Optimizing Location Positioning Using Hybrid TOA-AOA Techniques in Mobile Cellular Networks

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ABSTRACT
Mobile Positioning is a great aspect in mobile cellular networks (GSM, UMTS etc) as it makes it possible to introduce a new class of applications based on the knowledge of the subscriber's position. Therefore, it can be quite useful for the support of multimedia streaming application's performance. Although several complicated techniques have been introduced, the need for implementation simplicity holds interest for conventional techniques such as Time of Arrivals (TOA) and Angle of Arrivals (AOA). In this paper we introduce two enhanced versions of the latter techniques, Enhanced Time of Arrivals (E-TOA) and Enhanced Angle of Arrival (E-AOA), in order to optimize the location positioning estimations. The accuracy is improved by introducing additional weight coefficients reflecting the LOS/nLOS propagation. Finally, the resulting cost functions are simulated in three 2-D, single ray trace microcellular simulation environments and compared to existing techniques. The results have shown good reduction of the location error which in urban environment reaches the value of 40%.

Categories and Subject Descriptors
C.2.1 [**Computer Communication Networks**]: Network Architecture and Design – *Wireless Communication.*
F.2.2 [**Analysis of Algorithms and Problem Complexity**]: Nonnumerical Algorithms and Problems – *Geometrical problems and computations.*
G.1.6 [**Numerical Analysis**]: Optimization – *Quadratic programming methods.*

General Terms
Algorithms, Performance, Theory.

Keywords
Location Positioning, Time of Arrivals (TOA), Angle of Arrivals (AOA), Hybrid Techniques.

1. INTRODUCTION
Positioning algorithms are of great importance in mobile cellular telecommunications as means of providing LoCation Services (LCS). These services support applications which make use of the knowledge of the position of the mobile station and can be classified into Commercial LCS, Internal LCS, Emergency LCS and Lawful Intercept LCS. In addition, the knowledge of the position of a mobile system could be beneficial in multimedia streaming and still image applications [1]. For example, improved algorithms for resources' allocation, performance and QoS may be supported utilizing information extracted by location positioning.

In recent years, sophisticated contributions have been made such as Assisted GPS (AGPS) [2], Differential GPS (DGPS) and Time Difference of Arrivals (TDOA) [3-5] etc. which diminish the location error increasing the implementation complexity and the cost of investment. Our proposal is based on TOA and AOA location techniques which are main representatives of network based positioning thus not requiring modifications in existing handsets. On the contrary to satellite visibility (GPS), internetworking (A-GPS), BSs' synchronization (TDOA) etc. our proposal require least modifications in existing networks while introducing improved location accuracy (compared to corresponding conventional methods). In this paper, we demonstrate the mathematical analysis of both TOA and AOA and we introduce the use of weight coefficients against the nLOS propagation resulting in the improvement of location accuracy of the latter techniques. Using three 2-D, single ray trace microcellular simulation environments we compared our proposals against the conventional methods and computed the improvement of the location accuracy.

The remainder of this paper is organised as follows: Section 2 summarises the mathematical background of TOA and AOA algorithms, while in Section 3 we demonstrate the proposed hybrid algorithms. The analysis of the created simulation environments is given in Section 4. In Section 5 we provide the simulation results extracted by all three environments with the corresponding statistical elaboration. Finally, conclusions of our work are drawn in section 6.

2. CONVENTIONAL TOA, AOA

2.1 Time Of Arrivals (TOA)
In the TOA technique, the location of the Mobile Station (MS) derives from measuring the time needed for a signal to travel from a number of BSs to the MS. The equation $d = c \cdot t$ provides the distance between MS and BS. Geometrically, the MS lies on a circle centred at the BS's location and radius distance *d*. By using at least three BSs, the position of the MS is given by the intersection point of the three circles.

Quite a few methods have been introduced as solutions to obtain the time estimates including phase estimation, pulse transmission, burst transmission, signalling and spread spectrum

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techniques. In the first technique, phase detectors are employed in the BSs and synchronization of the BSs used for positioning is required [6]. In pulse transmission and spread spectrum systems, the time estimates are computed by implementing correlation techniques [6].

Due to measurement errors in time estimates the circles do not intersect at a single point. In that case, location algorithms have been introduced in literature to resolve the problem [7]. Moreover TOA method suffers from non Line Of Sight (nLOS) propagation. In that case, the signal does not travel directly from the MS to the BS but it reaches the latter through reflections or diffractions on buildings, cars, obstacles ext. Several contributions have been made to mitigate the location error caused by nLOS propagation. An effective one, proposed by Turin [6], is to change the location algorithm taking into consideration that in nLOS propagation the measured distance $c\tau_{BS_i}$ is greater than the real one $c(\tau_{BS_i} - \Delta t)$ (Δt is the nLOS propagation error) and therefore the possible location of the MS lies inside the circle centred in BS's position. For the three BSs TOA algorithm, the intersection of the three circles provides an area where the MS can possibly lie. An initial estimation of the MS location can be the centre of the feasible area [9]. In case of three BSs (figure 1), supposing that the coordinates of the three points of intersection which set the feasible area E, are (x_1, y_1), (x_2, y_2) and (x_3, y_3) the coordinates of the centre of the area E are:

$$(\hat{x}_{MT}^{(0)}, \hat{y}_{MT}^{(0)}) = \left(\frac{x_1 + x_2 + x_3}{3}, \frac{y_1 + y_2 + y_3}{3}\right) \quad (1)$$

In several cases where the MS is quite close to one BS and the circles do not intersect, the feasible area is estimated as a circle around the adjacent BS. Furthermore, a position nearby that BS is chosen as the initial guess. In order to enhance the initial guess and minimize the location error a non-linear least square solution is used. According to this, for each BS used in location process, the following function is formed [6] [10]:

$$g_i(x, y) = c\tau_{BS} - \sqrt{(x - x_{BS_i})^2 + (y - y_{BS_i})^2} \quad (2)$$

The feasible area E can be appointed by the following inequalities:

$$E = \{(x, y) \mid g_i(x, y) \geq 0 \forall i = 1, ...N_{BS}\}$$

$$=> E = \{(x,y) \mid (x - x_{BS_i})^2 - (y - y_{BS_i})^2 \leq (c\tau_{BS_i})^2 \forall i = 1, ...N_{BS}\}, \quad (3)$$

where N_{BS} is the number of the BSs.
The next step is to form the following cost function [6] [10]:

$$G(x, y) = \sum_{i=1}^{N_{BS}} a_i g_i^2(x, y), \quad (4)$$

where α_i are weights reflecting the signal strength as received at the i_{th} BS, *(i=1,…..N$_{BS}$)*.

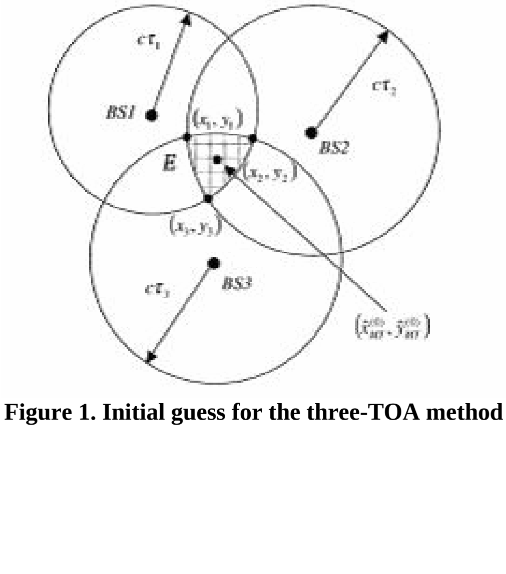

Figure 1. Initial guess for the three-TOA method

If no information about signal strength is available or not taken into account, it is possible to set $a_i = 1 \forall (i = 1, ...N_{BS})$. The location estimate is finally given by the couple *(x, y)* that minimizes the cost function inside the feasible region.

2.2 Angle Of Arrivals (AOA)

In the AOA technique, the angles of arrivals of a signal from the MS at a pair -or more- BSs are measured by using antenna arrays. The position of the MS is defined by the intersection of at least two directional lines of bearing. In [10], a single BS AOA technique using the TOA at the MPCs impinging at the BS is introduced.

Location errors occur in AOA technique by reason of nLOS propagation and multipath. Due to nLOS propagation the reflected signal received at BS antenna array has different AOA than the direction of the MS. Moreover, even in LOS propagation, multipath which means scattered signals near and around the BS would still alter the measured AOA. Because of measuring limitations of the devices, the higher the distance between MS and BS, the more the precision of the method decreases. Due to nLOS propagation and multipath, it is wiser in location estimation using the AOA method to utilize more than two BSs. In figure 8 the three BSs approach is shown. An initial proposal, for the solution to the positioning problem could be the following:

$$(\hat{x}_{MT}^{(0)}, \hat{y}_{MT}^{(0)}) = \left(\frac{a_1 \cdot x_1 + a_2 \cdot x_2 + a_3 \cdot x_3}{a_1 + a_2 + a_3}, \frac{a_1 \cdot y_1 + a_2 \cdot y_2 + a_3 \cdot y_3}{a_1 + a_2 + a_3}\right), \quad (5)$$

Where a_i are weights related to signal strength received at the BS_i. Again, if no information about signal strength is provided, it is possible to set $a_i = 1$.

For a more precise estimation, an AOA cost function is proposed. As the MS's location lies on a beeline determined by the AOA of the signal received at the BS and BS's coordinates (figure 2), the following function is proposed:

$$f_i(x, y) = (y - y_{BS_i}) - \tan\phi_i \cdot (x - x_{BS_i}) \quad (6)$$

Where (x_{BS_i}, y_{BS_i}) are the coordinates of the BS_i and ϕ_i the AOA of the signal received at the BS_i from the MS. The coordinates of the MS are those that minimize the following quadratic form (cost function):

$$F(x, y) = \sum_{i=1}^{N_{BS}} a_i f_i^2(x, y) \quad (7)$$

For macrocells, where the BSs are usually above roof level or at least above the terrain, the scatter signals are located close to the BS. As a result the received signals AOA follow a narrow spread distribution. On the other hand, for microcells where the BSs are placed below roof level and thus surrounded by local scatterers following a large spread distribution.

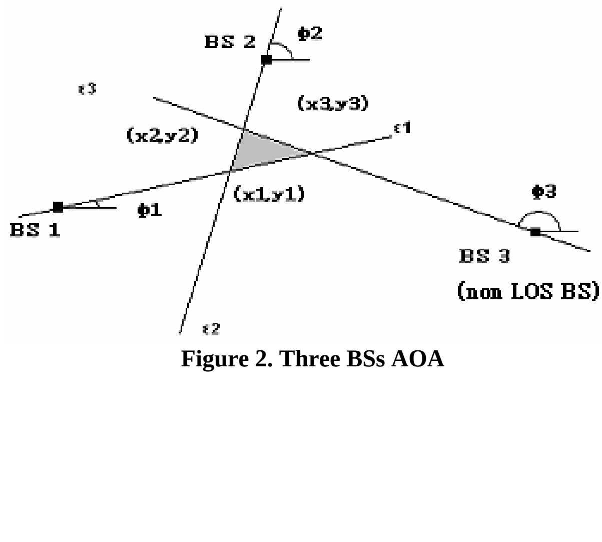

Figure 2. Three BSs AOA

3. PROPOSED HYBRID TECHNIQUES

3.1 Enhanced Time Of Arrivals (E-TOA)

In order to mitigate even more the effect of nLOS propagation in the Turin's cost function, a weight coefficient ℓ_i is proposed. To implement the weight ℓ_i, the network has to meet the following requirements:

- BS antenna arrays in order to measure the angle of the received signal
- A Geographical Information System (GIS) available to the network operator.

Another requirement is the application of Sentinel Function (SF), φ(θ), which is defined as the Euclidean distance between the BS and the nearest obstacle found along the azimuth direction identified by angle θ of the received signal and proposed by Porretta in [10]. φ(θ) can derive from GIS by sampling in steps of 0.5º the surrounding environment and eventually stored the distances at the BS. The more complex the clutter in the BS neighborhood is, the smaller sampling step is required. Even in demanding surroundings, however, a small amount of memory is needed to store the samples at the BS. For the received AOA, the distance between the BS and the MS (provided by TOA measurements) is compared to the first obstacle's distance at the same direction. If φ(θ)<ct (t is the time estimate) then the MS is in nLOS with the BS. If φ(θ)>ct the BS_i is in LOS and then $\ell_i = 1$. If one BS is in nLOS then $\ell_i = \frac{1}{10}$. If two BSs are in nLOS and $|ct_1-\varphi_1(\theta)|<|ct_2-\varphi_2(\theta)|$ then $\ell_1 = \frac{1}{10}$ and $\ell_2 = \frac{1}{100}$. If all three BSs are in nLOS and $|ct_1-\varphi_1(\theta)|<|ct_2-\varphi_2(\theta)|<|ct_3-\varphi_3(\theta)|$ then $\ell_1 = \frac{1}{10}$, $\ell_2 = \frac{1}{100}$ and $\ell_3 = \frac{1}{1000}$. These values have been chosen after several simulations and have shown the least location error. The difference $|ct_i-\varphi_i(\theta)|$ expresses the distance that the signal covers at the reflections before the final reflection above the obstacle, which will direct the signal in the BS. The longer this difference is, the greater the reflections' way due to nLOS propagation is. These reflections cause the increment in TOA, therefore they increase the divergence between the estimated, ct_i, and the real distance between the MS and the BS.

After the introduction of the ℓ_i coefficients the TOA cost function is reformed as follows:

$$G'(x,y) = \sum_{i=1}^{N_{BS}} \ell_i a_i g_i^2(x,y) \tag{8}$$

3.2 Enhanced Angle Of Arrivals (E-AOA)

In the same way, the AOA location error due to nLOS propagation can de reduced by the use of AOA weight coefficients l_i. The role and the demands of these coefficients are approximately the same with the corresponding in the enhanced TOA technique. Similarly to E-TOA, the implementation of AOA LOS coefficients require the formation of the Sentinel Function φ(θ). However, on the contrary to E-TOA, l_i coefficients are used to cease the contribution to the E-AOA cost function of the nLOS BSs. Therefore their value is binary (0 or 1). The proposed values cause the least location error as concluded by several simulation tests:

- In case that all three BSs are in LOS with the MS then $l_i = 1, \forall i = 1...3$. An exception may be ($l_i = 0$) if the AOA received at one BS is φ=90º. As tanφ cannot be defined, the contribution of the corresponding BS vanishes.
- When one BS (out of three) is in nLOS with the MS then $l_i = 0$ and the cost function estimates the position by the minimization of the other two directional lines. In that case, the nLOS propagation error vanishes and if we assume an environment without scattering close to the BS antenna the location error drops to zero.
- When two BSs are in nLOS with the MS we set $l_i = 0$ for the BS which corresponds to the greatest difference $|ct_i-\varphi_i(\theta)|$. The reason why, is that the greater the difference $|ct_i-\varphi_i(\theta)|$ is, the more the number of the reflections undertaken by the signal increases. In general, an increment in the reflections' number causes greater error in the AOA received after the final reflection.
- Similarly, when all three BSs are in nLOS, the location error caused by the E-AOA cost function diminishes if the contribution of the BS which corresponds to the greatest $|ct_i-\varphi_i(\theta)|$ difference vanishes ($l_i = 0$).

Using the E-AOA, the coordinates of the MS are provided by the minimization of the following quadratic form cost function:

$$F(x,y) = \sum_{i=1}^{N_{BS}} a_i \cdot l_i \cdot f_i^2(x,y) \cdot \tag{9}$$

4. SIMULATION ENVIRONMENTS

In order to evaluate the proposed positioning techniques, three 2-D simulation environments (rural, suburbs, city centre) were developed in C programming. All three environments (figure 3, 4, 5) have a coverage area of 440x440 m^2 which is divided to 100 square cells by the use of a 44m step, horizontally and vertically. The environments include buildings which are made of reinforced concrete and streets which are made of asphalt. It is suggested that there are no cars, trees ext. The white squares represent possible subscriber's positions while, the grey ones represent buildings (where it is forbidden for the subscriber to be).

4.1 Rural Environment

In this model, the subscriber is suggested to move on a highway (longest road) or two rural roads. Because of the highway, the microcellular communication scenario is assumed. Three BSs are located at the points of coordinates BS1=(198m, 66m), BS2=(154m, 374m) and BS3=(330m, 198m). The three BS antenna arrays are placed at 10m above ground level and they are below the roof level (approximately 50m). The electromagnetic field is simplified to a first-order ray trace contribution and the signal reaches the BS/MS directly (LOS propagation) or through reflections or diffractions on the buildings' walls (nLOS propagation). There are no reflections on cars, trees ext. What is more, we have considered BS antennas with space diversity techniques so that the measured data suffers the least possible number of reflections. The measurement of the time estimates is possible by translating time into distance through $d = c \cdot t$ equation. The AOA measurements were taken using the mathematical type:

$$\tan\varphi = \frac{y - y_{BS_i}}{x - x_{BS_i}}, \quad (10)$$

where (x_{BS_i}, y_{BS_i}) are the coordinates of the BS_i, i=1..3 while (x, y) are the coordinates of the BS (LOS propagation) or the coordinates of the point where the final reflection took place. For the positions where more than one BSs are in nLOS, the distance between the first obstacle and the nLOS BS is measured in order to form the differences $|cti-\varphi_i(\theta)|$ which are required for the implementation of the proposed hybrid techniques.

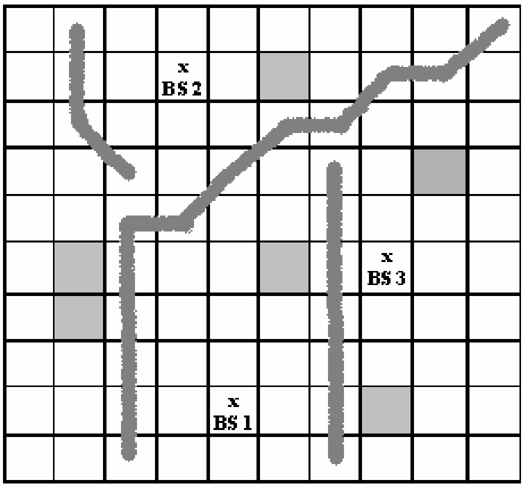

Figure 3. Rural simulation environment

4.2 Suburbs Environment

In a microcellular environment like this, the BS antenna is typically at the same height as lamp posts (3–6 m above ground level, although the antenna is more usually mounted on a side or corner of a building. The dominant propagation mechanisms are free space propagation plus multiple reflection and scattering within the cell coverage area, together with diffraction around the vertical edges of buildings and over the rooftops. Again, the electromagnetic field is simplified to a first-order ray trace contribution and the signal reaches the BS/MS directly (LOS propagation) or through reflections or diffractions on the buildings' walls (nLOS propagation). It is important to mention that in reality, since the BS antenna is below the average rooftop height, it is often surrounded by local scatterers. But, this effect is not taken into consideration in the simulation model.

In this model two BSs are located at the points of coordinates BS1=(418m, 242m) and BS3=(22m, 418m) while a BS is located on the corner of a building at the point of coordinates BS2=(154m, 110m). The subscriber's position follows two different roads which are indicated with the grey lines in figure 6. For the acquisition of the location data the procedure is the same with the previous analysed.

4.3 City Centre Environment

In order to access the location accuracy of the proposed techniques in a city centre environment the model presented in figure 5, is suggested. In this simulation model the microcellular (BS1, BS3) along with the picocellular (BS2) communication scenario is assumed. There are three BSs located at the points of coordinates BS1(110m, 418m), BS2(242m, 242m) and BS3(418m, 154m). Again, the required location data are gathered in the same way as above analysed. On the contrary to the previous two environments, in this model the subscriber's position may lie on every white square. In every simulation, the subscriber is placed in the centre of a white square and the algorithm locates him using a step of 0.44m in x, y direction. The complexity of the proposed location techniques is very modest. Simulations have been run on a Pentium 4 (2.66-GHz, 512 MB of RAM) personal computer; on average, fractions of second are required to determine each MS location.

5. SIMULATION RESULTS

In this section, the results taken by the simulation of the introduced hybrid techniques in the three environments-rural, suburbs, city centre- are presented. Both TOA and AOA are employed as reference techniques in order to evaluate the location accuracy of the proposed ones. In every

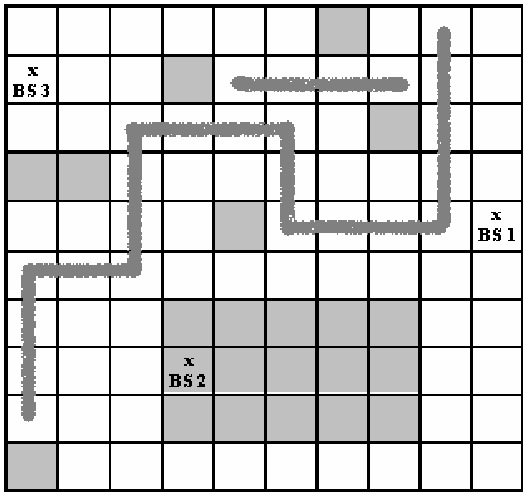

Figure 4. Suburbs simulation environment

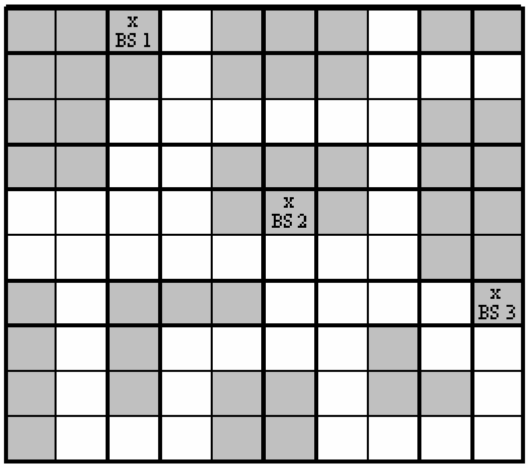

Figure 5. City centre simulation environment

possible MS's position, in all three environments, the location error (in meters) caused by the use of any positioning technique:

$$\varepsilon_r = \sqrt{(x_{MT} - \hat{x}_{MT})^2 + (y_{MT} - \hat{y}_{MT})^2} \quad (11)$$

is obtained by using the estimated location position given by the minimization of TOA, AOA, E-TOA or E-AOA cost function and the true location.

In figure 6, the locations obtained by the minimization of the cost functions and the true ones on the rural highway of the rural environment, are shown. In this figure, we notice that the estimations given by TOA and especially E-TOA technique are quite close to the real location of the subscriber. Except for the upper positions where the number of BSs in LOS decreases, in the other locations the error is in the area of 0.62m! On the contrary, this figure shows reduction of accuracy when using the AOA method which is predictable as AOA technique is quite sensitive in nLOS propagation. By the use of the hybrid AOA the location accuracy is becoming better and it is close to TOA and E-TOA error.

In figure 7, it is observed that all positioning techniques estimations follow the true positions. This happens because all the positions in the upper rural road are in LOS with more than two BSs. It is important to mention that using the AOA and E-AOA techniques in that case the location error drops to zero.

For the down rural road, figure 8, the conclusions are similar to the highway. TOA and E-TOA methods seem to follow the subscriber's move but AOA and E-AOA show a considerable error. In many positions this error occurs because the coordinates of the position and two BSs in LOS are in the same line. In that case, the number of directional lines in the AOA (or E-AOA) quadratic form is reduced.

As predicted, in figure 9, we notice that the more BSs are in nLOS the more the location error in all techniques increases. We also observe that in the rural environment the AOA and E-AOA techniques are more sensitive in nLOS conditions. Over all positions, the mean location error gets minimum when using the E-TOA technique which seems to cause a slight improvement in the TOA. On the other hand, the use of enhanced AOA improves the AOA accuracy in a remarkable way.

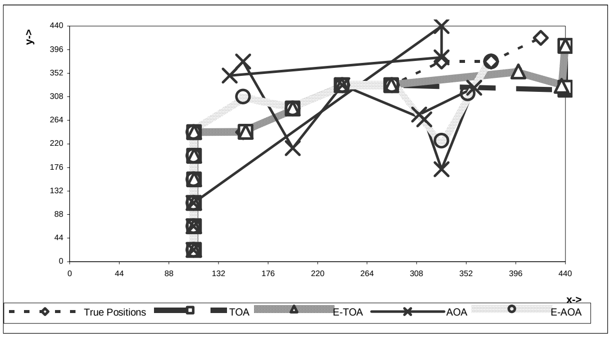

Figure 6. Location estimations in the highway of the rural environment.

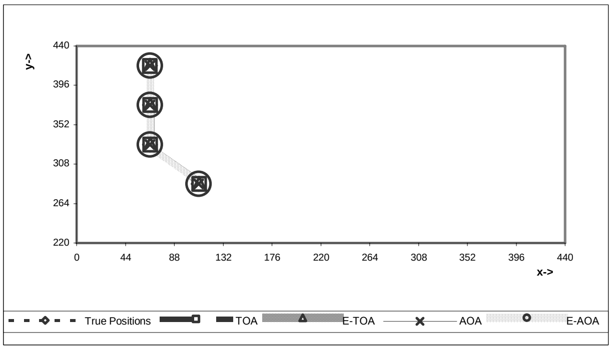

Figure 7. Location estimations in the upper rural road of the rural environment.

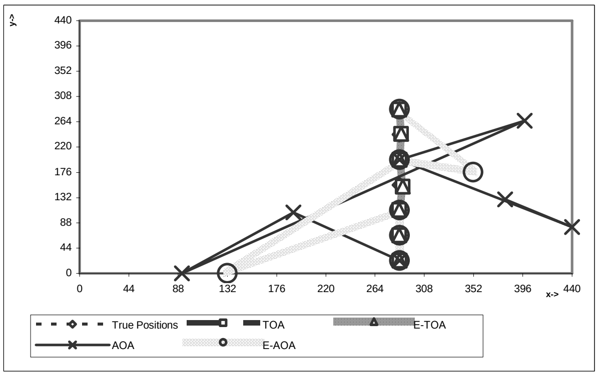

Figure 8. Location estimations in the under rural road of the rural environment.

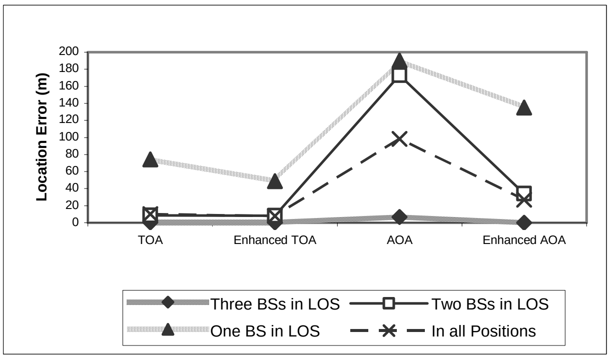

Figure 9. Mean location error in proportion to the technique used and the number of BSs in LOS (rural environment)

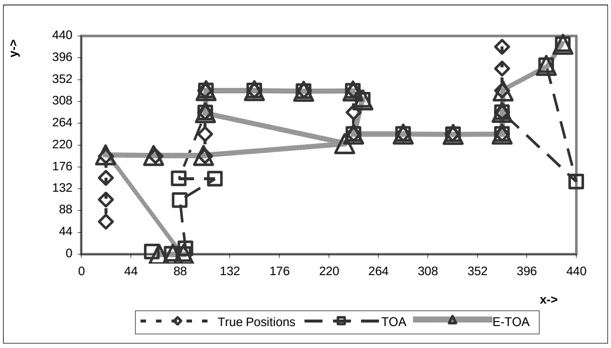

Figure 10. TOA and E-TOA location estimations in the first subscriber's way in the suburbs environment.

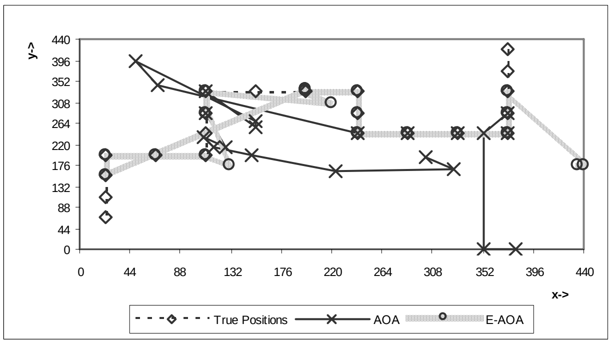

Figure 11. AOA and E-AOA location estimations in the first subscriber's way in the suburbs environment.

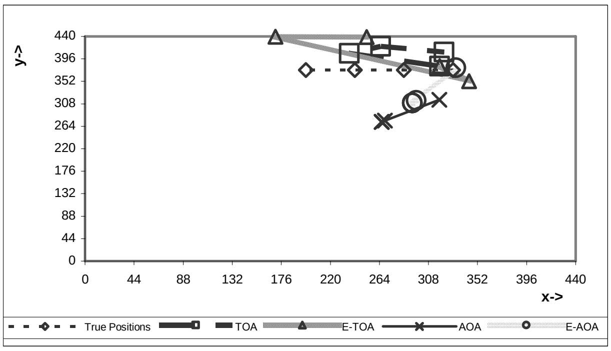

Figure 12. Location estimations in the second subscriber's way in the suburbs environment.

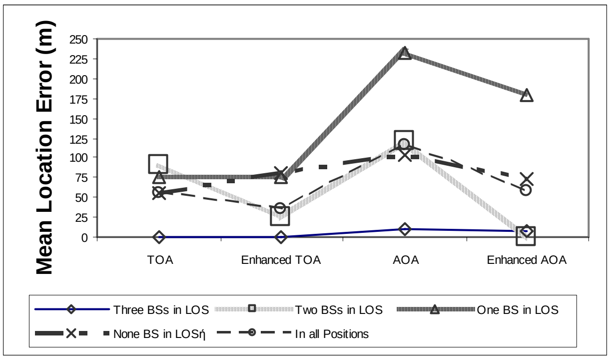

Figure 13. Mean location error in proportion to the technique used and the number of BSs in LOS (suburbs environment)

In figure 10, the reader can observe the satisfactory proximity to the true positions of the TOA technique and the accuracy upgrading that the E-TOA offers. On the contrary (figure 11), a great location error occurs in the same positions by the use of AOA technique. Apart from the remote from the centre positions, the E-AOA reduces the location error introduced by the AOA. In figure 12, all positioning techniques show a deviation from the real subscriber's move. This is inevitable since this move consists of positions where more than two BSs are in nLOS. However, the hybrid techniques seem to enhance the accuracy in comparison to existing ones. Again, in suburbs environment (figure 13) it comes as a conclusion that the more BSs are in nLOS the more the location error in all techniques increases. In all positions, the greatest accuracy appears using the E-TOA technique. Furthermore, the introduction of l_i coefficients improves the AOA accuracy which is then close to the TOA.

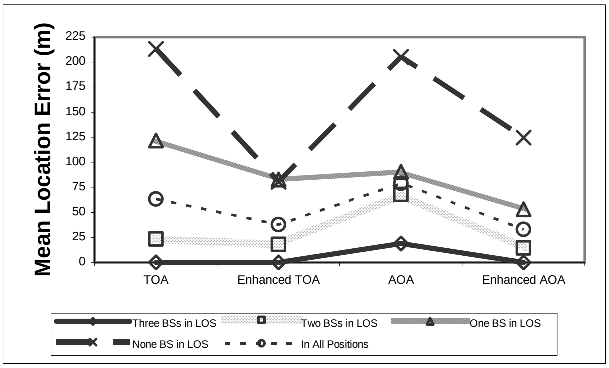

Figure 14. Mean location error in proportion to the technique used and the number of BSs in LOS (City Centre environment)

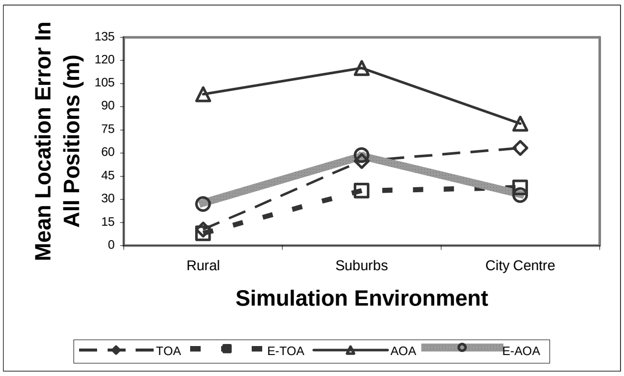

Figure 15. Mean location error in proportion to the technique used and the simulation environment

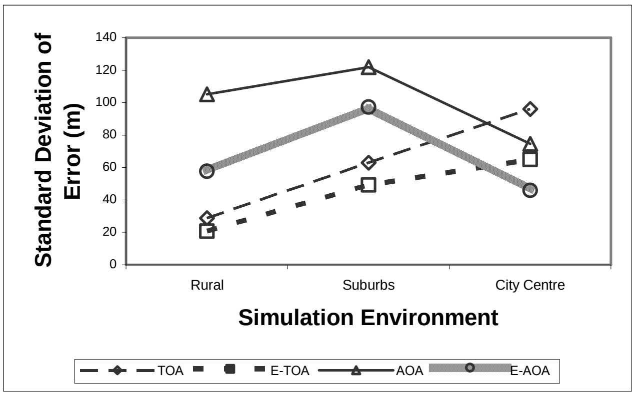

Figure 16. Standard deviation of error in proportion to the technique used and the simulation environment

Table 1. Mean location error in proportion to the technique used and the simulation environment

	Mean Location Error (m)		
Positioning Technique	**Rural**	**Suburbs**	**City Centre**
TOA	10,28	54,89	63,4
E-TOA	7,93	35,68	37,78
AOA	98,19	115,22	79,02
E-AOA	26,95	58,69	32,78

Table 2. Standard deviation of error in proportion to the technique used and the simulation environment

	Standard Deviation of errors (m)		
Positioning Technique	**Rural**	**Suburbs**	**City Centre**
TOA	28,78	63,05	96,08
E-TOA	20,59	49,21	65,07
AOA	105,08	121,81	74,58
E-AOA	57,66	97,32	45,86

Due to the complexity and importance of the city centre environment, the subscriber is suggested to lie on every possible location rather than a standard move. In figure 14 the mean location error (in meters) in proportion to the technique used and the number of BSs in LOS in the City Centre environment is presented. As previously mentioned, the less BSs are in LOS the more the location error increases. This occurs because in shadowed positions the location error is comparatively high due to many reflections that the signal suffers before reaching the

BS. Again, the hybrid techniques cause a positive effect on the location accuracy in comparison to the respective conventional ones. On the contrary to the previous environments the city centre shows the least error by using the E-AOA technique (32.8m).

A statistical roundup of the results according to the mean location error in all environments is given in figure 15. It shows that the error is greater by using the AOA technique regardless of the environment.

Table 3. Percentage of positions with location accuracy of 100m|300m in proportion to the technique used and the simulation environment

	Percentage of positions with location accuracy of 100m|300m		
Positioning Technique	**Rural**	**Suburbs**	**City Centre**
TOA	95.8%|100%	80%|100%	84.3%|96%
E-TOA	100%|100%	88%|100%	90.2%|98%
AOA	54.2%|95.8%	64%|100%	68.6%|98%
E-AOA	87.5%|100%	80%|96%	88%|100%

This is obvious due to AOA's sensitivity in nLOS propagation. Furthermore, the conventional techniques in all environments are getting improved by the use of the introduced nLOS coefficients. Another issue to mention is that while TOA and E-TOA's location error increases in proportion to the environment's complexity, the AOA and E-AOA methods show the least error at the city centre environment. The reason for this is that it is suggested that the BS antenna is not surrounded by local scatterers. Moreover, in environments like the city centre is more likely that the AOA of the reflected signal is closer to the real one in comparison to environments with a small number of buildings. On the other hand, the less the buildings are, the more likely is the reflected signal to need more time to reach the BS. Approximately the same conclusions arise by the observation of figure 16. The numerical results presented in figures 15 and 16 are given in tables 1 and 2, respectively.

As for the implementation of a positioning technique, the simulation results must abide by the revised Phase II US Federal Communication Committee's (FCC) regulation, which require E-911 location accuracy of 100m and 300m in 67% and 95% of the cases, respectively. The percentage of positions with the required accuracy is shown in Table 3. In this table, it is obvious that except for the AOA technique in rural and suburbs environments, the simulation results comply with the FCC regulations. Another conclusion taken from the table is that hybrid techniques enhance the percentage of the respective existing techniques. It is worthy to say that in the simulations the calculated accuracy is quite above the required standards, in most cases.

6. CONCLUSION

In this paper we have introduced the use of weight coefficients in order to deal with the location error caused by nLOS propagation in TOA and AOA location techniques. The resulting proposed hybrid techniques have shown good improvement of the location accuracy. This has been detected using three 2-D single ray trace simulation environments. All simulation results acquired by hybrid algorithms conform to the U.S. FCC regulations, while the location error reduction reaches the value of 40% in comparison to conventional methods.

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