

Original Research Paper

# Performance Evaluation of UE Location Techniques in LTE Networks

<sup>1,2</sup>Yahia Zakaria and <sup>1</sup>Lubomir Ivanek

<sup>1</sup>Department of Electrical Engineering, Faculty of Electrical Engineering and Computer Science, VSB-Technical University of Ostrava, 17, Listopadu 15, 70833 Ostrava, Czech Republic

<sup>2</sup>Engineering Research Division, National Research Centre (NRC), Dokki, P.O. 12622, Cairo, Egypt

## Article history

Received: 06-07-2016

Revised: 30-12-2016

Accepted: 05-01-2017

Corresponding Author:

Yahia Zakaria

Department of Electrical Engineering, Faculty of Electrical Engineering and Computer Science, VSB-Technical University of Ostrava, 17, listopadu 15, 70833 Ostrava, Czech Republic  
Email: yahia.salem.st@vsb.cz

**Abstract:** The goal of this research is to evaluate the location accuracy of User Equipment (UE) in Long Term Evolution (LTE) networks which depends on the timing advance parameters. The ability to locate the subscribers through the network is considered as a significant factor in wireless communication systems. The main method to geolocation based on specified distances from many base stations is stated. The possibility of geolocating a Long Term Evolution (LTE) subscriber station based on the timing advance ranging parameter within the network signal internals is investigated in the paper. Also, simulation is used to describe performance in multiple base station networks that evaluating locations of subscriber stations on a two-dimensional system coordinated. Performance estimation of UE location in LTE networks was analyzed using simulations. Simulations were performed by using MATLAB. The main method for determining the subscriber station location depends on radial distances from multiple base stations. We observe from the results that the calculation error for the network is frivolous and by using four eNodeBs we obtain the most accurate estimation. Our simulation analysis shows that increasing the eNodeBs that used in the network leads to increasing the error to 29 centimeters.

**Keywords:** eNodeB, Location, LTE, UE, Wireless Communication

## Introduction

Since previous few years, the growing demands for accessing the Internet through the mobile devices were noticed. Therefore, there has been increasing needs from wireless telecommunication industry to define a new aviation port for mobile communications in orderliness to provide a framework for senior high mobility broadband table service, increase the overall system capacity, reduce latency and improve performance of the cell edge. As a result of this effort, the Long Term Evolution (LTE) technology has been introduced. LTE system provides comprehensive support for Frequency Division Duplexing (FDD), Time Division Duplexing (TDD) and spectrum flexibility. Also, it targets a soft evolution from previously Third Generation Partnership Project (3GPP) technologies such as Time Division Synchronous Code Division Multiple Access (TD-SCDMA). LTE is incessantly evolving to meet current and future requirements as well. Recently, 3GPP has sealed the work on LTE Rel-11, Rel-10, Rel-8/9 and

Rel-12. A significant aim of LTE Rel-10 is to assure that the LTE accomplishes all the requirements for International Mobile Telecommunications (IMT)-Advanced as defined by International Telecommunications Union (ITU) (Li *et al.*, 2015; ITU, 2008). Along with the constantly increasing number of mobile phones approaching the cellular network every day, operators are swiftly trying to deploy broadband data services and infrastructure to meet the capacity requirements. LTE is the recently deployed monetary standard technology for wireless communication meshing which offers higher information speeds and improved bandwidth (Dahlman *et al.*, 2008). This new technology of cellular communication is the logical evolution of 3GPP based access networks for enhancing the Universal Mobile Telecommunications System (UMTS) (Sesia *et al.*, 2009).

LTE is planned to be embraced as the basis for the next generation emergency response communicating system response communication system due to its spectrum efficiency and great capacity (USDHS, 2014).

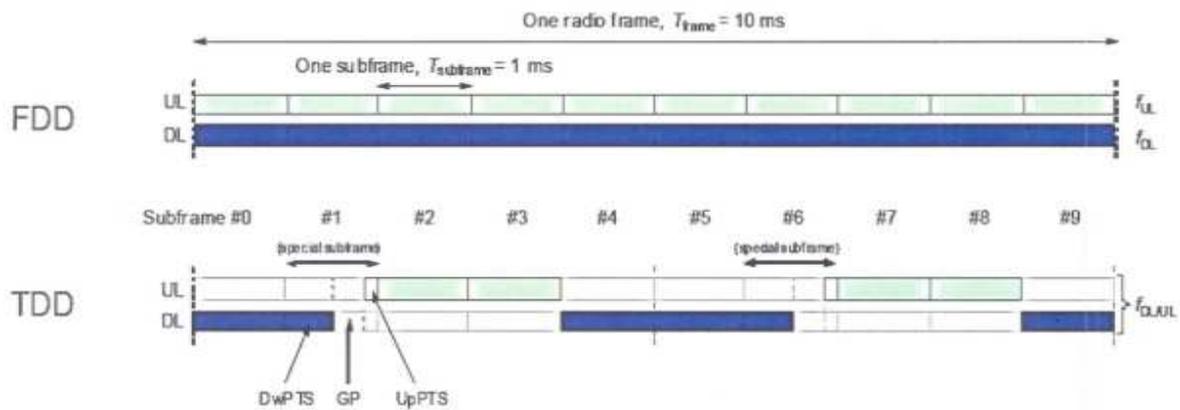


Fig. 1. LTE frame structure

Thus, the characteristics of such LTE based public utility networks are already under consideration by the industriousness (Doumi *et al.*, 2013). Moreover, LTE is an Orthogonal Frequency Division Multiple Access (OFDM) based radio access technology, with traditional OFDM on the downlink and Discrete Fourier Transform (DFT)-spread OFDM (DFTS-OFDM) on the uplink. DFTS-OFDM permits for more effective power amplifier cognitive operation to provide the opportunity for reduced terminal power consumption (Dahlman *et al.*, 2008). The use of OFDM on the downlink combined with DFTS-OFDM on the uplink to minimize terminal complexity on the liquidator slope (downlink) as well as on the sender side (uplink) star to a comprehensive reduction in terminal intricacy and power consumption.

As LTE provides capacitance to User Equipments (UEs) by means of a centralized job of radio resources, an enhanced physical layer was implemented based on OFDMA and virtually improves the operation of the prior Wideband Code Division Multiple Access (WCDMA) (Sesia *et al.*, 2009). So, the new modulation scheme provides a large capacity and throughput and perhaps reaching a bit rate of 300 Mbps in the downlink with advanced Multiple Input Multiple Output (MIMO) configurations (Sesia *et al.*, 2009).

Along with the spectrum flexibility considered as one of the key prop of the LTE radio communication applied science, a huge mountain range of various bandwidths is defined and supported by FDD and TDD in order to allow an performance in both paired and unpaired spectrum. The most significant requirement in LTE design is avoiding unnecessary fragmentation and struggle for commonality between the FDD and TDD way of operation. LTE technology supports a lot of multi antenna transmission techniques which contain downlink transmit diversity based on Space Absolute frequency Block Coding (SFBC) for the guinea pig of two transmissions transmitting aerial and SFBC in collection with Frequency Shift Time Diversity (FSTD) for four transmission antennas and

SFBC in collection with Frequency Shift Time Diversity (FSTD) for four transmission antennas.

In LTE structure, the transmitted signal is organized into sub shape s of 1 ms duration with ten sub frames forming a receiving set frame as illustrated in Fig. 1 (Parkvall *et al.*, 2011). Each downlink sub frame consists of a ascendance neighborhood including one to three OFDM symbols that are used to control the sign from the base post to the terminals. The data transmittance in each sub frame is dynamically scheduled by the base station and cell specific reference signals. These reference signals are used for data demodulation at the terminal and for measurement determination.

### Initial Access Procedure in LTE Networks

As the main substantial procedure for a mobile node to connect to a LTE network, any UE willing to access code the network must initially carry out a cellular telephone selection operation. After this stagecoach, the UE decodes the Physical Broadcast Epithelial duct (PBCH) to tear out the basic system information that allows the other channels in the cell to be configured and operated. This leads to the messages carried on this channels as unencrypted. Then, the UE can initiate an actual connection with the network by means of a random access procedure and establish a Radio Access Bearer (RAB) to send and receive user traffic. Furthermore, the procedure of the cell search contains a set of synchronization steps which allow the UE to determine time and frequency parameter that required to detect the downlink signaling as well as to transmit uplink signals with the right timing. The three main steps in this procedure are sampling clock synchronization, carrier frequency synchronization and symbol timing acquisition. So, in order to achieve full synchronization, the UE detects and decodes the Primary Synchronization Signal (PSS) and the Secondary Synchronization Signal (SSS), which are described in (Rossler, 2009).

Since Timing Advance (TA) is a representation of the propagation time, it may be used as an approximation for Time of Arrival (TOA) which is the crossing time from UE to Base Station (BS). This indicates that the wrongdoing in reporting the Tantalum entropy is patrimonial by the algorithm used for locating the UE. A problem here is that Tantalum is assigned to one of a finite lot of discrete values. Thus, each TA will correspond to an assured range of TOA values.

## Techniques of UE Location

There are several various techniques that can be used for network-based mobile location. One of the most widely used techniques is positioning based on the serving base station. This technique can be improved with Round Trip Time (RTT) mensuration or in Global System of Mobile Communications (GSM) by reporting Mobile Station (MS) and TA values. Also received signal level can be reported, it can be done through Short Message Overhaul (SMS). Other electronic network based positioning method is Prison term Divergence of Comer (TDOA) or Angle of Arrival (AOA) methods. Also a combination of these methods can be used; however they will need some investments to the mobile network (Keski, 2002). Moreover, Global Positioning System (GPS) offers very accurate location information for the end user location requirements, but has some coverage drawback and suffers from heights battery usage in MS. Also, there is content limitation due to extravagant signaling between the network and the user in order to have continuous location information. So, network assisted emplacement uses network based positioning and transfers the coordinates to the Disseminated multiple sclerosis via SMSs. There are several techniques used for determining subscriber station location as follows (Keski, 2002).

### Cell ID

In this technique, the UE can be located using its serving cell coordinates. The coordinates can either be the BS coordinates or sector of a BS within a Location Area Code (LAC). The accuracy of this method relies on the serving cell radius that can differ up to 60 km in rural areas.

### Received Signal Level

In received signal level technique, the mobile station measures the serving and the neighboring cell received signal stage to choose the best cell. This information and a simpleton generation poser can be used to calculate the distances between the MS and the neighboring BS.

### Time Difference of Arrival (TDOA)

In Time Difference of Arrival (TDOA) technique, the time difference between each pair of received signals can

be estimated by a receiver and the position from the intersection of the two hyperbolas can be determined. In general, TDOA measurement is made by measuring the difference in received phase at each chemical element in the antenna array. Moreover, this technique depends on the measurement of the difference in distance between two Stations of the Cross at known locating which programed signal at known times.

### Angle of Arrival (AOA)

This method includes measuring the AOA of a signal either from a BTS or a MS using for an example the antenna patterns. In AoA, the delay of arrival at each element in the antenna array is measured directly and converted to an AoA measurement. Furthermore, this technique is a method for determining the direction of propagation of a radio frequency wave incident on the transmitting aerial array. AoA determines the direction by measuring the (TDOA) at individual elements of the array and from these delays the AoA can be calculated.

### Time of Arrival (TOA)

This technique uses the speed of light, the speed of radio wave propagation and the time of a signal arrival to calculate the distance to determine the actual UE position. By knowing this distance, it is possible to derive an equation that represents the distance from the known station, BS, to the receiver, MS, within the Cartesian plane as the following (Gustafsson and Gunnarsson, 2005):

$$d = ct_{\text{TOA}} = \left[ (x_{\text{BS}} - x_{\text{MS}})^2 + (y_{\text{BS}} - y_{\text{MS}})^2 \right]^{1/2} \quad (1)$$

where,  $c$  is the speed of light,  $t_{\text{TOA}}$  is the time of arrival and  $x$  and  $y$  represent MS and BS locations in the Cartesian plane.

## Methodology of UE Location Estimation

LTE provides a wireless high upper connection available to fixed or mobile indorser whose positioning is not predetermined. Thus, location information of subscribers on the network is important, especially in state of affairs requiring emergency reply teams for security. Many methods exist for geolocating radio frequency equipment and gimmick and each has advantages and disadvantage. Time difference-of- arrival requires receivers that are synchronized precisely and frequency difference-of-arrival requires Christian Johann Doppler fracture generated by significant velocities. A solution Trygve Halvden Lie within Global Placement System (GPS) technology, where distribution of GPS chips within contributor gimmick could provide location. However, this adds significant costs for manufacturing and power related issues for the Mobile River devices.

In LTE, uplink and downlink between tug and indorser unit of measurement is conducted primarily with a frequency-division duplexing scheme, which facilitates simultaneous communication in both directions. However, the arrival of the uplink subject matter to the tugboat from multiple ratified requires coordination to prevent interference with other gimmick s. Proper scheduling is achieved through the use of timing overture (TA), which the base place tower sends to a device to velocity up or delay its data transmission and ensure each subscriber's data is received in the appropriate time slot. By successful extraction of these messages from the air interface, a length from the tower to the subscriber can be derived based on propagation speed, the speed of sparkle and how many units of timing advance the base station indicates to the subscriber to use. Modeling geolocation techniques used in the two-dimensional aspect, we focus on simulating a multiple base post meshwork with varying scenario of base station placements and TA-based radii fluctuations and approximate a subscriber station's location. Determining the location of subscribers on the network is very important issue since the first cellular networks introduction, but currently it is even more needful especially as an essential component of emerging services like Device-to-Device (D2D) or Proximity Services (ProSe). Another applications domain are the situations where the location information is required by emergency response teams for medical care, homeland security and aiding law enforcement. Therefore, several methods like TDOA, Frequency Difference of Arrival (FDOA), Received Signal Strength Indication (RSSI) and AOA exist for locating radio frequency devices (Dahlman *et al.*, 2008).

### Simulation Models and Scenarios

This part will give more information about calculating the location of UE by using TA in the two base station simulations by using two eNodeBs and four eNodeBs.

### Simulation Models

Both geolocation methods provide an excellent resource to be refined and expanded upon for employment by emergency reaction squad and tactical personnel. The current deployment of LTE for the two largest mobile carriers demands effective means of geolocation, such as those presented in this research. Furthermore, it is possible to geolocate an LTE UE within approximately 50 centimeters by using a three-dimensional mathematical function approach, taking into accounting that Atomic number 73 is a calculated distance from one height to another and is comparable to geolocation accuracy in GPS technologies.

In the two base stations simulation, by using TA the location of UE can be estimated. TA occurs when the base station tower sends a signal to a mobile phone in order to speed up or delay its data transmission and ensure that each subscriber's data is received in the convenient time slot. Thus, by using the modeling of the location of UE with the two dimensional aspect, we can simulate several base stations with different scenarios of base station placements and Atomic number 73 based radii fluctuation in order to approximate the subscriber station's location. So, the aloofness in meters per unit of TA can be derived by knowing the sampling frequency in LTE. Furthermore, calculations for timing advance determine a maximum possible timing advance of 0.68 milliseconds and each unit of timing advance equal to 75.14 m which is calculated by multiplying the sampling frequency calculated as  $F_s = 1/T$  by the speed of light, approximately  $3 \cdot 10^8$  m/s as the distance in meters per unit of TA can be derived with knowledge of the sampling frequency in LTE (Spirito and Mattioli, 1999). By using two eNodeBs the position of the UE may lie as one of the three possible situations shown in Fig. 2.

In case of the two radius circles intersected, triangles method can be used to calculate the intersections of circles as illustrated in Fig. 3 (Hussain *et al.*, 2007).

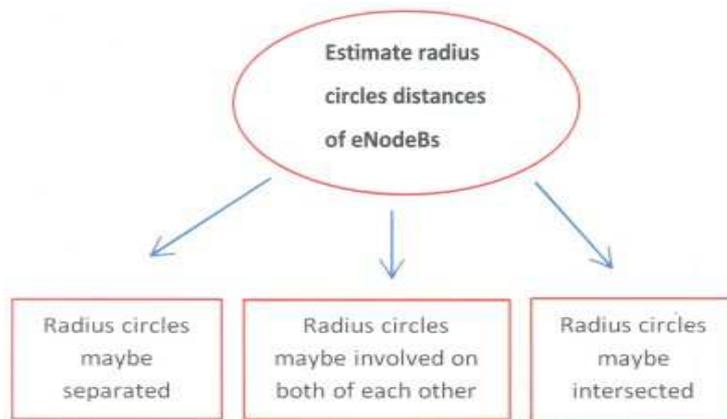


Fig. 2. Flow chart of possible situations of eNodeBs

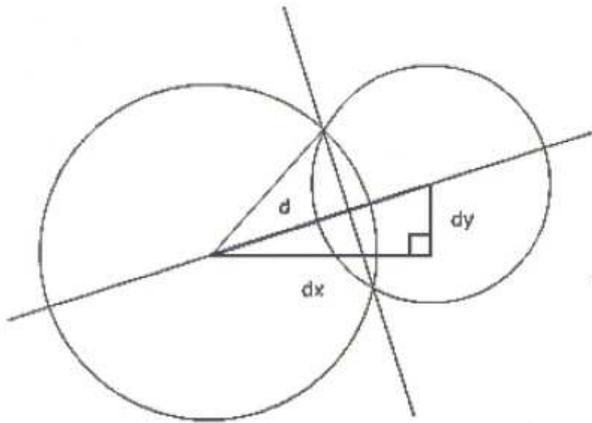


Fig. 3. Triangles method

The points of intersection can be calculated based on the space between the base station and the two radii when the radius circles do overlap. Therefore, the  $X$  coordinate of the intersection can be calculated as the following equation (Wu, 2013):

$$X = \frac{d_x^2 - d_y^2 + d^2}{2d} \quad (2)$$

### Simulation Scenario

By simulating the two eNodeBs the location of the UE should lie at the point where they are overlapping and three possible situations may happen as the radius circles maybe intersected or the two radius circles maybe separated or the radius circle maybe included on the other. The real location of UE is the origin on the X-Y plane in all cases. The simulations creates two eNodeBs at varying angles and four eNodeBs in relation with the actual UE position with standard deviation within a range of 250 m and mean distance per unit of TA equal to 75.14 m.

### Results

In this research, computer simulation is developed using MATLAB software to describe the location accuracy of subscriber station in LTE networks.

Multiple eNodeB scenarios were simulated with the mean distance per unit of TA of 75.14 m. In all showcase, the UE's true location is the origin on the X-Y carpenter's plane. The pretence creates two eNodeBs at varying degree in relation to the UE, each with normally distributed random distance with a mean of one kick from the UE, touchstone deviation within a range of 250 m and TA per the calculated value of 75.14 m.

The approach of simulating an LTE UE requires constitution of parameters. At first, the simulation employs a flat Earth example with calculations derived in Cartesian co-ordinate s. This provides for a meter by

meter coordinate arrangement with simplified calculations of range radii and intercepts points. Second, the method of intersecting radii is based upon propagation delay acquired from signal internals. By supposing free space propagation at the speed of light,  $3 \cdot 10^8$  m/s, at the bandwidth used, each unit of TA increases the range radius from the eNodeB by 75.14 m. The average distance from the midpoint between the two radius circle intersections, to the actual UE location for each separate run was recorded.

We get the aloofness between the eNodeBs using the Pythagorean Theorem based on their X-Y airplane co-ordinate and compared to the inwardness and remainder of their radii. The result of the comparison determines which of the situation is occurred. If the sum of the wheel spoke roofy is less than the total distance between the two eNodeBs, then a case of nonintersecting radii is occurred. So, the approximated UE location becomes the midpoint of the total distance plus an approximation spoke based on a scaling of the two radius circles along the same line of distance.

Related to the results of simulated two eNodeBs at different degrees in accordance with the genuine UE location Fig. 4-9 show it respectively.

By observing the above results of simulated two eNodeBs and (Hussain *et al.*, 2007; Yoast and Panchapakesan, 1998) we notice that the most accurate location approximation happens by using two eNodeBs when the two stop of convergence get closer to each other. Also, the two radius circles which are separated by a small distance can give a precise approximation location.

Attention should be paid to the fact that in case of the total distance between the two eNodeBs is more than the summation of the radius circles; the radius circles will not be intersected. Thus, the approximated UE location will be at the center of the total distance. On the other hand, by increasing the distance between the two radius circles we get an error in the approximation of the UE location.

The prerequisites of such accurate placement estimate reside with specific knowledge of TA values and setoff and eNodeB tower characteristic of location and summit above the mill. This information is imperative and important to consider when employing a system capable of geolocation. Any error in tower characteristics has potential to offshoot geolocation outcome since crossing of radii based on that tower, whether throwaway or spherical, will increase the space between the UE estimate and true location. Therefore, in case of the radius circles are not separated or included on both of each other, then they intersect. The most accurate method of approximating the UE location in this case is trilateral method as mentioned before. Thus, it can be mentioned from the results that the location of a subscriber can generally be approximated within 60 m in networks with various numbers of towers and random tower positions by knowing timing advance offsets.

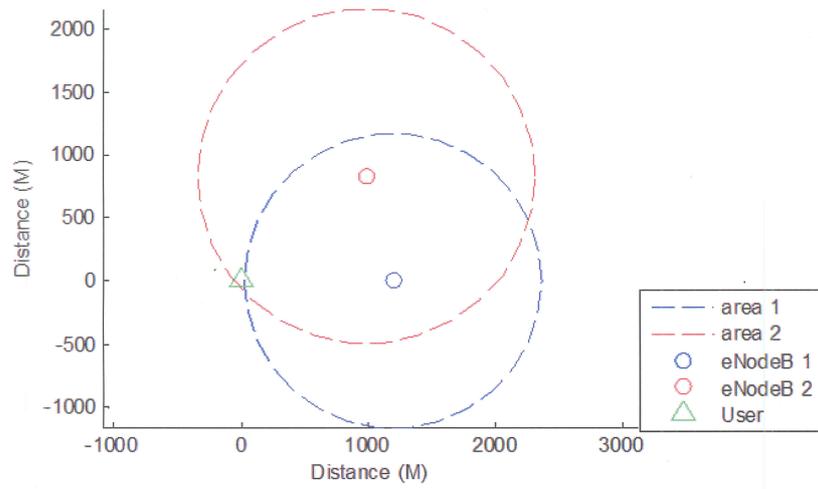


Fig. 5. Two eNodeBs at 40 angles

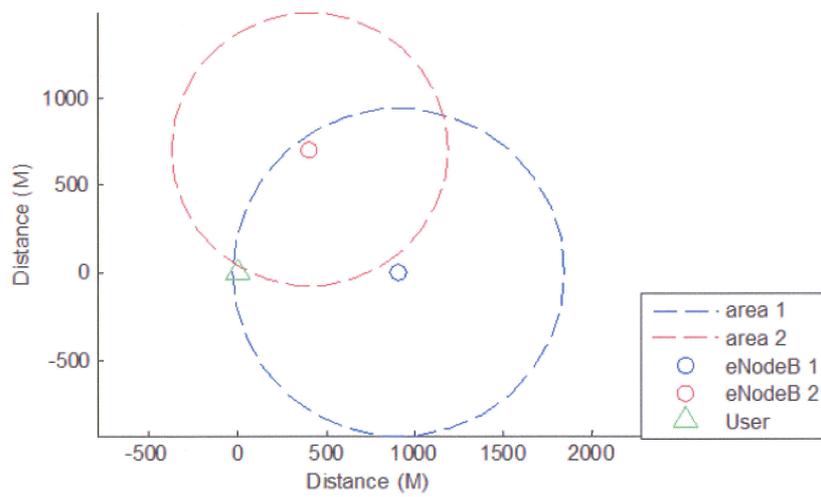


Fig. 6. Two eNodeBs at 60 angles

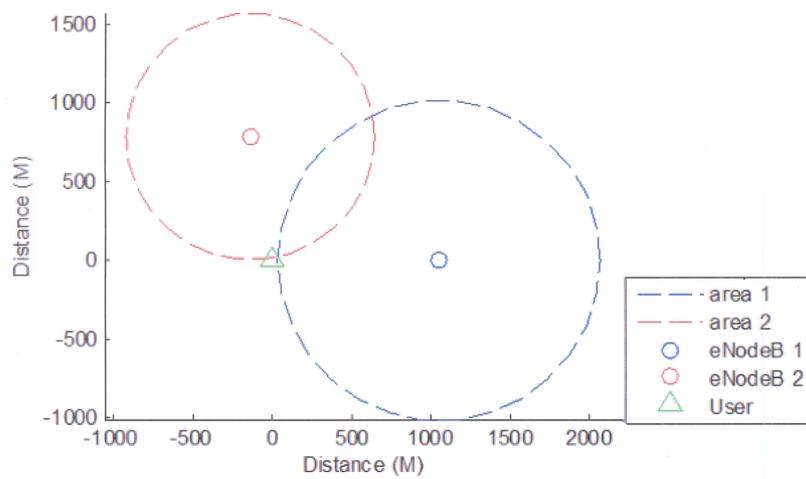


Fig. 7. Two eNodeBs at 100 angles

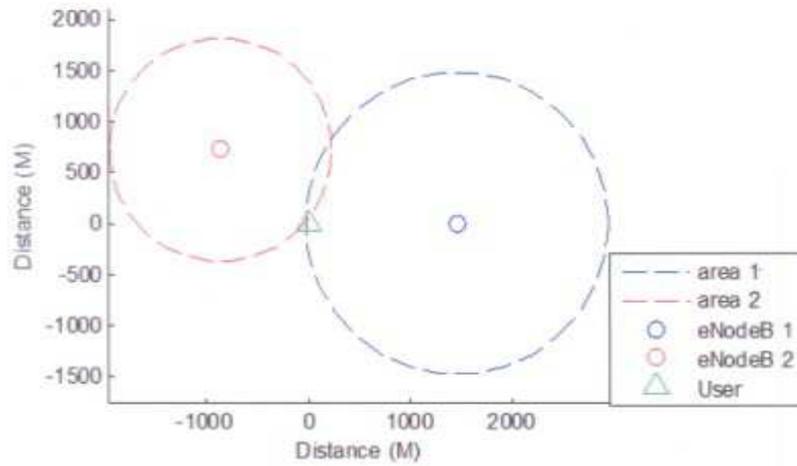


Fig. 8. Two eNodeBs at 140 angles

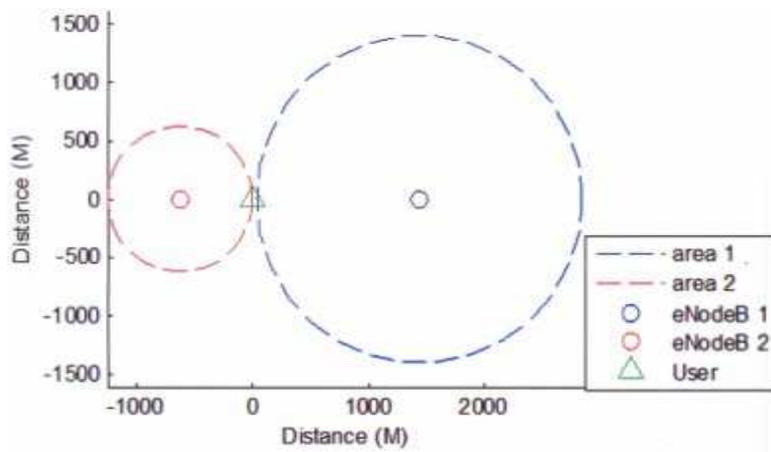


Fig. 9. Two eNodeBs at 180 angles

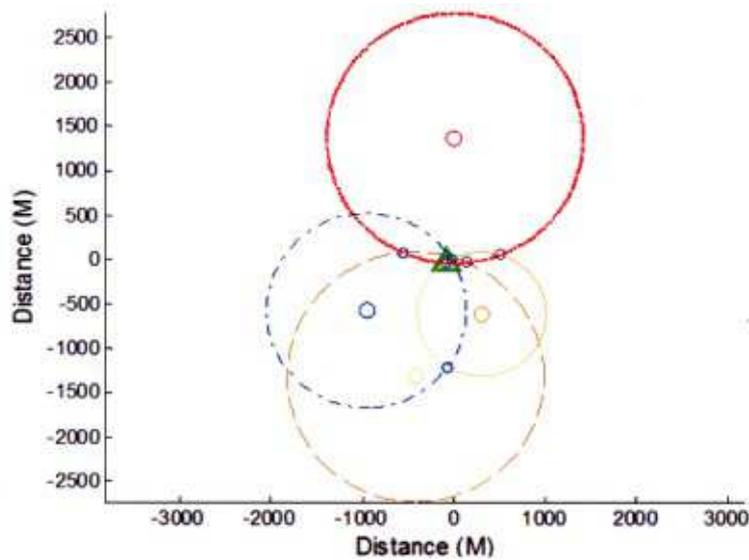


Fig. 10. Four eNodeBs

Thus, as the angle decreases, the approximation error increases due to the two intersections of the radii becoming farther and farther. Regardless of a high degree of confidence in the calculations for TA, it would be unrealistic to assume there would be no deviation from the mean 75.14 m when analyzing an LTE signal.

Results of the model showed that in net with various numbers of pillars and random tower placements, the location of a contributor could generally be approximated within 60 m. Measure provided accurate tower placement is given and timing advance offsets are known.

Furthermore, we observe that the most accurate prediction for the location of the subscriber station happens at  $180^\circ$  as shown in Fig. 9 where the position of the UE constructs a direct line with eNodeBs.

Moreover, Fig. 10 shows the result of simulated four eNodeBs.

Also, by comparing the results of simulated two and four eNodeBs with (Spirito and Mattioli, 1999) we can conclude that using four eNodeBs will usually remove the opacity between the points of intersections. On the basis of the above results by using two eNodeBs at varying angles, we have to point out that by decreasing the angle of eNodeBs we obtain an increasing of the approximation error because of the intersections of circles will be farther from each other.

At the end of this research we should point out that with the principles explored through research and simulation, it is possible to geolocate an LTE UE within approximately 60 m when using a two-dimensional mapping coordinate mapping scheme, offering potentially ten times better accuracy than GSM methods previously explored in literature.

## Conclusion and Future Work

Over the last few years, there has been increasing need for placement the users within a network through mobile telecommunication services. A lot of attention should be paid to the technologies of mobile location due to increasing the need for services of the new mobile generation. Special care should be taken to the fact that the techniques of determining subscriber station location are very significant issues especially in cases which need emergency reply for necessary medical auspices by determining the location of subscribers on the network. The average distance from the midpoint between the two radius circle intersections to the genuine UE location for each independent run was recorded. It was observed that the most precise location approximation occurs by using two eNodeBs when the two points of intersection get closer to each other. Also, the most accurate prognostic for the location of the subscriber station occurs at  $180^\circ$ . As a conclusion in the cases examined in this research, it can be easily realized that the precise UE location could be done by increasing the number of eNodeBs.

Future research should concentrate primarily on successful extraction of LTE signals from the air and analysis of TA data and real-world LTE signal internals behavior. Development of a package graphical user interface that employs the geolocation methods established for LTE would be a valuable commodity for emergency brake response teams. Increasing of the three dimensional multiple eNodeB simulation could provide less approximation error by comparing and contrasting location estimate solvent from individual groups of three eNodeBs within the larger network. Also, a comprehensive examination probe into the LTE specification for other aspects and mechanics of ranging should be conducted.

## Acknowledgement

The support of authors by VSB-Technical University of Ostrava, Czech Republic was acknowledged.

## Funding Information

This research is completely supported by the project SP 2016/143 "Research of antenna systems; effectiveness and diagnostics of electric drives with harmonic power; reliability of the supply of electric traction; issue data anomalies". The authors would like to express their thanks to the members of Department of Electrical Engineering at VSB-Technical University of Ostrava for their valuable instructions and support.

## Author's Contributions

**Yahia Zakaria:** Conceptualized the research, organized ideas, requisition and analysis of the data, results interpretation, conducting and analyzing the results and contributed to writing of the manuscript.

**Lubomir Ivanek:** Participated in the organization of ideas, interpretation of the results and also contributed to writing of the manuscript. Also, provided technical consultancy about the obtained results.

## Ethics

The authors have read and approved the manuscript and give the assurance that no part of this original research article is being considered for publication in whole or in part elsewhere.

## References

- Dahlman, E., S. Parkvall, J. Sköld and P. Beming, 2008. 3G Evolution: HSPA and LTE for Mobile Broadband. 2nd Edn., Academic, Amsterdam, ISBN-10: 0123745381, pp: 608.

- Doumi, T., M. Dolan, S. Tatesh, A. Casati and G. Tsirtsis *et al.*, 2013. LTE for public safety networks. *IEEE Commun. Magazine*, 51: 106-112. DOI: 10.1109/MCOM.2013.6461193
- Gustafsson, F. and F. Gunnarsson, 2005. Mobile positioning using wireless networks: Possibilities and fundamental limitations based on available wireless network measurements. *IEEE Signal Process. Magazine*, 22: 41-53. DOI: 10.1109/MSP.2005.1458284
- Hussain, S.A., M. Emran, M. Salman, U. Shakeel and M. Naeem *et al.*, 2007. Positioning a mobile subscriber in a cellular network system based on signal strength. *Int. J. Comput. Sci.*, 34: 245-250.
- ITU, 2008. Requirements related to technical performance for IMT-Advanced radio interface(s). ITU.
- Keski, M., 2002. End-user location in digital mobile networks. *Course in Radio Communications*.
- Li, S.F., L. Geng and S. Zhu, 2015. Joint dynamic radio resource allocation and mobility load balancing in 3GPP LTE multi-cell network. *Radioeng.*, 24: 288-295. DOI: 10.13164/re.2015.0288
- Parkvall, S., A. Furuskär and E. Dahlman, 2011. Evolution of LTE toward IMT-advanced. *IEEE Commun. Magazine*. DOI: 10.1109/mcom.2011.5706315
- Rosler, A., 2009. Cell search and cell selection in UMTS LTE. Rhode & Schwarz.
- Sesia, S., M. Baker and I. Toufik, 2009. LTE, The UMTS Long Term Evolution: From Theory to Practice. 1st Edn., Wiley, New York, ISBN10: 0470742887, pp: 648.
- Spirito, M.A. and A.G. Mattioli, 1999. Preliminary experimental results of a GSM mobile phones positioning system based on timing advance. *Proceedings of the IEEE VTS 50th Vehicular Technology Conference*, Sept. 19-22, IEEE Xplore Press, pp: 2072-2076. DOI: 10.1109/VETECONF.1999.797302
- USDHS, 2014. Nationwide public safety broadband network. US Department of Homeland Security.
- Wu, H., 2013. Teaching geometry according to the common core standards.
- Yoast, G.P. and S. Panchapakesan, 1998. Improvement in estimation of Time of Arrival (TOA) from Timing Advance (TA). *Proceedings of the IEEE International Conference on Universal Personal Communications*, Oct. 5-9, IEEE Xplore Press, pp: 1367-1372. DOI: 10.1109/ICUPC.1998.733714