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Line of Sight(LoS) Probability Prediction for Satellite and HAPs Communication in Trabzon, Turkey

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Abstract: The knowledge of Line of Sight (LoS) probability is curicial to estimate signal attenuation correctly in mobile wireless communication. Especially in built-up areas, more accurate LoS probability determination helps to obtain more realistic propagation models or path loss models. Geographic Information Systems (GIS) and City Information Systems (CIS) are used to provide a necessary data to calculate the LoS probability. In this study, LoS analyzes are made via Arcgis software for the most well-known streets in Trabzon, Turkey. For these analyzes, the Earth"s surface is accepted as flat and a simple geometrical approach is used for calculations in this paper. A Matlab algorithm was created to calculate LoS probability depending on the elevation angle which is an important parameter for satellite services. LoS probability vs. elevation angle is presented for interested streets. As a result, LoS probability for Trabzon dependent elevation angle is estimated and presented.

Keywords: *Line of Sight, Line of Sight Probability, LOS, Wireless Communication, GIS, CIS, Arcgis, Arcmap, Elevation angle, Matlab*.

1. Introduction

The increasing demand for higher data rate in wireless mobile communications services has expedited the need for more innovative and flexible communications infrastructures. Terrestrial ground-based systems and satellite systems are used for providing mobile communications services [1]. To overcome some of the disadvantages of both terrestrial ground-based systems and satellite systems, high altitude platform stations (HAPs) technology can be used to provide cellular communication. So, there is plenty of research in this area [2]. In [1], researchers obtain propagation models and performance analyzes for HAPs systems. It is obvious that elevation angle is the dominant parameter on the propagation models in [1]. The simplest definition of Line of Sight (LOS) is the straight path between two fixed point in two or three dimensional space when unobstructed by the horizon. On the other hand, non-line-of-sight (NLOS) is indirect path from one point to the other points in two or three dimensional space. LOS is an ideal condition for mobile ground communication because transmitted signal is received with best possible signal strength without exposing any obstacles [1]. In NLOS, there are many obstacles such as buildings, trees, forest, poles, tunnels and traffic lights. In this case, transmitted signal reaches the receiver weakened. Apart from these, transmitted signal also get attenuated due to rain. In urban type environment, the signal gets attenuated especially by buildings. Urban type environment is covered dense buildings which are closely located to each other and streets. Therefore, transmitted signal gets attenuated as a result of diffraction and reflection caused by these buildings.

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In urban type environment, when examined it was observed that signal quality in mobile communication systems is significantly affected on the streets for LOS and NLOS cases [1]. Therefore, the height of the buildings, transmitter height, receiver height, elevation angle from receiver to transmitter, street widths and lengths are most important factors to determine the LOS and NLOS conditions created by buildings. In terrestrial mobile communications, above mentioned characteristics of the building and the street can be obtained via digital maps which is used in geographic information systems(GIS) [3]. Transferring the entire city to digital map is a difficult and sensitive process. This has led to the emergence of City Information Systems(CIS) [4]. In Turkey, all municipalities are gradually creating their City Information Systems(CIS). Some of these cities are İstanbul, İzmir, Eskişehir, Konya, Kayseri, and Trabzon. In this study, City Information Systems of Trabzon Municipality is used to obtain LOS probability values [5].

A lot of software is available in the GIS and many of them are paid. ARCGIS [6] and MAPINFO [7] could be given as an example for most commonly used paid software. Also, NETCAD [8] can be given as an example national paid software. Some of the most commonly used free software is GRASS [9], QGIS [10] and SAGA GIS [11]. Urban Information System of Trabzon Municipality was created by the NETCAD software. In this study, GIS data sets received from Trabzon Municipality is adapted to ArcGIS software.

In her study [1], Hasırcı used direct sight (LOS) and non-direct sight (NLOS) probability values from Holis and Pchac [12]. Depending on this probability values, propagation models have created and performance analyzes of communication channels are made in [1].

In this study, the most well-known streets and avenues for the city of Trabzon were considered. For each street and avenue LOS and NLOS probabilities were calculated depending on the elevation angle through a code written in Matlab. After that, calculated LOS probabilities for streets were combined with Bayes conditional probability theorem [24] by performing simulation to create Trabzon city LOS possibilities.

Realistic LOS probability values calculated in this study will be put in LOS probability formulas (1) from [12] and HAPs propagation models and performance analyzes will be obtained for Trabzon. Also, these calculated real probability values can be used to estimate propagation and coverage area for Trabzon.

This LOS modelling idea is not new. Actually, LOS analyses were used in the military fields. First LOS analyzes were made at the beginning of the 18 century by the French military engineer Prestre de Vauban (1603-1707). LOS analyzes slowly began to gain importance over the following years because of increasing military activities as a result of wars [13]. LOS analysis has played an important role in military especially for the placement of an optimum observation tower, selection of military areas, and preparation of war plans.

ARCGIS software one of most commonly used GIS software. ArcGIS™ technology, developed by ESRI, is a scalable integrated Geographic Information System(GIS) software. ArcObjects is a development environment of the ArcGIS family of applications [14]. In this study, ARCMAP which is one of the module of ARCGIS software is used. ARCMAP has provided visualisation of available graphical and verbal data, data update, query and analysis, charting and reporting tools and, it also has high quality cartographic production functions. In ArcGIS 3D analysis tool, there are functions such as LOS (places visible and not visible among a line), Viewshed (visible areal places and not visible area places for desired specific point of view) and drawing LOS profile [14].

Height of buildings and the distances between the buildings are important parameters for radio propagation models and LOS probability calculations [1]. In the literature, it was shown that building height distributions have similarities with some known probability distributions.

When these studies were analysed, it is clear that rayleigh distribution is most commonly used distribution. Log-normal distribution is also used in some studies. Some references state that building height densities are similar to log-normal distribution rather than Rayleigh distribution while creating radio propagation models [16,17]. The distributions related to the height of the building are also investigated thoroughly in [15], [17] and [18].

Cheng and Wu have represented the LOS calculation model which determines security and route for vehicles traveling at highway [19]. Led and Pechac, using the ITU-R P.1410 model, use the data from existing GIS to calculate the LOS coverage probability in Prague capital city of the Czech Republic [20]. Oestges and Janvier have represented the physical and statistical model of LOS coverage probability calculation for HAPs [21]. Saunders and Evans has provided a physical model which calculates the probability LOS for land mobile satellite systems derived from a simple geometric model [22]. Rama Sarma,,in his research, has calculated the probabilities of LOS for interested regions and stated it analytically [23]. RamaSarma used two models in his research namely CRABS and PLEXTEK which estimate visibility [23]. Both models have a structure that will be an alternative to the ray tracing method in the literature. In both models, required parameters are produce by statistical methods from existing GIS data. Using these parameters, the radio propagation models were estimated.

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2. Line-of-Sight Probability Modelling Approach

In this section, propagation modelling and statistical study for channel performance analysis on HAPs systems in [1] were investigated. In above mentioned study, the analytical LOS probability expression depending on elevation angle was obtained. In her research, Hasırcı emphasizes propagation modelling of HAPs and gives performance analysis [1]. All possible propagation environments were divided into four groups: suburban (SU), urban (U), dense urban (DU) and urban high rise (UHR) area. These propagation environments were modeled using well-known statistical models with a dependence on elevation angle. Focusing only urban areas in this study provides a more detailed examination. With rapidly growing metropolitan areas, more detailed studies that have become much more important in signal attenuation will help to solve this problem. Statistical models were combined with free space path loss, and full formulations of total path loss for the four possible HAPs propagation environments and different conditions at 2-6 GHz frequency band were obtained [1].

Elevation angle and propagation environment are the most important parameters to determine propagation characteristics for HAPs systems.

First, using ITU-R Rec. P.1410 [17] statistical model, LOS and NLOS probability distributions corresponding to each elevation angle in each propagation environment were calculated [12], the data has been created to be used in the produced model.

Probability distribution for LOS and NLOS corresponding to each elevation angle have been created on the following geometry for four propagation environment [see Figure. 1]. This geometry is essential scenario for simulation result in this paper.

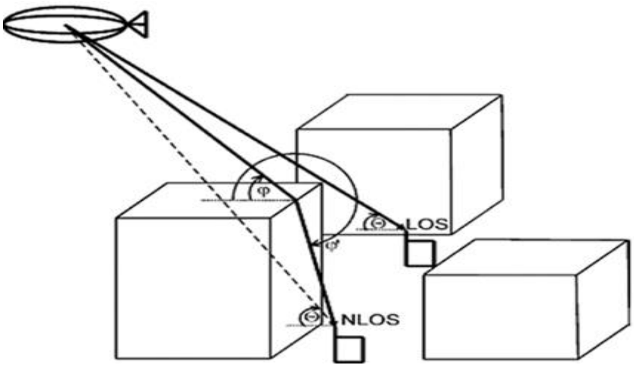

Figure 1. Geometry of basic LOS and NLOS [12].

A 2 x 2 km size city area was considered in analyzes and the layout of the building sampled every meter in simulation setup. Simulation were separated in two group. In first group simulations, LOS probability in the streets was analysed as a function of elevation angle for different propagation environment filled with buildings. A much simpler geometry was shown in Figure.1 for LOS and NLOS conditions of area. Calculations were made every 9 degree increments for azimuth angles in a range of from 0 to 360 degrees. Initially, buildings were randomly generated by the statistical models. After that, to implement and analyse a large number of scenarios, HAPs location were determined separately for each sampled point of the street for given elevation and azimuth angles. LOS probability for a given elevation angle were set to the median value of data obtained for all azimuth angles. Thus, the results have become independent from the azimuth angle because buildings in the real world are usually not located regularly. These simulations were applied from 1 degree to 90 degrees for all elevation angles and a distribution was obtained as in Figure. 2.

Formulas (1) depending on the elevation angle was obtained with the help of the data [12] in Figure. 2.

$$P_{LOS}(\theta) = t - \frac{t-n}{1+(\frac{\theta-k}{l})^p} \quad (1)$$

Table 1 shows parameter change of formulas (1) according to propagation environment.

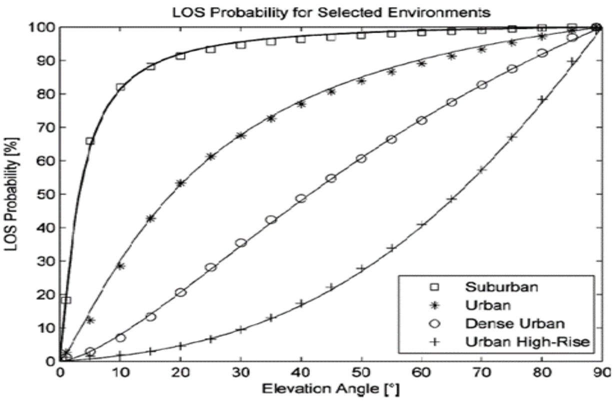

Figure 2. Geometry of basic LOS and NLOS [12].

Table 1. Parameters for LOS probability calculation [12].

Propagation Medium	t	n	k	l	p
Suburban(SU)	101.6	0	0	3.25	1.241
Urban(U)	120	0	0	24.3	1.229
Dense Urban(DU)	187.3	0	0	82.1	1.478
Urban High-Rise(UHR)	352.0	-1.37	-53	173.8	4.670

Where $P_{LOS}(\theta)$ is the probability of LOS in percent, θ is an elevation angle in degrees and t,n,k,l,p are the empirical parameters given in Table 1 for the four typical environments.

3. Our Empirical LOS Probability Modelling Approach

Flat unobstructed path from the transmitter to the receiver is called free line of sight. Line of Sight is very important for transmitted signal in wireless communication. Even there is not line of sight in the signal path, the signal can still reach its target. Actually, if all transmitted signals move through free Line of sight path, the best propagation occurs. The high-frequency signals need more free line of sight path than the low frequency signals. Infrared communication is particularly sensitive to obstacles which is in the free LOS fields.

In this study, firstly, it was opened Trabzon data set which have binalar.shp, yollar.shp and mahalleler.shp file. After that, they were compiled via ARCMAP module of ARCGIS software. The most well-known streets and avenues were selected in the city center of Trabzon, Turkey. After that, the buildings which is on the north side of this streets and at a certain distance from these streets were selected. Finally, various operations which use some ARCMAP tools were applied for selected buildings and streets. As a result of these processes, the knowledges such as the height of the buildings, the area occupied by the buildings, the edge lengths of the buildings and the distance to the road from buildings are extracted from the attribute tables which are obtained from Trabzon GIS dataset. It was created a Matlab algorithm that calculates LOS probability depending on the elevation angle for interested streets. Input variables of this algorithm are the height of the building, the edge lengths of the building and the distance from building to the road. Firstly, LOS probability was calculated for every building on the interested street. After that, Additive LOS probability which consists also building spaces was calculated and this additive LOS probability was added to pre-calculated LOS probability created by building. As a result of this, Elevation angle dependent LOS probability for interested street were estimated. When it was examined LOS probability graphs in this study, it has been seen that they are similar to some known probability distributions in the literature [25]. This study has been no analyzes of similarity to known probability distributions in the literature. LOS probability values depending on the elevation angle for Trabzon was obtained by utilizing Bayes' conditional probability theorem [24].

3. 1. ARCGIS and Trabzon City GIS Data

In this study, it was used ARCGIS 10.1 software version [6]. In ARCGIS software, basic file extension is ‘shp’. ‘Shp’ file extension name is obtained by shortening ‘shape’ word. The streets which LOS probability was calculated were created by using the necessary analyzes and operations in ARCMAP. ARCGIS have many modules. The input data which will be entered to the geometric-based algorithm is obtained by using ArcMap. Figure. 3 illustrates the ARCMAP module screenshots of Trabzon GIS data.

Figure. 3. ArcMAP module screenshots of Trabzon GIS data

Figure. 4 illustrates a simple LOS scenario in Urban city. When Figure.4 is examined, it can be seen that there are buildings, trees and cars that prevent direct sight (LOS) between the transmitter and the receiver. They are common obstacles that may exist in all the typical urban-type settlements.

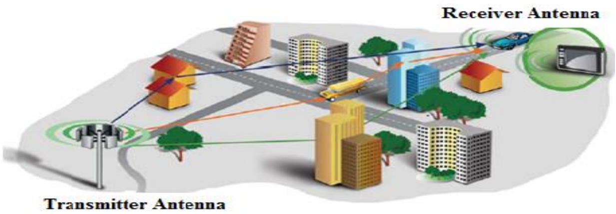

Figure. 4. A simple LOS scenario in Urban city

3.2. Our LOS Probability Model and Calculation Algorithm

LOS probability prediction models use Ray Tracing (RT) methods mostly. Ray tracing techniques are applications that require large computational load and time. Ray Tracing techniques are used in electromagnetics applications, radio communications, cellular communication systems, radar applications, image processing applications, etc. In RT, rays from transmitter are sent to all angles in medium and all calculations are accomplished.

LOS prediction algorithm in this study has geometrical approaches and it is flexible because it can be applied for all cities in Turkey. Firstly, LOS probability of every building in the street was calculated. After that, LOS probability of street was calculated by using LOS probability of every building. Finally, LOS probability of every street was combined conveniently according to the Bayes' conditional probability theorem [24]. After these operations, LOS probability of Trabzon city was calculated. The more streets taking into account for calculation, the more realistic the LOS probability values of Trabzon city will be obtained. Figure. 5 illustrates typical LOS scenario used in this study.

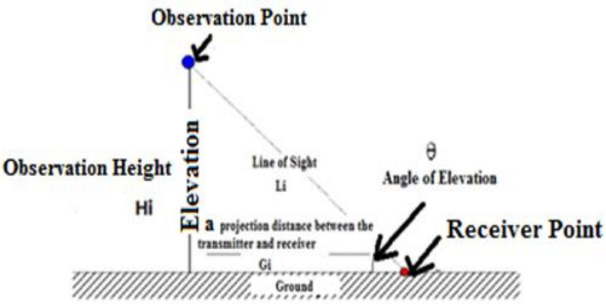

Figure. 5. Line-of-Sight scenario in this study

As seen in Figure. 5, Hi is observation height, Li is distance of LOS, θ_e is elevation angle, Gi is distance to the receiver from building edge which is parallel to road, 'i' is building index which helps to differentiate buildings from each other in the street and 'e' index represents elevation angle ranging from $1^\circ - 90^\circ$. Relationship between elevation angle, θ_e and distance of LOS, Li can be stated as shown in formulas (2).

$$\tan(\theta_e) = \frac{Hi}{Gi} \quad \text{and} \quad Li = \sqrt{Hi^2 + Gi^2} \qquad (2)$$

First, NLOS probability was calculated in this study. After that, LOS probability was calculated. Relationship between these probabilities was shown below.

$$Sall=Snlos+Slos \qquad (3)$$

where Sall is total area of the interested region in square meters, Snlos is area of NLOS region in square meters, and Slos is area of LOS region in square meters. Relation between area of regions is was given in formulas (3). NLOS probability can be calculated by using formulas (4).

$$Pnlos=Ss/Sall \qquad (4)$$

where Pnlos is NLOS probability.

Substituting Pnlos in formulas (4) into formulas (5), LOS probability(Plos) can be calculated using formulas (6).

$$Plos+Pnlos=1 \qquad (5)$$

$$Plos=1-Pnlos \qquad (6)$$

where Plos is LOS probability.

3.3. Our LOS Probability Model and Calculation Algorithm for Trabzon City

After LOS probability of N number streets was calculated, LOS probability values depending on the elevation angle for Trabzon was obtained by utilizing Bayes' conditional probability theorem [24].

If elevation angle of between the receiver and the transmitter is known previously, LOS probability for Trabzon ($Ploscity$) for arbitrary angle can be calculated using formulas (7).

$$Ploscity(\theta i) = \frac{1}{L} * \sum_{n=1}^{N} Li * Plos(Li \backslash \theta i) \qquad (7)$$

where $Ploscity(\theta i)$ is LOS probability of Trabzon, $Plos(Li \backslash \theta i)$ is LOS probability of i-th street when θi elevation angle between the receiver and the transmitter is known previously, Li is length of i-th street, θi is elevation angle, and L is total length of N number streets (given by formulas (9)).

The clearest expression of formulas (7) is given by formulas (8).

$$Ploscity(\theta i) = \frac{L1}{L} * Plos(L1 \backslash \theta i) + \frac{L2}{L} * Plos(L2 \backslash \theta i) + .. + \frac{LN}{L} * Plos(LN \backslash \theta i) \quad (8)$$

L in formulas (7) and (8) can be calculated as below:

$$L=L1+L2+L3\ldots\ldots..+LN \qquad (9)$$

In above formulas, Li and L are easily obtained by using ARCGIS attribute tables.

3.4. Our LOS Probability Graphics for Trabzon street and city

In this section, LOS probability figures vs. elevation angle were presented for four streets. The LOS probability figures were plotted in Matlab software. LOS probability of four streets were given this section (Figure. 6, Figure 7, Figure. 8 and Figure. 9). After that, LOS probability figure of Akif Saruhan street was examined and discussed.

Figure. 6 illustrates LOS probability figure vs. elevation angle of Akif Saruhan street. Figure. 7 illustrates LOS probability figure vs. elevation angle of Deliklitaş street. Figure. 8 illustrates LOS probability figure vs. elevation angle of Ahmet Barutçu Kütüphanesi street. Figure. 9 illustrates LOS probability figure vs. elevation angle of Moloz street. Figure. 10 illustrates LOS probability figure vs. elevation angle of Trabzon city.

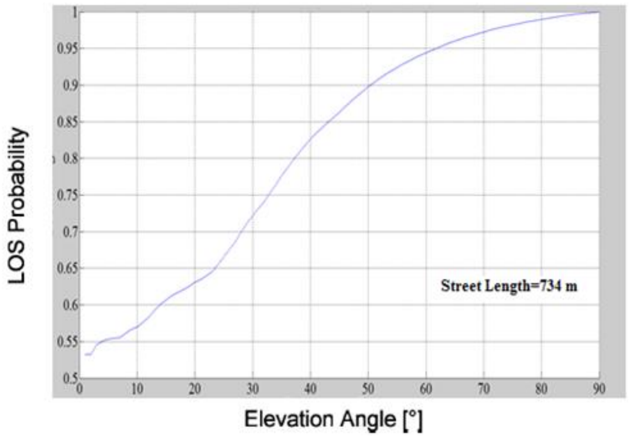

Figure. 6. LOS probability of Akif Saruhan street

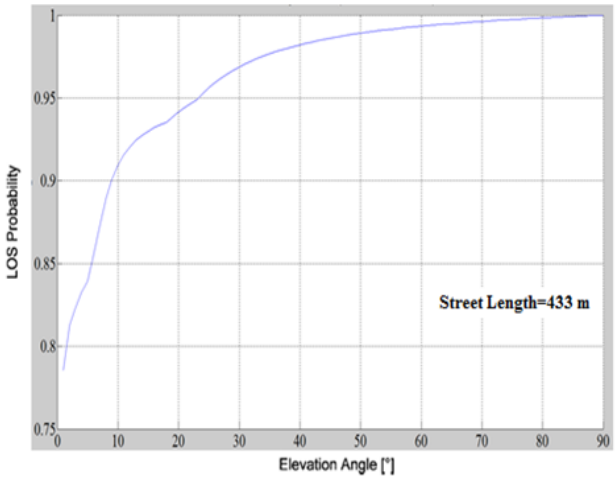

Figure. 7. LOS probability of Deliklitaş street

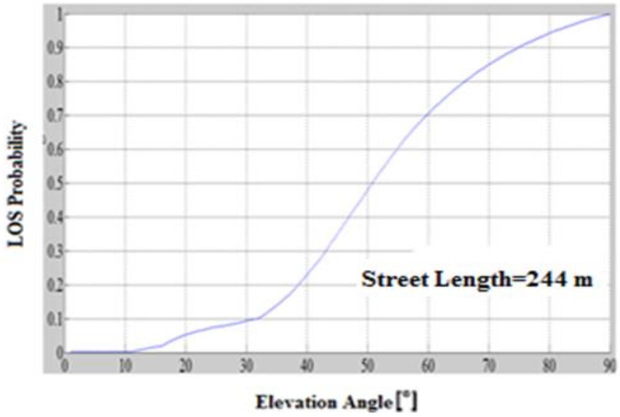

Figure. 8. LOS probability of Faik Ahmet Barutçu Kütüphanesi street

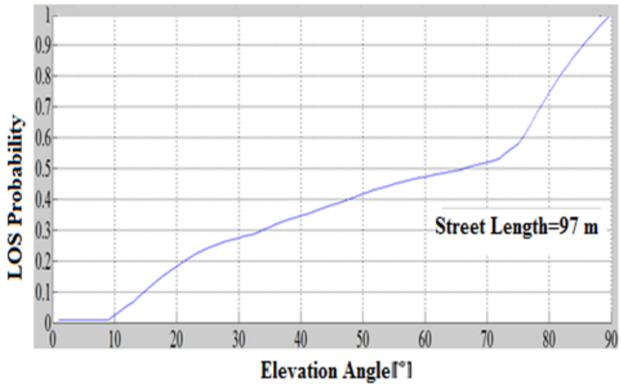

Figure. 9. LOS probability of Moloz street

To illustrate, when LOS probability figure in Figure. 6 is examined, it is clear that even if elevation angle is very low, LOS probability of Akif Saruhan street value is about 0.55 This indicates good quality of wireless communication at low elevation angles.

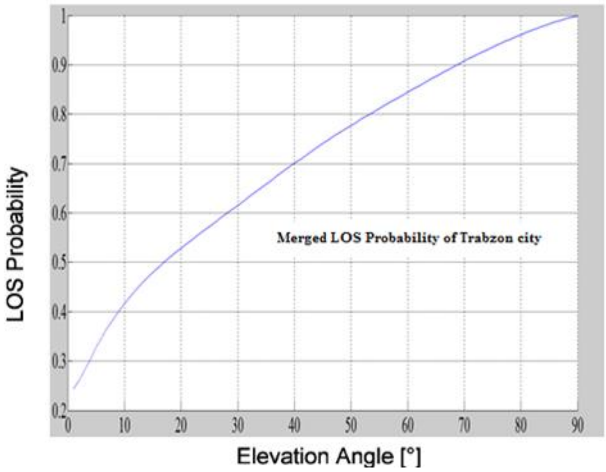

Figure. 10. Merged LOS probability of Trabzon city

When LOS probability figure in Figure. 10 is examined, it can be understood clearly that even if elevation angle is very low, LOS probability of Trabzon city is about 0.25. This indicates that low quality of wireless communication at low elevation angles. LOS probability of Trabzon at low elevation angles is low because of Trabzon's irregular building structures and settlements. It can be seen clearly that LOS probability figures in this study show similarities with other LOS probability figures in [12] and the other studies in literature.

4. Conclusions and Suggestions

Trabzon GIS data was analysed by using ARCIS software. As a result of this analysis, it was obtained building heights, road, street widths, distances between buildings, building floor area, etc. These obtained knowledges were used as an input data for geometrical algorithm and LOS probability of interested streets in Trabzon city were calculated.

As a future study, it will be investigated that the LOS probability values complies with which well-known cumulative distributions. As result of this, empirical formulas which represents LOS probability depending on the elevation angle will be derived. Instead of flat terrain in in this study, rough terrain can be taken into account. LOS probability values obtained in this study can be used for HAPs propagation modelling and wireless channel modelling in Trabzon.

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