Mobile-Based TDoA Estimation in UMTS Using Multichannel Serial Correlator

Mladen Veletić, Nebojša Maletić, Slavko Šajić
Department of Communications
Faculty of Electrical Engineering
Banja Luka, Bosnia-Herzegovina
mladen.veletic@etfbl.net

Milan Šunjevarić
RT-RK
Institute for Computer Based Systems
Novi Sad, Serbia
micosun@eunet.rs

Abstract— **This paper presents a novel Time Difference of Arrival (TDoA) estimation algorithm for mobile station positioning in Universal Mobile Telecommunication System (UMTS) based on cell search procedure defined by 3GPP. Standardized method for Time Difference of Arrival (TDoA) measurement and cell search procedure are stated. Furthermore, proposed solution for TDoA parameter estimation via multichannel serial correlator utilizing Primary Synchronization Code (PSC) at Primary Synchronization Channel (Primary SCH) within UMTS air interface is given.**

Keywords- cell search, correlator, PSC sequence, TDoA

I. INTRODUCTION

Positioning within contemporary third-generation (3G) cellular networks, mainly used for mobile users communication, became additional feature that enhances users security and opens wide range of opportunities for mobile operators providing this type of service (e.g. emergency calls). Also, accurate position information for the mobile users within the wireless network would significantly enhance the network efficiency and usefulness of the multimedia services provided by operators.

According to Third Generation Partnership Project (3GPP), Location Based Services (LBS) based upon the knowledge of user`s location, represent services within cellular radio-networks that use available information about user location. There are eight standardized LBS, summarized in Table 1 [1].

Mobile station positioning in cellular networks started with simple methods, which required slightly modified network infrastructure. Due to low precision of such techniques, initiated development of more sophisticated methods has not been finished yet. However, European Telecommunication Standards Institute (ETSI), responsible for positioning techniques standardization in UMTS, prescribed four methods for UMTS Terrestrial Radio Access Network (UTRAN):

- Cell Identification – Cell ID,
- Observed Time Difference of Arrival – O-TDoA,
- Uplink Time Difference of Arrival – U-TDoA and
- Global Navigation Satellite System – GNSS [2].

Foregoing positioning methods are characterized by trade-off between positioning precision and requirements for additional hardware that are the major holdback for service implementation.

TABLE I. STANDARDIZED SERVICE TYPES

Location based services categories	**Standardized Service Types**
Public Safety Services	Emergency Services Emergency Alert Services
Location Sensitive Charging	
Tracking Services	Person Tracking Fleet Management Asset Management
Traffic Monitoring	Traffic Congestion Reporting
Enhanced Call Routing	Roadside Assistance Routing to Nearest Commercial Enterprise
Location Based Information Services	Traffic and Public Transportation Information City Sightseeing Localized Advertising Mobile Yellow Pages Asset and Service Finding
Entertainment and Community Services	Gaming Find Your Friend Dating Chatting Route Finding Where-am-I
Service Provider Specific Services	

Theoretical considerations in this paper are mostly engaged in mobile-based (downlink) TDoA estimation algorithm for purpose of O-TDoA positioning technique. Inductive problem has been considered in [3] where authors investigated the relaying issue of Zero-Padding Orthogonal Frequency Division Multiplexing (OFDM) technique to estimate TDoA for locating applications. Technique possesses bandwidth efficiency although pilot or preamble is prerequisite. In [4] authors analysed Expectation-Maximization (EM) algorithm in the presence of correlated multipath interference and noise with assumption that the signal is band limited complex Gaussian process. Reference [5] deliberates non-line-of-sight (NLOS) error mitigation approach in measuring TDoA for tracking issues, using the probability density estimation of the state of the moving target.

Compared with related works, proposed algorithm for TDoA estimation with downlink signal processing has no computational complexity and requires slightly modification of mobile phone hardware with no usage of network resources (capacity). Nevertheless, demerits of proposed algorithm are present in the form of increased processing power and cognition of discernible Node Bs` coordinates.

II. Time Difference of Arrival, TDoA

This localization parameter shows the difference of two Time of Arrival (ToA[1]) measurements obtained from two equivalent signals emitted at the same point in time. Unlike the ToA measurements method, TDoA method does not require synchronization between the transmitter and receiver. Assuming that signals from two base stations are broadcast at the time t_{tx} and that the mobile station is at distance r_1 and r_2 from the first and second Node B, respectively, TDoA is determined by

$$t = t_{tx} + r_1/c + \varepsilon_{sync} - (t_{tx} + r_2/c + \varepsilon_{sync}) = (r_1 - r_2)/c, \tag{1}$$

where ε_{sync} denotes compensation factor for synchronization absence between Node B and User Equipment (UE) and c is speed of light. TDoA might be measured on uplink or downlink. On uplink, UE emits signal received by two Node Bs. This type of measurement might have a scalability problem due to operations carried out just by network infrastructure. In contrast, two Node Bs emits two equivalent signals at the same point in time on downlink making scalability problem overcome. Regardless of method applied, Node Bs must be mutually synchronized, although UE and Node Bs may not.

Introducing variable component, we can get

$$\begin{gathered} t = (r_1 - r_2)/c + \mu_t + \mu_{prop}, \\ \mu_t \equiv Tri(-c/f,\ c/f),\ \mu_{prop} \equiv Norm(0,\ 2\sigma_{prop}), \end{gathered} \tag{2}$$

where triangular error distribution from $-c/f$ to c/f, formed by subtracting two uniform distributions, takes its role. In addition, identical noise components are assumed in communication channel from UE to Node B1 and from UE to Node B2.

III. Standard Method for TDoA Measurement in UMTS

Measurement of OTD (*Observed Time Difference*), which is done by UE, is based on *SFN (System Frame Number) - SFN_{OTD}* parameter. There are some differences when it comes to definition of OTD depending on Node B mode (UTRAN-FDD or UTRAN-TDD). Further, TS 25.215 and 3GPP TS 25.225 define two types of $SFN - SFN_{OTD}$. Type 1 is used for soft handover, whereas positioning methods make use of type 2. In accordance to the above, 3GPP TS 25.215 defines $SFN\text{-}SFN_{OTD}$ for UTRAN-FDD as:

$$SFN - SFN_{OTD} = t_{CPICH,\ Rxj} - t_{CPICH,\ Rxi} \tag{3}$$

where $t_{CPICH,\ Rxj}$ represent time of primary Common Pilot Channel (CPICH) slot reception from cell *j*, whereas $t_{CPICH,\ Rxi}$ represent time of primary CPICH slot reception from cell *i.* Difference between introduced two timestamps is small. UE is receiver in both specified cases.

3GPP TS 25.225 defines $SFN\text{-}\ SFN_{OTD}$ for UTRAN-TDD as:

$$SFN - SFN_{OTD} = t_{Rx\ Frame\ Cell\ k} - t_{Rxi\ Frame\ Cell\ i} \tag{4}$$

where $t_{Rxi\ Frame\ Cell\ i}$ represent start point at process of frame reception from TDD cell *i*, whereas $t_{Rx\ Frame\ Cell\ k}$ represent start point at process of frame reception from cell *k*, which frame time is closest to the frame time of cell *i*. Also, UE is receiver in both specified cases.

These measurement methods has problem of furlough of time synchronization between UTRAN-FDD Node Bs and insufficient number of pilot signals. Nevertheless, hearability effect in CDMA causes the major problem. To overcome this problem, each Node B needs to stop emission within short time periods when UE becomes able to detect CPICH channel from the neighbouring Node B. These periods are called as idle and corresponding method IPDL (*Idle Periods Downlink*) mode.

IV. UMTS Technology Features

A. UMTS Air Interface

Since we examined UMTS air interface and remarked identical fraction (binary sequence) broadcast from all Node Bs simultaneously, parallel multichannel serial correlation as the method of TDoA estimation has been envisioned. Basic UMTS system characteristics, relevant to the topic discussed, are specified in the following text.

The chip rate of the system is *3.84 Mchip/sec*. The radio frame length is *10 ms* and each frame is divided into 15 slots. Whereas mobile-based method is considered, only downlink physical channels are investigated. There is one downlink dedicated physical channel, one shared and five common control channels in UMTS:

- Downlink dedicated physical channel –DPCH,
- Physical downlink shared channel – DSCH,
- Primary and secondary common pilot channels – CPICH,
- Primary and secondary common control physical channels – CCPCH and
- Synchronization channel - SCH.

The SCH is used for cell search and its existence is crucial for TDoA estimation procedure described in this paper. This physical channel consists of two subchannels, primary and secondary SCH. The primary SCH consists of a modulated

[1] ToA, sometimes called time of flight (ToF), is the travel time of a radio signal from a single transmitter to a remote single receiver

code of length 256 chips named Primary Synchronization Code (PSC), which is transmitted once per slot. *The PSC sequence is the same for every cell in the system*. The secondary SCH consists of repeatedly transmitted sequence of 256 chips chosen from a set of 16 different codes named Secondary Synchronization Codes (SSC). The secondary SCH is transmitted in parallel with primary SCH [6]. PSC and SSC are Gold codes that do not change bandwidth.

As noted above, the SCH is used by UE in cell search procedure which is backbone for solution proposal. Accordingly, the following section gives procedure review.

B. Cell Search Procedure

When creating the handover list, UE receive signals from all Node Bs. Therefore, UE have the opportunity to correlate identical PSC sequences broadcast from different Node Bs and thereby determine TDoA. Cell search procedure is described from the 3GPP specification TS25.214 as follows.

Step 1: UE uses SCH`s PSC to acquire slot synchronization to a cell. For instance, synchronization can be done by detecting correlation peaks in the matched filter output.

Step 2: UE uses SCH`s SSC to acquire frame synchronization and identify the scrambling code group of the cell found after the first step. This can be also done by correlation applying.

Step 3: UE detects the exact primary scrambling code used by the found cell whose signal is being analysed. The primary scrambling code is typically identified through symbol-by-symbol correlation over the CPICH with all codes within the code group identified in the step 2.

When procedure is complete, UE can read specific Broadcast Channel (BCH) information from identified Node B. Modified procedure for TDoA estimation would constitute "feedback loop" which would return process from third to first step, in order to comprehend which Node B broadcast the PSC. Procedure is in detail described in the following section.

V. A Novel Algorithm for TDoA Estimation in UMTS

A. Digital Correlator with Serial Bit Processing

Multichannel digital correlator with serial bit processing [7], shown in Fig. 1, should be used. Nevertheless, the correlator should have additional incoming channels for parallel processing to be used in TDoA estimation procedure described further. The correlator's core is $M \times 256$ FIFO buffer with length of 256 and width of M binary symbols. While time-shifted PSC sequences are being written in FIFO, random content is written in the receiving channel. Clarification is given below.

Writing clock (C_{in}) is phase shifted compared to reading clock (C_o). At each clock C_o, the corresponding binary symbols of the receiving binary PSC sequence ($D(BS_i)$) and local PSC sequences (S_{ji}, $i=1,...,256; j=1,...,k$) are present at the output. EXOR circuits compare binary symbols $D(BS_i)$ with corresponding column of local PSC sequences binary symbols S_{ji}, while outputs associated counters count uncorrelated binary symbols. After one cycle of circling enabled by signal C_s (duration time of $L \times T_c$ seconds), the i-th counter is in state B_i ($i=1,...,k$) (B_i is the number of uncorrelated bits between sequences) and local sequences take the same position in FIFO buffer which they had before circular operation. If the number of uncorrelated binary symbols is less than the decision threshold then the correlation peak would be generated at the i-th output of the correlator. The readers are referred to [7] to get the operation principle of correlator.

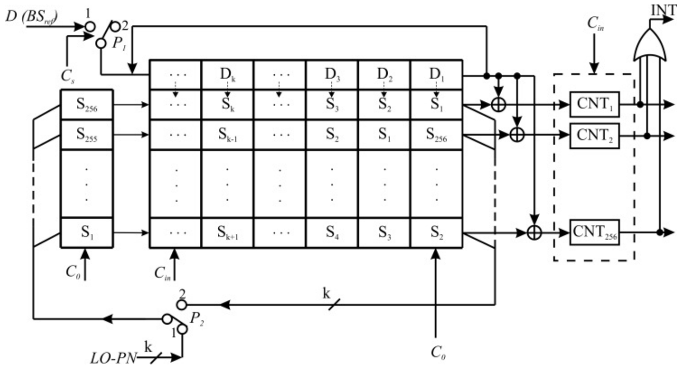

Figure 1. Multichannel digital correlator with serial processing [7]

B. Procedure Description

A scheme of TDoA estimation procedure is depicted in Fig. 2. Upon step 1 at the matched filter output, correlation peaks occur in case of time slot identification ($CP1_i$ signals, where i denotes channel index number). These peaks are phase-shifted for $T = 256xT_c + \Delta t$ seconds compared to the time slot start point. T_c represents chip duration ($1/(3.84$ $Mchips/sec) = 260.416$ ns) and Δt required correlation time. After generating correlation peaks signals at step 2 ($CP2_i$ signals) and scrambling code identification at step 3, novel algorithm of TDoA estimation in UMTS can be introduced. Based on detected unique scrambling codes, it can be specified from which Node B PSC sequence originates.

Upon first scrambling code identification, correlator`s local register is enabled to load PSC sequence of identified Node B, which is labeled as reference Node B in respect of which a delay of other sequences will be evaluated. Control signal that enables PSC sequence to be written in is $(2560-256) \times T_c + \Delta t$ seconds delayed $CP2_i$ signal (*Input Enable* signal, Fig. 3) in order to write whole sequence. 2560 is the total number of chips in one slot and 256 is PSC sequence length. During the *Input Enable*`s logical 1, new binary symbols of PSC sequence are clocked via $C_{in}$ mentioned previously. Correlator`s FIFO buffer should be loaded with time-shifted versions of reference PSC sequence. Observed sequence is written as follows:

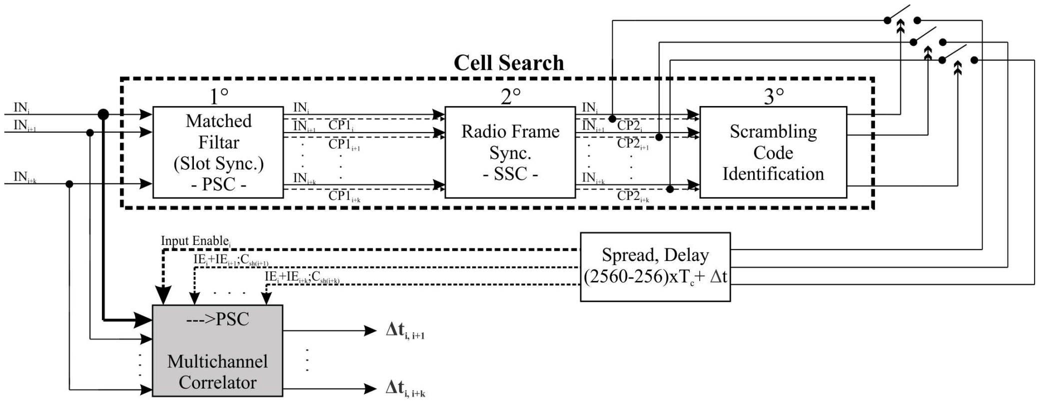

Figure 2. Scheme of the proposed solution for TDoA estimation

- *Input Enable* control signal which enables reference PSC loading will also enable partly load of succeeding PSC into subsequent register (channel 2);
- whole sequence loading will be finished when *Input* $Enable_{i+1}$ (IE_{i+1}) logical 1 end; thus, signal that enables whole sequence load is IE_i+IE_{i+1};
- after this step, it is necessary to carry out cyclic shift of saved sequence to determine delay by correlation peak detection; cyclic shift is controlled by time shifted signal $C_{sh} = (IE_i+IE_{i+1}) - IE_i$ which is generated after sequence load process; all control signals are shown in Fig. 3.

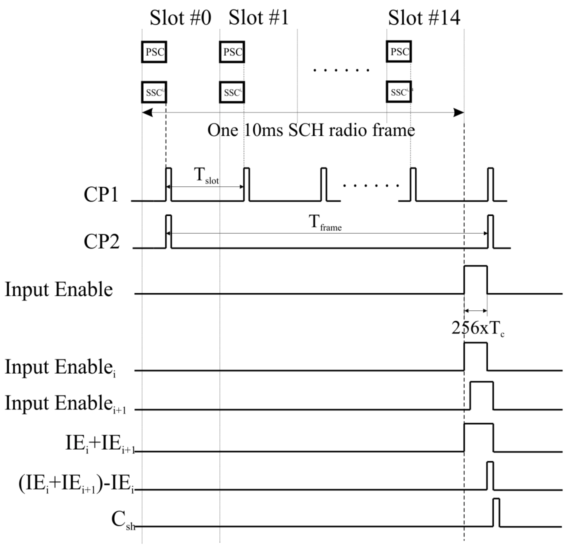

Figure 3. Control signals in relation to primary and secondary SCH

According to [7], channel number where correlation peak appears determines signal delay with regard to referent Node B. For instance, if delay of signal broadcast by n-th Node B is being measured, and if correlation peak is being occurred at k-th correlator channel, than it is known that $\Delta t_{ref,n}$ is $k \times T_c$ seconds. This way, the TDoA parameter is easily obtained. TDoA technique implementation requires at least three TDoA parameters. FIFO buffer width directly affects the TDoA measurement accuracy. Registers in FIFO buffer should be of length 256 chips which correspond to PSC sequence length. If buffer width is 256, than it is possible to record one chip shifted versions of PSC sequence, therefore making a maximum error of *260.416 ns* which correspond to *78.125 m*.

VI. Conclusion

This paper presents a novel algorithm for TDoA estimation. Since cell search procedure is set up as the algorithm basis, aside from multichannel digital serial correlator, algorithm requires no additional hardware. As shown in [7], multichannel digital correlator allows simultaneous correlation of multiple local shifted PSC sequences and receiving PSC sequence, without increase of correlation time in comparison to one sequence processing. Thereby more TDoA values can be acquired at the same time. Further work will be towards method simulation and implementation. Also, robustness and accuracy of proposed TDoA algorithm in all kinds of propagation environments will be analyzed.

References

[1] 3GPP TS 22.071, release 10 (v10.0.0), Location Services (LCS) Service description; Stage 1, 2011.

[2] Milan Šunjevarić, Mladen Veletić, Branislav Todorović, "Radio-localization of mobile station in third generation network", ("Radio-lociranje mobilne stanice u mrežama treće generacije"), *Vojnotehnički glasnik*, to be published.

[3] Hao Lu, P. Martinez, Homayoun Nikookar, "Cooperative TDOA estimation with trigger relay", *International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC)*, 2011, pp. 1309-1313.

[4] Belanger, S. P., "Multisensor TDOA estimation in a multipath propagation environment using the EM algorithm", *Record of the Twenty-Ninth Asilomar Conference on Signals, Systems and Computers*, Vol. 2, 1995, pp. 1096-1100.

[5] Hao Jiang, Jie Xu, Zhen Li, "NLOS mitigation method for TDOA measurement", *Sixth International Conference on Intelligent Hiding and Multimedia Signal Processing (IIH-MSP)*, 2010, pp. 196-199.

[6] 3GPP TS 25.211, release 11 (v11.0.0), Physical channels and mapping of transport channels onto physical channels (FDD), 2011.

[7] Slavko Šajić, Nebojsa Maletić, Milan Šunjevarić, Branislav Todorović, "Low-cost digital correlator for frequency hopping radio", *In Proc. of 18th International Conference on Systems, Signals and Image Processing (IWSSIP)*, 2011, pp. 43-46.