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Modeling Approach of LTE Mobile Positioning Simulator for OTDOA Measurements

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Abstract— Positioning techniques in LTE (Long Term Evolution) network are gaining more interest since the majority of mobile communication operators are deploying their 4G Solution all over the world. In this paper, we present a tool, based on Matlab/Simulink, for simulating the LTE positioning reference signal (PRS) generation, transmission and reception in a realistic propagation environment. The received signal at mobile station will be processed to obtain the time difference of arrival estimates which are used to calculate the handset position.

Keywords—positioning, OTDOA, MATLAB, accuracy, emergency calls, LTE, PRS.

I. INTRODUCTION

Due to the low power of global Navigation Satellite Systems (GNSS) signals, their performances are limited in indoor environments and NLOS (Non Line Of Sight) cases. Positioning methods based on cellular networks are now gaining more interest thanks to their accuracy, availability and performances in emergency cases, indoors environments as well as outdoor environments. Among these techniques we can find three categories [1], which are the following:

- Handset-based: The handset measures the data needed for its approximate location and calculates its own position on its own out of this data.
- Network-based: The network measures all data needed for the handset’s approximate location and calculates the position of the handset. The handset is passive in the whole progress.
- Hybrid positioning: In hybrid positioning, the network and the handset work together to first measure and then calculate the device’s position.

LTE steps towards the fourth generation of mobile communications. Most of its standards, set by the 3GPP, has been inherited from the UMTS (Universal Mobile Communication System). The main new features introduced by the LTE are the Orthogonal Frequency Division Multiple Access (OFDMA), Multiple Input Multiple Output (MIMO) data transmission and Positioning Reference Signal (PRS).

The aim of cellular positioning is to find the position of user equipment (UEs) in a noisy environment without external assistance. In cellular localization, the locations of eNodeBs are fixed and known while those of UEs are unknown and need to be determined. Among the positioning techniques used by cellular networks we find: Assisted-GNSS, enhanced Cell-ID (e-CID) and Observed Time difference Of Arrival (OTDOA).

In this paper, we are interested in OTDOA since the LTE standard use a dedicated downlink positioning reference signal (PRS) to perform the time measurements needed to estimate the UE location.

II. NETWORK MODELING

The radio network model id the basis element of the positioning simulator. In this section, we describe the cellular structure or topology and the radio propagation models used in our simulation.

A. Network Topology

The cellular network is designed as a regular hexagonal pattern. ENodeBs are placed each in the center of a hexagon with a distance of 1500 meters, the cell radius is then equal to 865.5 meters. In this work, the network model is limited to a 19 cell topology because the use of a 7-cell structure can underestimate the total interference in the system whereas 19 is considered a suitable number of cells according to [2].The moving UE at the boundaries may leave the network and lose the connectivity while the simulation is still running. To avoid this a wrap-around technique is applied to the network modeling [3]. When the UE is about to leave the simulation area, it will be wrapped around to the opposite side of the network topology.

B. Radio Propagation Model

In the literature there are several possible radio environments where the mobile radio systems are expected to operate [4].Most of these environments could be characterized with multiples propagation models. The first effect is the path loss, which models how the received signal strength decreases as the distance between the Mobile and the eNodeB increases. The second effect is the fast fading – also known as Rayleigh fading or multipath fading – which is due to multipath reflections of the transmitted signal by obstacles.

1) Path Loss

The Path Loss model implemented in this simulator is The Cost Hata model [5]. It is a radio propagation model, which is based on the Okumura model to cover a more elaborated range of frequencies. It is also known as the COST 231 Hata propagation Model. This model is applicable to urban areas. It works for Frequency up to 1500–2000 MHz. The Mobile station antenna height is about 1–10 m [6]. ENodeB antenna height is 30–200 m [6]. Median path loss in urban areas is given by

$$P_L(dB)=46.3+33.9\log(f_c)-13.02\log(h_b)-a(h_r)+[44.9-6.55\log(h_b)]\log(d)+c \qquad (1)$$

Here, f represents the frequency in MHz, d denoted the distance between the transmitter & Receiver, Correction factors for base station height and receiver height are hb&hr respectively. The parameter c has a value of 3dB for urban and is zero for suburban & rural environments. a (h_r) is Mobile station antenna height correction factor, for urban areas it is given by

$$a(hr) = 3.2(\log(11.75hr))^2 - 4.97 \qquad (2)$$

And for rural area it is given by

$$a(hr) = (1.1\log(f) - 0.7h_r - (1.58f - 0.8)) \qquad (3)$$

2) Fading channel

As mentioned before, the transmitted signal may reach the receiver over multiple paths. Each version of the received signal, by different paths, present a different attenuations and delays [7]. In LTEthe multipath fading channel model specifies the following three delay profiles.

- Extended Pedestrian A model (EPA)
- Extended Vehicular A model (EVA)
- Extended Typical Urban model (ETU)

These three delay profiles represent a low, medium, and high delay spread environment, respectively. In this paper we are interested in the pedestrian model [8], the multipath delay profile for this channelis shown in the following table:

Table I EPA delay profile

Excess tap delay (ns)	Relative power (dB)
0	0.0
30	–1.0
70	–2.0
90	–3.0
110	–8.0
190	–17.2
410	–20.8

Table II Maximum doppler frequency

Channel model	Maximum Doppler frequency
EPA 5Hz	5 Hz
EVA 5Hz	5 Hz
EVA 70Hz	70 Hz
ETU 70Hz	70 Hz
ETU 300Hz	300 Hz

All the taps in the preceding table have a classical Doppler spectrum. In addition to multipath delay profile, a maximum Doppler frequency is specified for each multipath fading propagation condition, as shown in Table II.

In the case of MIMO environments, a set of correlation matrices is introduced to model the correlation between UE and eNodeB antennas [8].

III. LTE LINK SIMULATOR

The communication link between the UE and an eNB is modeled based on the system-level radio network model presented in the last section. Timing measurements obtained from this link will be then used for LTE mobile positioning. The modeled link-level simulator includes an eNB transmitter, a communication channel, and an UE receiver.

A. eNB Transmitter Model

The transmitter model presented in our simulator is composed of two main blocksas shown in fig.2: the transport channel processing block and the physical channel processing block as described by the 3GPP standard [9].

1) Transport channel processing

In this block the UE's data are coded into codewords which will be transmitted to the physical channel processing block. It includesdata generation, Cyclic Redundancy Code (CRC) generation and attachement, turbo coding and rate matching.

Turbo coding is one of the spesific features of the Long Term Evolution satndard, it corresponds to the error correction and coding technology of the LTE. Compared to the precedent standards (2G & 3G),it differs from previous standards by the channel capacity performances that approaches the Shannon bound, that means we are almost at the maximum channel capacity. It is based on two parallel convolutional coding and an iterative decoding scheme.

2) Physical channel processing

This is where the encoded data is processed and transmitted to the UE. This block includes the following functions [10]:

- ✓ *Scrambling:*Scrambling of coded bits in each of the code words to be transmitted on a physical channel
- ✓ *Modulation Mapping:*Modulation of scrambled bits to generate complex-valued modulation symbols. Here a 16QAM modulator is used.
- ✓ *Layer mapping:*Mapping of the complex-valued modulation symbols onto one or several transmission layers. For this simulator the layer mapping scheme adopted is a layer mapping for spatial multiplexing with two antenna ports and two layers to mapp the two codewords.
- ✓ *Precoding:* precoding of the complex-valued modulation symbols on each layer for transmission on the antenna ports
- ✓ *Reference signal generation:* generation of Cell Specific Referene Signal (CSR) and the Positioning Reference Signal (PRS)
- ✓ *Mapping to ressource elements*: Mapping of complex-valued modulation symbols for each antenna port to resource elements
- ✓ *OFDM signal generation:*generation of complex-valued time-domain OFDM signal for each antenna port

The PRS have been introduced in the 3GPP LTE release 9 standard to allow proper timing measurements of a UE from eNodeB signals to improve positioning performance.

The positioning reference signal sequence is defined by [11] .

B. Channel Model

The transmitted signal Tx from the previous block is served as an input to the propagation channel as schown in Fig.1. The MIMO fading and the Additive White Gaussian Noise (AWGN) channel models emulates the effects of the multipath propagation of a fading process discussed before. The AWGN represents the co-channel interference.

The delay profile chosen is an EPA 5Hz corresponding to a maximum doppler frequency of 5Hz; The antennas configuration between the eNB and the UE is a 2x2scheme.

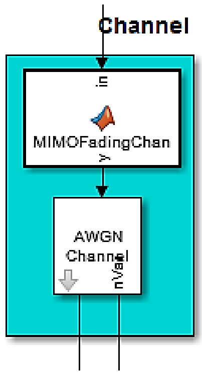

Fig. 1. MIMO fading channel + AWGN

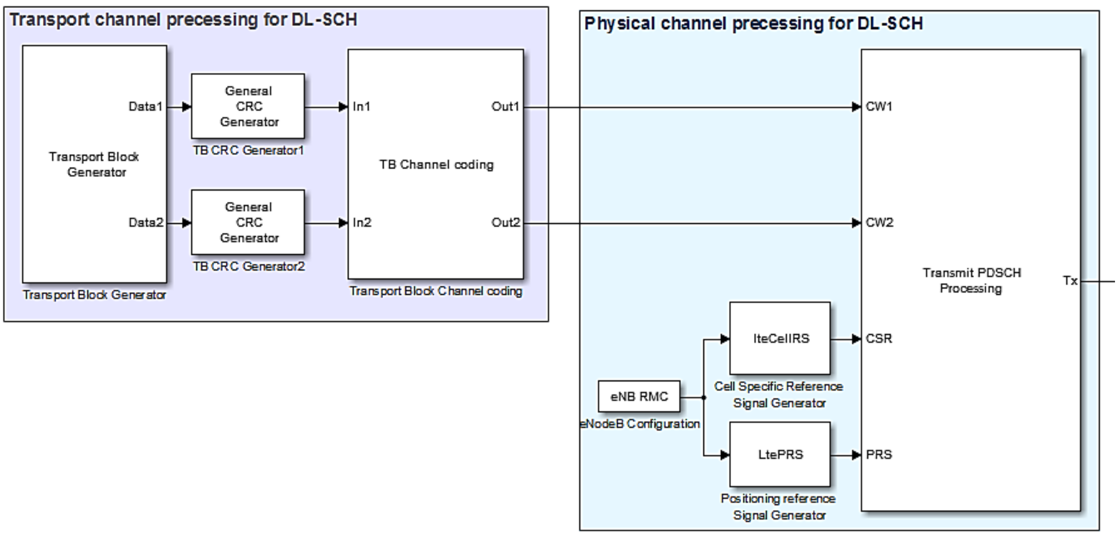

Fig. 2. LTE Transmitter block diagram.

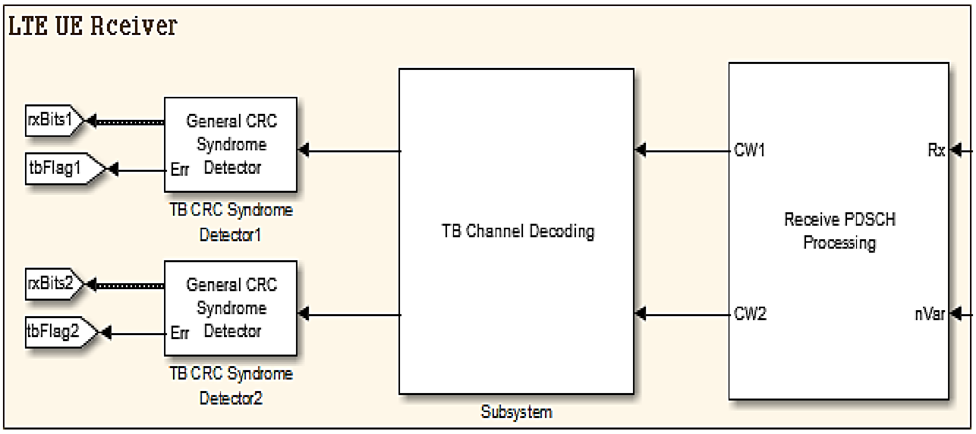

Fig. 3. LTE User Esuipement Receiver.

C. *LTE receiver Model*

The UE receiver model includes the inverse procedures of these performed in the transmitter as shown in fig.3[10]:

- ✓ OFDM signal demodulation
- ✓ Resource elements demapping and extraction of reference signals.
- ✓ Channel estimation end deprecoding
- ✓ Layer demapping
- ✓ Demodulation 16QAM
- ✓ Descrambling
- ✓ Transport channel decoding (Turbo decoding) and CRC check to retrieve original data.

IV. OTDOA BASED LTE MOBILE POSITIONING

Observerd Time Difference Of Arrival is a downlink positioning approach in the LTE Rel-9. It is a multilateration method in which the UE measures the time of arrival (TOA) of signals received from multiple eNBs. One of the eNBs is selected to be the reference of measurements, most of the times it's the one serving the UE. The TOAs from neighbour eNB's are substracted from the TOA of the reference eNB to form the Time Difference Of Arrival's [12].

Geometrically, each TDOA determines a hyperbola, and the desired UE location is the inersection of these hyperbolas. At least three TDOA measurements are required to solve a two dimension coordinates of the UE. The principe is illustrated in fig.4.

Since the time measurements has a certain uncertainty, in reality the intersection will be an area not a single point

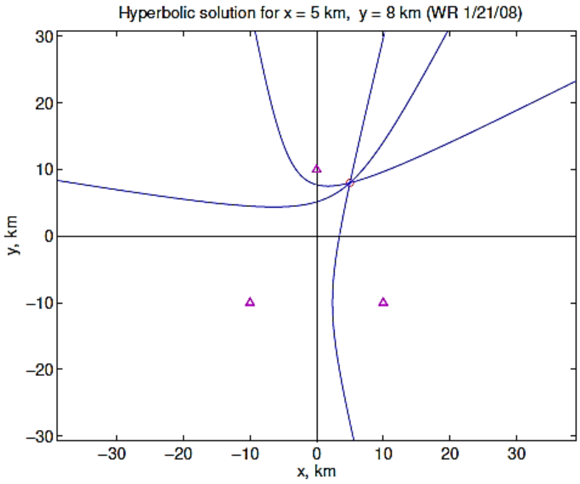

Fig. 4. TDOA hyperbolic multilateration

The UE measurements for OTDOA positioning is the Refrence Signal Time Difference measurement (RSTD). It is defined as the relative timing difference between two cells calculated as the smallest time difference between two subframes received from two different cells.

The time of arrival measurements performed by the user equipement are related to the geometric distance sparating the UE and the eNB. We denote (x_i , y_i) the known coordinates of the ith eNB (the reference eNB is denoted as the 1st) and (x , y) the unknown coordinates of the UE.

$$RSTD_{i,1} = \frac{\sqrt{(x_i - x)^2 + (y_i - y)^2}}{c} - \frac{\sqrt{(x_1 - x)^2 + (y_1 - y)^2}}{c} + (T_{i-}T_1) + (n_{i-}n_1)$$

Where $(T_{i-}T_1)$ is the time offset between the two eNBs reffered to as RTDs (Real Time Differences), n_i et n_1 represent the UE TOA measurement errors and c is the speed of ligth.

V. CONCLUSION

This paper presented the models and methods used to develop the LTE mobile positioning simulator. The simulation tool is composed of three main parts, the radio network, the MIMO channel and the UE positioning. Thhis simulator, developped according to the 3GPP standards for OTDOA positioning, will be further used to study and improve the positioning algorithms in LTE and LTE-A with support of vehicule location applications, indoor enviroments and hybridation with Assisted GPS to develop a robust solution for location estimation.

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