioned[2]. The positioning capabilities built for this purpose can be used also for other applications benefiting from location information. Other possible LCS applications include e.g. location based billing, location based "yellow pages", "where am I" or "where is the nearest restaurant" type of services. The terminal location information can be utilized also in cellular network internal tasks like aiding the handovers and radio resource allocation & management. At the present moment LCS for GSM and WCDMA is under standardization within 3rd Generation Partnership Project (3GPP)[3].

Currently, the WCDMA LCS functional specification [1] includes three standard positioning methods i.e. i) *cell-identity based method*, ii) *OTDOA-IPDL* (cellular network based method), iii) *network assisted GPS method*. The cell-identity based method is a trivial one, but it can give a sufficient accuracy to a significant fraction of the LCS applications especially in urban microcellular environment where the cell sizes are small. The network-assisted GPS does not cause significant WCDMA system implications. Thus, from WCDMA system point-of-view the OTDOA-IPDL is the most interesting of these method, and therefore it is discussed in detail in this paper.

In section 2 the design requirements for terminal positioning in WCDMA are discussed. In section 3 the positioning operation is described. In section 4 simulation results in realistic scenarios are presented. Section 5 concludes this paper.

2 OTDOA-IPDL METHOD IN WCDMA

In this section the OTDOA-IPDL (*Observed Time Difference of Arrival - Idle Period DownLink*) positioning method is described, and how it is tackling the generic problems in CDMA positioning are discussed. The terminal positioning in CDMA systems have been treated e.g. in [2, 3, 4], but the results and system implications presented therein are not fully applicable to WCDMA.

2.1 OTDOA

The basic terminal positioning methods are based on the range estimates

$$r_i = c \cdot t_i = \|\mathbf{x}_i - \mathbf{x}\|_2 \quad (1)$$

or range difference estimates

$$r_{i,j} = c \cdot t_{i,j} = c \cdot (t_i - t_j) = \|\mathbf{x}_i - \mathbf{x}\|_2 - \|\mathbf{x}_j - \mathbf{x}\|_2 \quad (2)$$

between several known positions and the unknown position of interest. c is the speed of light and t_i is the signal propagation time between the unknown position in question and ith known position. $\mathbf{x}_i$ and $\mathbf{x}$ are the Cartesian coordinates of the ith known position and the unknown position, respectively, and $\|\cdot\|_2$ is the Euclidean distance. In order to carry out the location calculation, at least two range difference estimates (or three range estimates) are required when positioning is done in 2-D.

The WCDMA network is asynchronous, and the different network elements and terminals do not have a common timebase. Therefore arranging *time-difference-of-arrival* (TDOA) measurements $t_{i,j}$ is easier than trying to carry out *time-of-arrival* (TOA) measurements t_i,

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[1] Federal Communication Commission

[2] The original ruling was that the accuracy of positioning should be within 125 m in 67 % of cases. This requirement was tightened in 1999 to 50 m for handset-based schemes and 100 m for network-based schemes.

[3] 3GPP is a joint activity of the European ETSI, American T1, and Japanese ARIB to standardize next generation wireless communication systems

as it requires only that the asynchronity of the transmitters is known, which can be measured. When the bias due to network asynchronity has been compensated, the TDOA measurement result is called Observed TDOA (OTDOA) (see Section 3.1).

2.2 Downlink

Basic requirement for a positioning method utilized in a cellular system is that the cellular system capacity should not be significantly affected by the positioning measurements. In practice this means that additional positioning-only signals should not be introduced, and the transmission powers should not be significantly affected.

By taking this limitation into account, the conclusion is that in WCDMA the positioning measurements need to be based on downlink[4], where the common pilot channel (CPICH) is very suitable for the measurement purposes. It is transmitted continuously with significantly higher power than the other traffic or control channels to facilitate coherent reception.

2.3 Idle periods

For downlink based positioning, transmissions from at least three surrounding base stations must be received in order to carry out the positioning operation. When a terminal is close to its' serving base station, it might not receive other base stations, and the positioning cannot be carried out with certainty. This is called the *hearability* problem in CDMA positioning.

In order to come over this problem, so called *idle periods* can be introduced in WCDMA [5]. In this scenario each base station pseudorandomly turns off its' transmission for a short period of time, creating an idle period during which terminals within its' coverage area can measure other base stations for positioning purposes. The length of a single idle period should be so short that its' effects to system level performance (due to an inherent increase in bit error rates) are negligible. On the other hand the idle periods should be so long that they can be used for positioning measurements, especially when measurement results are combined over several consecutive idle periods. Typical values for the parameters of idle periods are on the order of 1 slot (667 μs) per 10 frames[5].

3 POSITIONING OPERATION

In this section the positioning operation in WCDMA system is described. The operation is originated by a LCS application, residing either in the network or in the terminal, requesting the location information of the particular terminal. The major tasks in the positioning operation are first to carry out the required measurements, and then based on the results, to estimate the terminal location.

3.1 The measurements

3.1.1 Terminal measurements

In OTDOA-IPDL the terminals carry out most of the measurements. In order to overcome the hearability problem the measurements are done during the idle periods.

The idle periods are so short (e.g. on the order of 1 slot) that in order to obtain reliable results (i.e. to ensure high enough signal-to-interference ratio, SIR) the measurements need to be carried out over several consecutive periods. The required number of idle periods depends on the power level of the base stations of interest. The maximum number of idle periods for one measurement is limited by some facts. As the terminal can move during the measurement, the total measurement time (i.e. the time between the first and last idle periods used for the single measurement) must be limited to such that the uncertainty due to the movement is tolerable. Also, the accuracy of the base station and terminal clocks is limited, and the clock drifts cause inaccuracies to the timing measurements. For example if the clock stability is 0.05 ppm, in the worst case the inaccuracy due to clock drift would correspond to 30 meters per second. From this perspective the total measurement time should be limited to values below 1 second.

The measurement procedure is following. The received signal during idle period is correlated with the given spreading codes (the spreading codes of the common pilot channels of the cells of interest). The size of the search window (the lags over which the correlations are calculated) depends on the distances between base stations and uncertainty due to network asynchronity, i.e. on the uncertainty of the signal arrival time. The correlation results are noncoherently combined with the correlation results of previous idle periods, i.e.

$$z_t^{(k)} = \sum_{l=1}^{N} |y_{t,l}^{(k)}| \tag{3}$$

where $y_{t,l}^{(k)}$ is the correlation result of kth base station during lth idle period with lag t, and N is the number of idle periods used for the measurements. Noncoherent combining is required due to the phase uncertainty caused by the terminal movement and clock drifts during the measurement interval.

After a predefined number of idle periods have been combined, the *first in time* multipath component is detected from the correlation results. For example if threshold detection is used, then

$$\tau_k = \min_t (D(z_t^{(k)}) > T), \tag{4}$$

[4] from base station to terminal direction

[5] In WCDMA the frame duration is 10 ms, and each frame consists of 15 slots.

where T is the detector threshold. The first in time component is of interest, as this corresponds to the component that has traveled the shortest route between transmitter and receiver in a dispersive multipath channel.

To obtain the "raw" TDOA measurement result (before the asynchronity correction), one of the measured base stations (e.g. the serving base station) is selected as the reference and the time differences of other base stations are calculated with respect to it,

$$\tau_{k,1} = \tau_k - \tau_1. \qquad (5)$$

3.1.2 Network measurements

As the WCDMA network is asynchronous, real TDOA measurements are possible only if the asynchronity between base station transmissions are known. This information can be obtained by measuring this timing difference (RTD, i.e. Real Time Difference) at a known, fixed location. As the locations of the base stations are also fixed and known, the asynchronity between the base stations transmission is then directly obtained. Also these measurements can utilize the idle periods to maximize the SIR of the measurements.

When the RTD measurement information is combined with the actual TDOA measurement information the OTDOA measurement result is obtained, i.e.

$$t_{k,1} = \tau_{k,1} + \mathrm{RTD}_{k,1} \qquad (6)$$

3.2 Location calculation

When the OTDOA values are available the actual location calculation can be carried out. The calculation involves finding a solution to the system of equations where the equations are of form (2), each representing a hyperbola. Solving of the system of equations thus corresponds to finding the intersections of these hyperbolas.

To solve this problem a lot of research has been done in different application areas, and these results can be directly utilized in this case also. Different approaches to this problem has been taken e.g. in the papers [6, 7, 8, 9, 10].

Special features in WCDMA that affect the location calculation operation, and thus need to be taken into account in the algorithm selection, are at least the following:

- Due to reuse 1[6] only few of the neighboring base stations can be measured with high enough SIR. Thus the number of useful measurements is limited. Also the quality of the measurements is not uniform. The base stations that are closer can be measured more reliably than those further off.

- Nonline-of-sight signal propagation can cause significant errors to the measurement results. Thus the location calculation algorithm should be robust against these kind of errors.

[6]In reuse 1 all cells operate on the same frequency band

Chip rate	3.84 Mchip/s
Idle period length	5*256 chips(half a slot)
Frequency of idle periods	10 Hz
Number of idle periods	10
Channel models: T1P1.5 models [11]	Rural, SubUrban, UrbanA, UrbanB, BadUrban
Cell size:	1 (Urban), 3 (SubUrban) 20 km (Rural)
Pathloss model: Hata	$\beta + \alpha * 10 \log(\text{range in m})$
Urban	$\alpha = 3.52,\ \beta = 29.03$
SubUrban	$\alpha = 3.48,\ \beta = 22.2$
Rural	$\alpha = 3.41,\ \beta = 0.34$
Terminal velocity	50 km/h
Lognormal fading, σ	8 dB

Table 1: *OTDOA-IPDL simulation parameters. The number of base stations in the simulation was 24.*

4 SIMULATION RESULTS

The OTDOA-IPDL was simulated in WCDMA system setup. The simulation parameters representing a realistic system scenario are shown in Table 1. As channel models, which are very crucial especially in the case of LCS, the ones developed within T1P1.5[7] [11] were utilized.

The simulation results are presented in Figures 1 and 2. In Figure 1 the LCS performance in different propagation environments is presented. As can be seen, in rural and suburban environments the performance can be very good, as line-of-sight propagation between several base stations and the terminal exist. In these cases the positioning accuracy is limited mainly by the measurement resolution in time. In urban environments the losses due to different degrees of nonline-of-sight (NLOS) propagation can degrade the performance significantly, and the NLOS situation limits the achievable accuracy.

In Figure 2 the effect of the location calculation method to the positioning accuracy is depicted. As an example Chan-Ho's method [10], Taylor-series method [6], and basic least squares solution to the resulting system of equations were used to derive these results. As can be seen the performance differences between methods vary in different environments. This is due to the fact that the sensitivity of the methods to certain type of errors varies. Therefore in the selection of the location calculation method the expected operating environment needs to be taken into account, e.g. are the measurement results likely to be biased or not. The effect of bias errors to location calculation algorithms has been studied in [12]

[7]Subgroup of T1 which took care of the LCS standardization for PCS1900

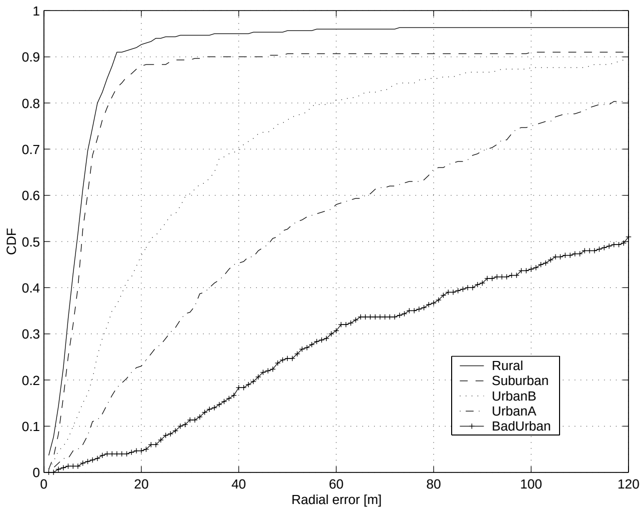

Figure 1: *Performance of OTDOA-IPDL in different radio propagation environments as the cumulative distribution function of the radial positioning error. Taylor-series method [6] was used for the location calculation.*

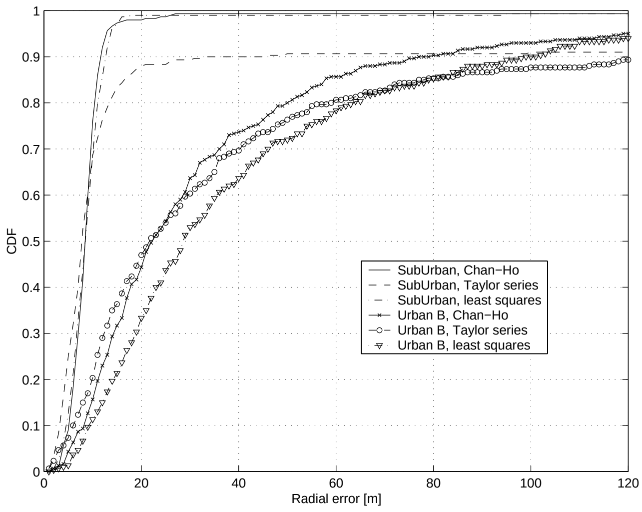

Figure 2: *Positioning accuracy with different location calculation methods in different environments.*

5 CONCLUSIONS

In this paper an overview was given on the system support for terminal positioning in WCDMA. The practical problems in CDMA positioning were briefly described as well as the solutions how they are mitigated in WCDMA. The positioning operation was described shortly, and simulation results with WCDMA system parameters were presented. These results show that in some radio propagation environments high positioning accuracy can be achieved with cellular network based methods. In difficult propagation environments, like urban environments with difficult nonline-of-sight situation, the achievable accuracy can be much worse.

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