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OPTIMAL STATION DISTRIBUTION FOR CLOSED FORM TDOA MEASUREMENT

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ABSTRACT

Mobile communication is one of the main areas of telecommunications and it is evolving incredibly rapidly today, thanks to improvements in technology in all areas of mobile and wireless communications. The use of positioning methods is now widely used in many applications such as navigation, mobility, emergency services and also used for warfare in the army. To detect the user in a very accurate place, the significance of the positioning methods is needed. Global Positioning System (GPS) is the most commonly used and acknowledged positioning system, but it has some constraints on outdoor place and forest / mountain region. Many methods of geo-location predate and were suggested as an alternative to GPS. Some of the positioning methods are the arrival time difference (TDOA), which uses the hyperbolic technique of place to predict the user's location. In closed form time difference of arrival (TDOA) positioning system locating the moving target in 2D, 3D (same and different altitude), at least five stations are required. Positioning accuracy is significantly affected by position station distribution. First, a positioning accuracy model is created and the factors influencing positioning accuracy are evaluated in line-of-sight (LOS) settings through the study of the TDOA location system principle. Geometric dilution of precision (GDOP) is a standard for determining a system's efficiency. There are eight different models of distribution of geometric dilution of precision (GDOP) for five station. Finally, in this paper, the optimal distribution principle of five-station in 2D, 3D (with same and different altitude) are presented with comparison with each of the distribution.

Keywords: *Time Difference Of Arrival, Geometric Dilution Of Precision, Optimal Distribution, Passive Location, Positioning*

1. INTRODUCTION

Mobile communication has drastically evolved from early sound systems to present days highly sophisticated integrated communication platforms providing multiple services and supporting numerous technologies used by billions of people around the world. Mobile customer requirements for greater capacity and rates of data are just two of many factors influencing wireless access systems evolution. Since Antonio Meucci's creation of the telephone in 1871 to this day, communication has become increasingly important in the daily life of humans. The mobile phone has now become component of human demand development. The wireless sector has been struggling for more seamless interworking between a Wi-Fi carrier and 3G/4G, particularly with Long Term Evolution (LTE), since the last few years. Since 1981, generations of wireless networks have evolved heavily every 10 years. The current 5G network is expected to succeed the next generation of wireless networks through 2020. More than 5 billion portable wireless phones are presently in use. This figure is expected to be surpassed in the future as the number of subscribers / users worldwide is rapidly increasing. Figure 1 illustrates the evolution of wireless networks from the first generation to the next five generation. As the generation is changing from one to another, the data capacity is also improving to accommodate the user and improving many communications worldwide.

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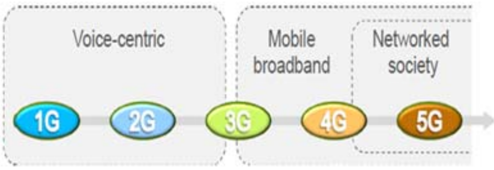

Figure 1: Evolution of wireless network[1]

Massive use of mobile devices is anticipated with the evolution of wireless networks. The number of mobile phone subscriptions in Europe, such as the number of registered SIM cards per 1000 citizen, was an average of 1298 in 2012 for the EU-28, which means more mobile phone subscriptions than people [2]. Country comparison between the EU-28 and other non-member states in Europe can be found in Figure 2.

	2004	2006	2008	2010	2011	2012
EU-28	870		1 060	1 225 (*)	1 267	1 298
Belgium	810	890	1 050	1 112 (*)	1 144 (*)	1 181
Bulgaria	620	1 070	1 370	1 359 (*)	1 474	1 601
Czech Republic	1 060	1 240	1 330	1 276 (*)	1 290	1 251
Denmark	960	1 070	1 200	1 415 (*)	1 473	1 516
Germany	900	1 040	1 310	1 170 (*)	1 211	1 242
Estonia	930	1 170	1 210	1 205 (*)	1 350	1 499
Ireland	940	1 120	1 220	1 124 (*)	1 134	1 197
Greece	840	1 250	1 690	1 172 (*)	1 121	1 200
Spain	910	1 050	1 100	1 185 (*)	1 249	1 220
France	720	820	910	936 (*)	1 001	1 060 (*)
Croatia	659	970	1 100	1 479 (*)	1 192	
Italy	1 080	1 370	1 520	1 584 (*)	1 615	1 642
Cyprus	900	1 130	1 290	1 243 (*)	1 296	1 312
Latvia	660	950	980	1 580 (*)	1 701	1 898
Lithuania	890	1 390	1 490	1 558 (*)	1 614	1 649
Luxembourg	1 430	1 520	1 460	1 432 (*)	1 428	1 458 (*)
Hungary	860	990	1 220	1 084 (*)	1 102	1 107 (*)
Malta	770	860	940	1 062 (*)	1 267	1 319
Netherlands	910	1 130	1 230	1 165 (*)	1 251	1 233
Austria	980	920	870	1 430 (*)	1 506	1 571
Poland	600	960	1 160	1 144 (*)	1 194 (*)	1 311
Portugal	930	1 160	1 410	1 526 (*)	1 573	1 577
Romania	470	810	1 140	1 188 (*)	1 168	1 129
Slovenia	930	910	1 020	1 032 (*)	1 055	1 069
Slovakia	790	910	1 020	1 140 (*)	1 119	1 153
Finland	960	1 080	1 300	1 508 (*)	1 633	1 694
Sweden	980	1 060	1 190	1 307 (*)	1 380	1 444
United Kingdom	1 000	1 160	1 260	1 331 (*)	1 352	1 371
Iceland	998	950	1 070	1 181	1 212	1 249
Liechtenstein	750	820	970	:	:	:
Norway	990	1 050	1 110	:	:	:
Switzerland	850	1 000	1 170	:	:	:
Montenegro	779	1 127	1 093	2 260	1 870	1 595
FYR of Macedonia	492	695	883	1 098	1 105	1 085
Albania	415	636	1 002	1 558	1 801	1 936

Figure 2: Number of mobile phone subscriptions per 1000 people[3]

The proportion of smartphone subscribers for Malaysian people continues to rise from 68.7 percent in 2016 to 75.9 percent in 2017, according to the 2017 Malaysian Communication and Multimedia Commission (MCMC) research. The research also showed a 22.0% decrease in feature phone users from 53.0% in 2016 to 31.0% in 2017. This can be seen in Figure 1.3. Major circumstances leading to enhanced use of smartphones include low-cost hardware, subsidies, aggressive campaigns and service provider promotions, affordable voice-data packages, enhanced use of smartphone-based applications and enhanced reliance on them are important contributing factors to growth [4].

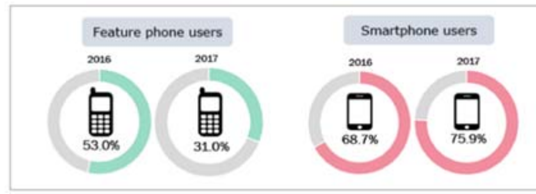

Figure 3: Percentage distribution of smartphone versus feature phone share, 2016 and 2017[4]

Mobile positioning is one of the most evident techniques behind the wireless network. Today, fourth generation and Long Term Evolution (LTE) involve mobile positioning. It has introduced many helpful alternatives into daily life as wireless technology grows greater. Recently, location-based service (L&P) has been one of the most effective applications and offers great convenience to clients. For example, many new applications, often called Location Based Services (LBS), can be operated by knowing the position of a subscriber or mobile station [5]. LBS uses location data to associate with any telematic service. LBS is able to search the geographical location of the mobile device and then provide services depending on the location information. Based on the availability of location information, there are many different types of services that already exist or could be achieved in the coming years. Other methods are based on network placement, which generally depends on particular signal triangulation methods from cell sites serving a mobile phone. LBSs can deliver excellent tailored services using Global Navigation Satellite System (GNSS), Geographic Information System (GIS) and wireless communication and networking methods. Depending on their current condition, LBSs can provide excellent tailored services to users/subscribers. Therefore, with the involvement of LBS, there are growing offers to detect a mobile user's position at low price correctly and rapidly.

LBS involves using the location of mobile devices for both emergency services (E911) and infotainment (map services, location addresses, local advertising / information and "finding a friend"). The 911 service was created to provide a call forwarding agreement for emergencies such as accidents, natural disasters and also crime with a public safety agency. With the various characteristics for LBS implementations, the evolution of smartphones is becoming increasingly advanced, high-speed data usage levels for mobile consumers and client demand for' always-on' communication indicate that LBS apps will massively improve in the years to come [6]. One of the primary advantages of communications evolution contributes to the implementation of mobile user placement. On this basis, positioning implementation includes wide-ranging function in many elements such as navigation, monitoring, emergency system and army. There is a correlation between positioning application and technology evolution that contributes to greater demand.

Positioning is the method used to define the geographical location of a device such as a smartphone, laptop or tablet, private digital assistant (PDA) and instruments for navigation or tracking. Mobile tracking refers to the technical ability to accurately and correctly recognize mobile devices in time and space using mobile network equipment or other software containing location data for mobile devices. Mobile positioning information is known as gathered data on mobile device location and mobility. Positioning of mobile devices may be required in real time or historically. It is possible to recognize or unidentified the user of the located devices. There are two significant techniques to require active and passive positioning of mobile positioning information. The difference between active and passive data techniques is that for active placement a certain chosen application is performed to locate the mobile phone (location request is performed, location reaction is returned), while historical information is collected for passive place and no active applications are returned. Active and passive data can be tracked in real time as well as historically, although applications for historical data must be made commonly over a long period of time in active placement [3,5,7].

2. LITERATURE REVIEW ON TDOA POSITIONING

TDOA, which represents for Time Difference of Arrival and is a wireless or network-based positioning approach that attempts to calculate the location of a mobile device by evaluating the time difference of arrival between different base station/receiver (BS) signals. The time difference of arrival between the two signals can be converted into a constant ratio of the distance between the mobile device and the two base stations. Therefore, it is a mechanism of multilateration. While TDOA is a latest subject, hyperbolic location and navigation systems have frequently been used [8,9,10].

2.1 Brief History Of Hyperbolic Localization

Since the last century, hyperbolic location systems have been researched and analyzed. During World War I, the first military applications were created as an acoustic method for detecting enemy artillery, also known as sound ranging. The artillery firing sound was captured using several microphones and the measurement timing information was sent to a computing base for measuring and detecting the weapon's position. During the Second World War, sophisticated radio systems substituted the acoustic systems. In addition to detecting enemy equipment / machine, new applications were discovered as navigation methods for vessels and aircraft. United Kingdom's Royal Air Force with its code-name "Gee" used the first hyperbolic navigation system that came into service in 1942. After that, the Decca Navigator System used by the Royal Navy since 1944 and on and also the LORAN scheme of the United States followed this system. These two techniques have been used mainly in ship navigation since Decca's precision is inferior to LORAN. Decca operated at a low frequency range (from 70 to 130 kHz) and had a range of approximately 400 nautical miles, equivalent to 740 km. The precision depended heavily on some variables such as the moment of day and the cutting angle of the position hyperbolic lines. It could vary from a few meters to a nautical mile on the finest situations.

Hyperbolic navigation systems became popular after the war for non-military apps and were used until GPS switched them. Some of the schemes included LORAN evolution, known as LORAN-C introduced by the U.S. Coast Guard facilities, the Soviet Union's global Alpha or Omega system, and CHAYKA schemes. LORAN-C was first launched as an evolution of the LORAN scheme in 1957 and its transmission was terminated in 2010 after the U.S. government decided that it was no longer needed because of the existence of GPS. Hyperbolic localization has now been resurrected as a technique for locating a mobile device with the advent of mobile phone communications. Besides, it also acts as a fall-back system in the absence of GPS [3,11,12,].

2.2 Time Difference Of Arrival

The TDOA principle is linked to the signal delay system. The basic idea / principle of TDOA is to assess differences in the delay in signal propagation. For further understanding, the TDOA principle is briefly explained below. Suppose two signals are transmitted synchronously from two BSs *i* and *j* at the time instance *To*. The signal then gets *Ti* and *Tj* on the phone from BSs *i* and *j* [13]. The respective distance of propagation is calculated from the delays of propagation:

$$\Delta d_{i,j} = (d_i - d_j) = c(T_i - T_o) = c(T_i - T_j) = c\cdot\Delta T_{i,j} \quad (1)$$

It is obvious that the distinction in the area of propagation depends on the difference in the delay of the signal propagation ΔTi,j. Due to building differences, the unknown time To of signal transmission can rid of and faces no issues due to different time scales at the BSs and the mobile. Both Ti and Tj cases are used to measure the difference in signal propagation delay and are calculated on the mobile phone thus result from the same time base station [14,15,16]. Signal propagation delay differential measurement of TDOA specifies points of equal range to the considered base stations which, unlike TOA, specifies a circle around a BS with a propagation delay. This is the definition of a two-dimensional case hyperbola or a three-dimensional space hyperboloid. Consequently, TDOA is often called hyperbolic positioning.

Figure 4 shows the concept of TDOA positioning. Hyperbolas with foci defining geometric points of equal range difference to those BSs at the locations of the BSs involved. The position of the mobile terminal (MT) is given by the intersection in the three-dimensional scenario of different hyperbolas or hyperboloids. The intersection of two hyperbolas (solid lines) in the instance shown in Figure 4 offers a distinctive MT position.

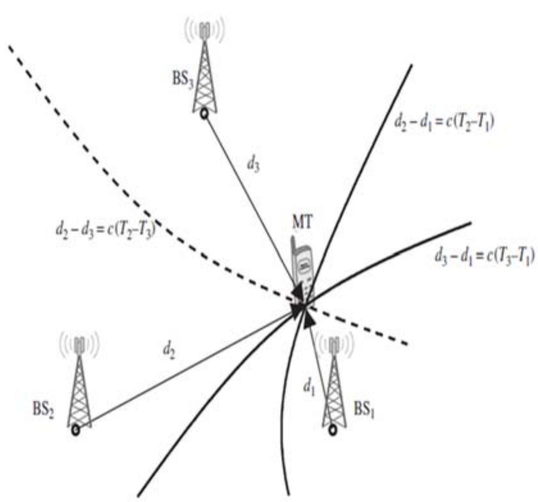

Figure 4: Principle of TDOA in 2-dimensions[17]

Another hyperbola (dashed line) is determined by equation of $d_2 - d_3 = (d_2 - d_1) - (d_3 - d_1) = c\Delta T_{2,1} - c\Delta T_{3,1}$. Hence, this hyperbola is obtained by signal propagation delay difference measurements from the first two [18]. The measurement of propagation delay differences Ti − Tj provide hyperbolas with BSs as foci given LOS propagation and the speed of light c. The intersection of these hyperbolas produces the Mobile Terminal position. The system of N − 1 nonlinear equations can be explained as:

$$\begin{aligned} &[(x-x_2)^2 + (y-y_2)^2 + (z-z_2)^2]^{1/2} - \\ &[(x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2]^{1/2} = d_2 - d_1 = c\Delta T_{2,1} \\ &[(x-x_3)^2 + (y-y_3)^2 + (z-z_3)^2]^{1/2} - \\ &[(x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2]^{1/2} = d_3 - d_1 = c\Delta T_{3,1} \quad (2) \\ &[(x-x_N)^2 + (y-y_N)^2 + (z-z_N)^2]^{1/2} - \\ &[(x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2]^{1/2} = d_N - d_1 = c\Delta T_{N,1} \end{aligned}$$

MT and BSi positions are defined respectively by (x, y, z) and (xi, yi, zi). For the two-dimensional condition, the terms containing (z − zi) are ignored. This stage solves the unknown BS time base To compared to TOA. With N BSs, a formula can obtain independent equations through a set of N –1 [18,19].

Two general techniques are available to estimate the TDOAs. To generate a comparative TDOA, the first is to subtract TOA readings from two stations. The second is to use a method of cross-correlation in which the signal obtained at one station is linked with the signal obtained at another station. Because the timing reference on the source to be situated is very hard to understand and because the signals of concern are ongoing waves, the cross-relation method is frequently used to assess the TDOA. For this method, the fundamental timing requirement is to synchronize the receivers. Compared to the need to understand the signal's originating transmission time, this requirement is comparatively simple. Many errors affect the cross-relation method, which can be regarded a Gaussian distribution [9].

The closed-form solution described here is an analytical solution that does not involve range data calculation and does not rely on the accessibility of any information other than arrival times. The solution is mainly based on the transformation into a collection of vector equations of the hyperbolic equations (which are algebraic but nonlinear equations). It is then shown that the vector equations are linear and can be divided from these equations by the emitter's position vector. Finally, the emitter's three coordinates can be

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achieved from three linear, simultaneous equations [19-23].

Geometric dilution of precision (GDOP) is a rule of criteria for determining system efficiency. The current job art stated that location station allocation influenced passive system location efficiency and made a greater step in determining accuracy. Using distinct geometric patterns such as straight, trapezoidal, parallelogram, inverted triangle, Y shape, lozenge, square and rectangle, four base stations can be situated around the mobile. [24]. GDOP or total standard deviation can be calculated by using:

$$\text{GDOP} = \sqrt{\sigma^2{}_x + \sigma^2{}_y + \sigma^2{}_z} \quad (3)$$

In Sun [25], optimal stations distribution for a single source target is suggested to enhance performance of four stations passive location system based on time difference of arrival (TDOA) measurements. Geometrical dilution of precision (GDOP) is achieved by deriving Cramér-Rao Lower Bound (CRLB). It suggested using distribution of the formation of square form, T-shape, Y-shape and I-shape, and only in 2D.

The precision of the TDOA location model is affected by several variables. Wang et al.[26] evaluated the impact of measurement error, location error observers and systematic bias on the tri-satellite TDOA location scheme, which is instructive in designing calibration model. Yang et al. [27] addressed the impact of the allocation of stations and the baseline duration of the TDOA location scheme with four stations and described the features of the allocation of different stations. But there are no universal findings that can be expanded to multi-station cases. Wang et al.[28] evaluated the range of location accuracy for the TDOA-based irregular four-station Y-shaped allocation and drawn two conclusions. But the conclusions cannot be extended to other station allocation form as well as to the ideal distribution form for single destination stations.

3. CLOSED FORM SOLUTION OF TDOA

For the detection of the mobile/emitter, three-dimensional (3D) geo-location methods are essential because the terrain situation is very mountainous or deep forest. A 3D issue is unavoidable as the base station/receivers cannot be situated or placed with the mobile/emitter at the same place. A unique solution to a TDOA-based 3D problem based on Bakhoum's strategy has therefore been introduced [19]. Firstly, the basic form of time of arrival equation may be implemented:

$$t_i = t_o + \frac{D_i}{c} \quad (4)$$

where t_i is indicates the time of arrival at base-station i, D_i refer to the distance between the base-stations and mobile, c is indicates the speed of light,
t_o is about the time of the transmission.

Upon fulfillment of this condition, t_o can be removed from any pair of two equations, which results:

$$t_2 - t_1 = \frac{D_2 - D_1}{c} \quad (5)$$

Hence, this is turns into the equation of TDOA. This equation can form into a 3D hyperboloid as mentioned previously when there is a presence of z-coordinates. For 2D, there is no presence of z-coordinates. When the mobile position referred as x_o, y_o, and z_o are implemented into equation (3.2), it can be rewrite as:

$$\sqrt{(x_2 - x_0)^2 + (y_2 - y_0)^2 + (z_2 - z_0)^2} - \sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2 + (z_1 - z_0)^2} = c(t_2 - t_1) \quad (6)$$

where x_2, y_2, z_2 and x_1, y_1, z_1 are the coordinates location of the base-station/receiver of 2 and 1.
By getting three more base station / receiver coordinates, three extra arrival times result in an extra three equations such as Equation (6), which can be solved for the target coordinates of the mobile/ emitter.
Based on Backhum, it indicates that a propagation mode is mathematically equivalent to a straight line propagation between any two points where the signal path is not a straight line, but at a speed is lesser than c. In this case, the TDOA equation in which the signal path is nonlinear will be concluded as follows after the path delay has been inserted:

$$t_2 - t_1 = \frac{D_2}{\propto_2 c} - \frac{D_1}{\propto_1 c} = \frac{1}{c}\left(\frac{D_2}{\propto_2} - \frac{D_1}{\propto_1}\right) \quad (7)$$

Hence, all the coefficients of path delay are considered to be one in this research.
Next steps a set of vector equations must be change from hyperbolic equations.

$$a_{11}x_0 + a_{12}y_0 + a_{13}z_0 = b_1 \quad (8)$$

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$$a_{11} = \frac{2}{(t_2 - t_1)}\left(\frac{x_2}{\propto_2{}^2} - \frac{x_1}{\propto_1{}^2}\right) - \frac{2}{(t_3 - t_1)}\left(\frac{x_3}{\propto_3{}^2} - \frac{x_1}{\propto_1{}^2}\right)$$

$$a_{12} = \frac{2}{(t_2 - t_1)}\left(\frac{y_2}{\propto_2{}^2} - \frac{y_1}{\propto_1{}^2}\right) - \frac{2}{(t_3 - t_1)}\left(\frac{y_3}{\propto_3{}^2} - \frac{y_1}{\propto_1{}^2}\right)$$

$$a_{13} = \frac{2}{(t_2 - t_1)}\left(\frac{z_2}{\propto_2{}^2} - \frac{z_1}{\propto_1{}^2}\right) - \frac{2}{(t_3 - t_1)}\left(\frac{z_3}{\propto_3{}^2} - \frac{z_1}{\propto_1{}^2}\right)$$

$$b_1 = \frac{1}{(t_2 - t_1)}\left(\frac{x_2{}^2 + y_2{}^2 + z_2{}^2}{\propto_2{}^2} - \frac{x_1{}^2 + y_1{}^2 + z_1{}^2}{\propto_1{}^2}\right) - \frac{1}{(t_3 - t_1)}\left(\frac{x_3{}^2 + y_3{}^2 + z_3{}^2}{\propto_3{}^2} - \frac{x_1{}^2 + y_1{}^2 + z_1{}^2}{\propto_1{}^2}\right) + c^2(t_3 - t_2) \quad (9)$$

Equation (8) can be summarized as

$$AX = B \quad (10)$$

Equation (3.23) can be solved in least square estimation method into

$$X = (A^T \cdot A)^{-1} A^T \cdot B \quad (11)$$

Included in this algorithm and simulation is the impact of noise in TDOA positioning:

$$TDOA = t + e_N \quad (12)$$

which
t is indicates the actual time difference of arrival
e_N is the noise error from a normal distribution

Noise in this simulation are generate randomly for every channel related to Standard Deviation on TDOA measurement accuracy. The noise of standard deviation, σ_τ = 50nsec, γ = 0dB for 1sec are implement in the simulation.
The covariance matrix contains variances and correlation coefficients for every axis which can be observed in Equation (12).

$$C_{UU} = \begin{bmatrix} \sigma_x^2 & \sigma_{xy} & \sigma_{xz} \\ \sigma_{xy} & \sigma_y^2 & \sigma_{yz} \\ \sigma_{xz} & \sigma_{yz} & \sigma_z^2 \end{bmatrix} \quad (13)$$

Equation of covariance matrix (13) shows the noise correlation between each axis and must be transformed to a matrix of covariance diagonalized as in Equation (14) in order to achieve the axis correlation with itself, which can be explained together with the three orthogonal position axes as standard deviations. It is therefore necessary to transform the covariance matrix, which indicates the only variance for each axis, such as:

$$C_{UU} = \begin{bmatrix} \sigma_x^2 & 0 & 0 \\ 0 & \sigma_y^2 & 0 \\ 0 & 0 & \sigma_z^2 \end{bmatrix} \quad (14)$$

The output in Equation (14) provides the variances diagonally for each axis as stated above. On that basis, the square root of these variances provides the standard deviation needed to evaluate the system's accuracy:

$$\sigma_{total}/GDOP = \sqrt{\sigma_x{}^2 + \sigma_y{}^2 + \sigma_z{}^2} \quad (15)$$

σ_x is the value of standard deviation for x-axis
σ_y is the value of standard deviation for y-axis
σ_z is the value of standard deviation for z-axis

4. RESULTS

The five base-stations/receivers can be positioned around the mobile/emitter in this part using separate geometric patterns in order to find the optimum base station/receiver distribution for greater precision. There are eight distinct types of situations that are performed to find optimum allocation for five base stations/receivers. The base station/receiver scenarios are positioned in trapezoidal (same and different altitudes), parallelogram (same and different altitudes), lozenge (same and different altitudes), triangle (same and different altitudes), circle (same and different altitudes), base-stations/receivers in rectangular (same and different) situation. The location of the mobile/emitter is set as (0, 0, 0) for all of the scenarios in this simulation. From the scenarios, the measurement of GDOP are collected and being compared with 2D, 3D (same altitude) and 3D (different altitude) in the table 17.

4.1 Parallelogram Formation

In this scenario, the location of the position for the base-stations/receivers are placed in shaped of formation of trapezoidal as can be seen in Figure 5 for five base-stations/receivers. The table

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below shows the location of the base-station/receivers from base-station/receivers 1 until 5 with same and different altitude.

Table 1: Base-stations/receivers coordinates with same altitude for trapezoidal formation

Base-stations/receivers	X-Axis (km)	Y-Axis (km)	Z-Axis (km)
1	0	-2	0.1
2	-2.5	-2	0.01
3	-5	-5	0.01
4	5	-5	0.01
5	0	-5	0.01

Table 2: Base-stations/receivers coordinates with different altitude for trapezoidal formation

Base-stations/receivers	X-Axis (km)	Y-Axis (km)	Z-Axis (km)
1	0	-2	1.0
2	-2.5	-2	2.0
3	-5	-5	0.5
4	5	-5	2.5
5	0	-5	1.5

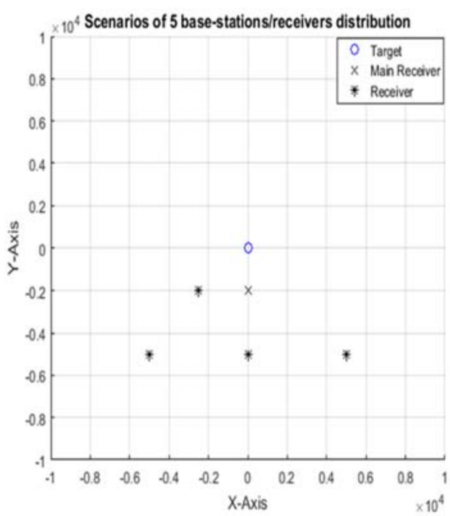

Figure 5: Five base-stations/receivers distribution in trapezoidal formation

4.2 Parallelogram Formation

In this scenario, the location of the position for the base-stations/receivers are placed in a shape of formation of parallelogram as can be seen in Figure 6 for five base-stations/receivers.

Table 3: Base-stations/receivers coordinates with same altitude for parallelogram formation

Base-stations/receivers	X-Axis (km)	Y-Axis (km)	Z-Axis (km)
1	0	-2	0.1
2	3	-2	0.01
3	-3	-2	0.01
4	-1	-4	0.01
5	5	-4	0.01

Table 4: Base-stations/receivers coordinates with different altitude for parallelogram formation

Base-stations/receivers	X-Axis (km)	Y-Axis (km)	Z-Axis (km)
1	0	-2	1.0
2	3	-2	2.0
3	-3	-2	0.5
4	-1	-4	2.5
5	5	-4	1.5

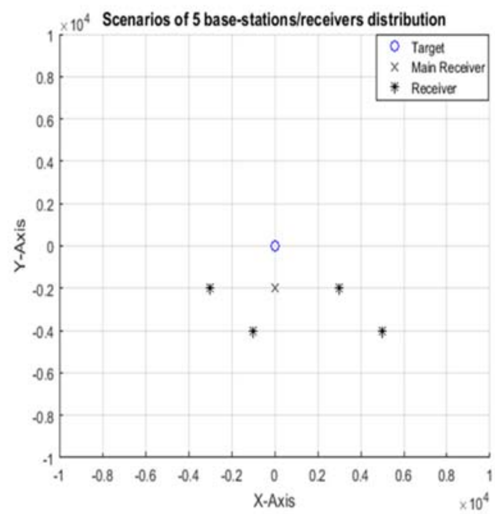

Figure 6: Five base-stations/receivers distribution in parallelogram formation

4.3 Lozenge Formation

In this scenario, the location of the position for the base-stations/receivers are placed in a shape of formation of lozenge as can be seen in Figure 7 for five base-stations/receivers.

Table 5: Base-stations/receivers coordinates with same altitude for lozenge formation

Base-stations/receivers	X-Axis (km)	Y-Axis (km)	Z-Axis (km)
1	0	-2	0.1
2	0	-6	0.01
3	6.5	-3.75	0.01
4	-6.5	-3.75	0.01
5	0	-3.75	0.01

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Table 6: Base-stations/receivers coordinates with different altitude for lozenge formation

Base-stations/receivers	X-Axis (km)	Y-Axis (km)	Z-Axis (km)
1	0	-2	1.0
2	0	-6	2.0
3	6.5	-3.75	0.5
4	-6.5	-3.75	2.5
5	0	-3.75	1.5

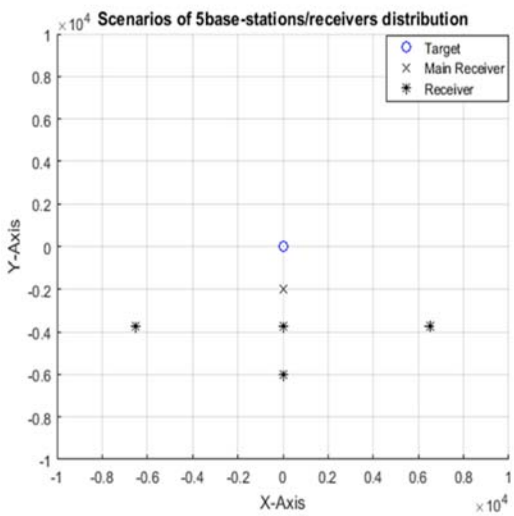

Figure 7: Five base-stations/receivers distribution in lozenge formation

4.4 Triangle Formation

In this scenario, the location of the position for the base-stations/receivers are placed in a shape of formation of triangle as can be seen in Figure 8 for five base-stations/receivers.

Table 7: Base-stations/receivers coordinates with same altitude for triangle formation

Base-stations/receivers	X-Axis (km)	Y-Axis (km)	Z-Axis (km)
1	0	-2	0.1
2	4.5	-6	0.01
3	2.1	-3.9	0.01
4	-4.5	-6	0.01
5	-2.1	-3.9	0.01

Table 8: Base-stations/receivers coordinates with different altitude for triangle formation

Base-stations/receivers	X-Axis (km)	Y-Axis (km)	Z-Axis (km)
1	0	-2	1.0
2	4.5	-6	2.0
3	2.1	-3.9	0.5
4	-4.5	-6	2.5
5	-2.1	-3.9	1.5

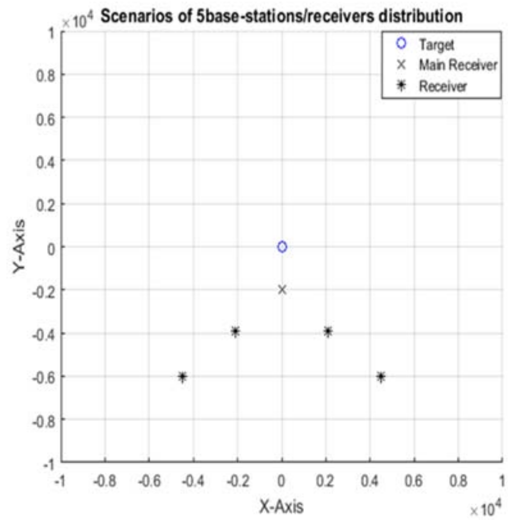

Figure 8: Five base-stations/receivers distribution in triangle formation

4.5 Circle Formation

In this scenario, the location of the position for the base-stations/receivers are placed in a shape of formation of circle as can be seen in Figure 9 for five base-stations/receivers.

Table 9: Base-stations/receivers coordinates with same altitude for circle formation

Base-stations/receivers	X-Axis (km)	Y-Axis (km)	Z-Axis (km)
1	0	-2	0.1
2	1.35	-2.52	0.01
3	-1.35	-2.52	0.01
4	1.42	-5.41	0.01
5	-1.42	-5.41	0.01

Table 10: Base-stations/receivers coordinates with different altitude for circle formation

Base-stations/receivers	X-Axis (km)	Y-Axis (km)	Z-Axis (km)
1	0	-2	1.0
2	1.35	-2.52	2.0
3	-1.35	-2.52	0.5
4	1.42	-5.41	2.5
5	-1.42	-5.41	1.5

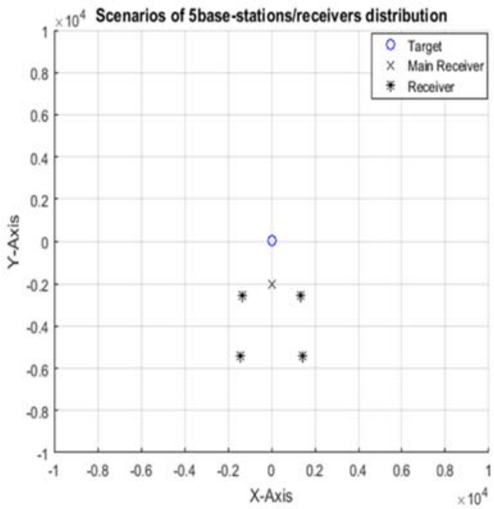

Figure 9: Five base-stations/receivers distribution in circle formation

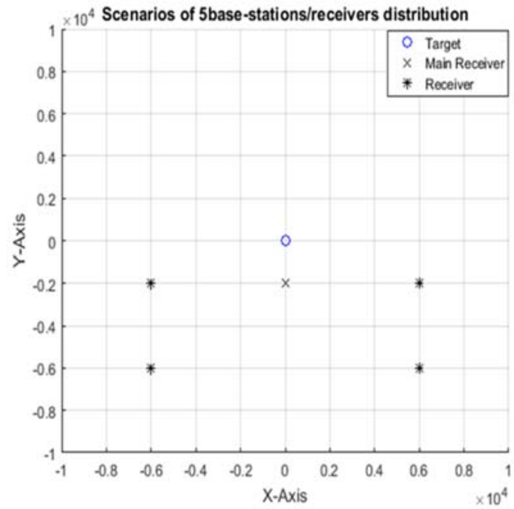

Figure 10: Five base-stations/receivers distribution in rectangle formation

4.6 Rectangle Formation

In this scenario, the location of the position for the base-stations/receivers are placed in a shape of formation of rectangle as can be seen in Figure 10 for five base-stations/receivers.

Table 11: Base-stations/receivers coordinates with same altitude for rectangle formation

Base-stations/receivers	X-Axis (km)	Y-Axis (km)	Z-Axis (km)
1	0	-2	0.1
2	-6	-2	0.01
3	-6	-6	0.01
4	6	-6	0.01
5	6	-2	0.01

Table 12: Base-stations/receivers coordinates with different altitude for rectangle formation

Base-stations/receivers	X-Axis (km)	Y-Axis (km)	Z-Axis (km)
1	0	-2	1.0
2	-6	-2	2.0
3	-6	-6	0.5
4	6	-6	2.5
5	6	-2	1.5

4.7 Straight Line Formation

In this scenario, the location of the position for the base-stations/receivers are placed in a shape of formation of straight line as can be seen in Figure 11 for five base-stations/receivers.

Table 13: Base-stations/receivers coordinates with same altitude for straight line formation

Base-stations/receivers	X-Axis (km)	Y-Axis (km)	Z-Axis (km)
1	0	-2	0.1
2	6	-2	0.01
3	-6	-2	0.01
4	-3	-2	0.01
5	3	-2	0.01

Table 14: Base-stations/receivers coordinates with different altitude for straight line formation

Base-stations/receivers	X-Axis (km)	Y-Axis (km)	Z-Axis (km)
1	0	-2	1.0
2	6	-2	2.0
3	-6	-2	0.5
4	-3	-2	2.5
5	3	-2	1.5

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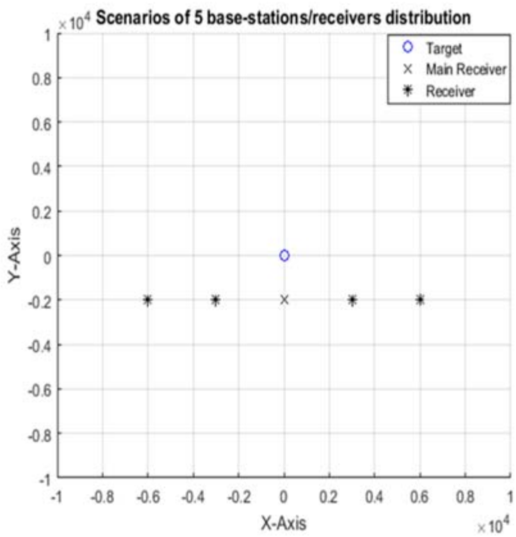

Figure 11: Five base-stations/receivers distribution in straight line formation

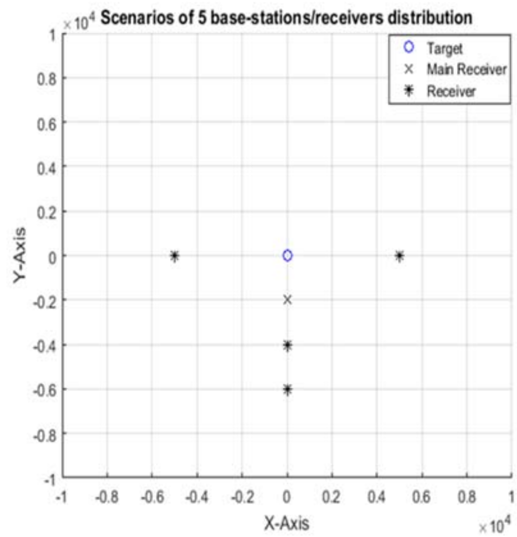

Figure 12: Five base-stations/receivers distribution in Y-shaped formation

4.8 Y-shaped Formation

In this scenario, the location of the position for the base-stations/receivers are placed in a shape of formation of Y as can be seen in Figure 12 for five base-stations/receivers.

Table 15: Base-stations/receivers coordinates with same altitude for Y-shaped formation

Base-stations/receivers	X-Axis (km)	Y-Axis (km)	Z-Axis (km)
1	0	-2	0.1
2	0	-4	0.01
3	0	-6	0.01
4	5	0	0.01
5	-5	0	0.01

Table 16: Base-stations/receivers coordinates with different altitude for Y-shaped formation

Base-stations/receivers	X-Axis (km)	Y-Axis (km)	Z-Axis (km)
1	0	-2	1.0
2	0	-4	2.0
3	0	-6	0.5
4	5	0	2.5
5	-5	0	1.5

Table 17: Comparison of base/stations receiver distribution towards accuracy for 2D and 3D

Base Station Distribution	Condition	GDOP (km)
Trapezoidal	2D	0.1273
	3D (same altitude)	2.3898
	3D (different altitude)	0.2414
Parallelogram	2D	0.0968
	3D (same altitude)	2.8468
	3D (different altitude)	0.1848
Lozenge (Diamond)	2D	0.0913
	3D (same altitude)	3.3614
	3D (different altitude)	2.8999
Triangle	2D	1.1393
	3D (same altitude)	1.6251
	3D (different altitude)	1.8236
Circle	2D	0.3433
	3D (same altitude)	2.3898
	3D (different altitude)	0.7977
Rectangle	2D	0.0780
	3D (same altitude)	1.0376
	3D (different altitude)	0.2310
Straight lines	2D	18.052
	3D (same altitude)	∞

	3D (different altitude)	31.607
Y shaped	2D	0.0517
	3D (same altitude)	3.8720
	3D (different altitude)	0.1764

5. CONCLUSION

Based on a comparison of the base-station / receiver distributions from table 17, it can be found that the best possible distributions are when base-station/receivers are in 2D and 3D (different altitude) condition as it provides the smallest standard deviation which improves GDOP for an efficient mobile/emitter estimate position. 3D (same altitude) provides a greater complete standard deviation as it results in the smallest precision. It can be seen in 3D (same altitude) straight line formation where the measurement can not be calculated as the infinity value has been achieved. This is because it is important to notice the inversion of the matrix resulting from $(A^T \cdot A)^{-1}$. If this product is not resulting in a matrix of range (or column space) equal to the number of unknown variables, the matrix is not invertible and the system has no solution. That implies, for instance, that base-station which are in the same line-of-sight to the mobile/emitter will not constitute two independent equations or that if all base-stations/receivers are in the same plane, a 3-D position cannot be computed.
Hence, TDOA is not suitable to position with same altitude as it gives lowest accuracy.

Y-shaped and rectangular formation obtaining the smallest total standard deviation or GDOP between all 2D and 3D (distinct altitude) situations for five base stations/receivers provides a better situation for estimating the location of the mobile/ emitter. The above baseline station/receiver geometry types should be used to locate the estimate position of the mobile/emitter as accurately as possible as it has the smallest total standard deviation or GDOP and the greatest precision.The highest GDOP which is straight line and triangle formation are not a suitable formation to use for five base-stations/receivers. Both of this type formation are not suitable to be used in locating the position of mobile/emitter due to lowest accuracy as the value of the GDOP is high. Besides, the other formation such as parallelogram, lozenge (diamond), circle and trapezoidal also are not the best to locate the position of mobile/emitter as the range of the GDOP is between the highest and lowest from the best and worst formation.

Based on the table 4.25, it can be seen that the axis plays important factors in increasing or decreasing accuracy. X-axis has the lowest standard deviation for all types of formations following by y-axis and z-axis. If the simulations only involved with two axis which is x and y-axis (2D), the accuracy are increase compare to three axis that involves z-axis (altitude) which makes the value of GDOP increase and lowering the accuracy to estimate the position of the mobile/emitter. Z-axis with different altitude and same altitude plays important parts to determining the locations of the mobile/emitter as the applications for tracking, mobility and navigations will not be accurate as in the real situation, our surroundings have a geographical surface such as mountains and hills.

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