Comparison of Propagation Loss Prediction Models of UMTS for an Urban Areas

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***Abstract* — Knowledge of propagation characteristics in the mobile channel is important to the design of a cellular system. In this paper, three path loss models were used to predict path loss for the UMTS, in Istanbul, Turkey. Used models are Advanced Okumura-Hata model and Algorithm 9999 from the empirical path loss model class and Advanced Walfisch-Ikegami model from the deterministic path loss model class. The study concentrates on comparative parametric analysis for propagation path loss in macro cell region using different models and contains comparative study with real measurements obtained from a WCDMA based wireless network. This study concluded that among three models, the Advanced Walfisch-Ikegami model gives the best result in the urban environment for Istanbul.**

***Index Terms* — Communication systems, path loss measurement, mobile communication, UMTS.**

I. Introduction

The first GSM network was launched in Finland in 1991, since then GSM and other second generation systems have been expanding and evolving continuously [1], [2] .

GSM system is very good at delivering voice services to its subscribers, and is the most common 2G system in all over the world. However, when data service is concern, the situation is not the same. There are some upgrade studies over existing GSM system in order to support more efficient data services. Nowadays, totally new air interface, namely WCDMA air interface system is being deployed on existing GSM core network in Turkey with the goal of supporting more efficient data services. This new system was called the Universal Mobile Telecommunications System (UMTS). UMTS is one of the third-generation (3G) systems. In fact third generation systems are designed for multimedia communication; with them person to person communication can be enhanced with high quality images and video, and access to information and services will be enhanced by the higher data rates and new flexible communication capabilities.

UMTS networks need the use of new air interface, which entails new, different base stations and base station controllers, which means a huge cost for operators.

UMTS network planning is far more complicated than GSM voice planning [3]. Because in UMTS, it is not possible to think of minimum received signal level to achieve one maximum interference threshold. Each service needs a specific threshold values and also network behavior changes with traffic. So the need for an accurate propagation prediction is now more vital than before [3].

Propagation prediction models used in GSM 900/1800 systems are not one to one applicable UMTS due to frequency differences. Path loss prediction models used in GSM system should be extended to find suitable expression for 2100 MHz. Another important difference between UMTS and GSM systems in terms of radio propagation is the difference in the carrier spacing which is 5 MHz in UMTS system and 200 kHz GSM system. For this reason, UMTS system is more is more vulnerable to frequency selective fading than GSM systems.

II. Propagation models

For radio propagation prediction, there are many propagation models. Different models have been developed to meet the needs of realizing the propagation behavior in different conditions. Each propagation model is valid in a specific scenario and specific frequency. If the model is not chosen correctly, model will either overestimate or underestimate the path loss. If model overestimate the path loss, that means users may need lower signal energy to reach services. Underestimating the path loss means, users may need more power, also interference between cell may not be predicted correctly. So path loss prediction should be as accurate as possible.

We can classify propagation models according to the principle approach used to develop propagation models. There are empirical models and deterministic models.

A. Empirical Models (Statistical Model)

Empirical models based on extensive measurement data. In empirical models, all the environment factors are implicitly considered.

B. Deterministic Models(Theoretical Models)

The deterministic model is based on theoretical analysis, so it can be applied in different scenarios without affecting its accuracy. However, the realization of theoretical model is based on large database on scenario features and accurate 3D digital map, which sometimes are impractical or even sometimes are impossible [4].

Since UMTS site density will be higher than GSM site density, the accuracy in the first hundreds of meters from the base station is more important [3]. So the usage of deterministic models may give better result in UMTS system.

C. Okumura-Hata Related Models

1) Okumura Model: The Okumura method is semi-empirical and based on extensive measurements performed in the Tokyo area [4]. It is a pure experience statistical model, so its statistics are represented by curves without a specific formula.
2) Okumura-Hata: The Okumura model was intended for manual use. Hata, in 1980, [5] derived semi-empirical formulas from Okumura's curves for computational use. The Okumura-Hata model applies well for large cells. In the configuration of large cells, the antenna of base station is usually higher than surrounding buildings or obstacles. The main propagation loss for Okumura-Hata model is the diffraction and scattering over rooftop near the mobile station.
3) The COST-231 Hata Model: COST is a European Union forum for cooperative scientific research. COST 231 group extended the studies of Okumura-Hata. Okumura-Hata propagation model works frequencies below 1500 MHz and thus not work e.g. the 2100 MHz band. Okumura's propagation curves have been analyzed in the upper frequency band to find a suitable expression for 2100 MHz [5].

D. Algorithm 9999

There have been several suggestions for improving the Okumura-Hata and COST231-Hata models to take more propagation environment into account. One of the improved Okumura-Hata models is Algorithm 9999 [5].

Even if the validity of the model here is stated to be up to 2 GHz, it is possible to adapt Algorithm 9999 to higher frequency bands by tuning the model against measurements [5].

E. Walfisch-Ikegami Related Models

1) COST231-Walfisch-Ikegami Model (COST231-WIM): In the urban areas with large population and densely located buildings, the cell radius is usually smaller than 1 km due to capacity restriction. The error to use Hata model in such mini cells is large. To enable Hata model to apply to the areas with densely located high buildings, Cost231 proposes the COST231-Walfisch-Ikegami model based on numerous on-site tests and model analysis [4]. COST231-Walfisch-Ikegami Model is a combination between the two models described in The Ikegami model [5] and The Walfisch-Bertoni model [5], including a line-of-sight component.

In the urban areas with large population and densely located buildings, the base station antenna is usually higher than the average height of surrounding buildings but lower than the tallest building. The COST231-Walfisch-Ikegami model, based on theoretical Walfisch-Bertoni model [5], [6] and [7] calculates the multiple screen forward diffraction loss of antenna of high base station. It uses the test-based data for antenna of low base station.
2) Advanced Walfisch-Ikegami Model : There have been several suggestions for improving Walfisch-Ikegami Model to take more propagation environment into account. This model works at the same physical condition as the COST¬231 Walfisch-Ikegami Model described before. Like COST¬231 Walfisch -Ikegami Model, Advanced Walfisch-Ikegami Model works as best when uniform building separation and building heights exist and there is flat ground. It requires height information for the calculation of effective antenna height and knife-edge diffraction [5].

F. Ray Tracing Models

The objective of the ray-tracing path loss models is to predict the physical propagation process of the radio waves for a given environment. In ray tracing models, there are two techniques used, namely image theory and ray launching technique [7]. These models have high computational demands and consequently, there are mostly used in microcells and picocells and they are not appropriate for macrocells.

In order to make a comparison of the performance of the empirical and theoretical path loss prediction approaches on UMTS systems, two models from empirical class and one model from theoretical class are chosen for simulation. Models from empirical class are Advanced Okumura-Hata Model [5] and Algorithm 9999 model [5] and from theoretical model class is Advanced Walfisch-Ikegami model [5]. And prediction results are compared with real measurement obtained a UMTS based wireless network for city of Istanbul.

III. AREAS OF INVESTIGATION

Two sites were selected for simulation of path loss models, namely Taksim and Besiktas sites. These sites are pre-commercial UMTS FDD network deployed in dense urban environment in Istanbul. The distance between sites is 2779 meters.

In these sites, the average antenna height is close to average roof top level, hence forms a combination of macro and micro-cellular environments. The site configuration consists of 3-sectored cells. Generally mechanical and electrical downtilting is used. Some important site parameters are shown below:

A. Beşiktaş and Taksim Sites Properties

1) 3-sectorized sites
2) All three Besiktas site antennas are 20 meters from ground, two of Taksim antennas are 12 meters and the other antenna of Taksim is 14 meters from ground.
3) Base station maximum power is 43 dBm
4) Pilot power is 30 dBm
5) Used antenna in simulation for both sites is Kathrein 742215 Multi-band Panel Dual Polarization Half-power Beam Width Adjust. Electrical downtilt can be set by hand or by optional RCU (Remote Control Unit), provides a gain of 18 dBi.

In Taksim Site, all three antennas have two degrees electrical downtilt and a mechanical downtilt of 2 degree. In Besiktas site, all three antennas have 4 degrees electrical downtilt and a mechanical downtilt of 0 degree. For Besiktas site, the azimuth of the first antenna is 0 degree, the second antenna 90 degrees and the third antenna has 240 degrees azimuth angle. For Taksim site, the azimuth of the first antenna is 10 degrees, the second antenna 70 degrees and the third antenna has 210 degrees azimuth angle.

The digital map is used in order to take environmental effect into account in simulation. Used map has a resolution 10 meter x 10 meter. Generally, for path loss calculation, the more resolution, the better performance. In the map, there elevation data, land usage (clutter) data, vector data and text data. Map Projection is Longitude/Latitude (NTF with Greenwich prime).

IV. Simulation Results

A. Simulation Results Versus Measurements

As a quality factor of a path loss prediction model, generally standard deviation of the error and mean error are used. Table I shows mean prediction error, the standard deviation of the error which were calculated in Besiktas and Taksim sites by using Algorithm 9999, Advanced Okumura-Hata and Advanced Walfisch-Ikegami path loss models.

In Table I, μ stands for mean error and σ stands for standard deviation of error.

TABLE I
STATISTICAL ANALYSIS OF THE ERROR IN BESIKTAS AND TAKSIM WITH DIFFERENT MODELS

Test Area	Okumura-Hata		Walfisch-Ikegami		Algorithm 9999	
	μ(dB)	σ(dB)	μ(dB)	σ(dB)	μ(dB)	σ(dB)
Beşiktaş	5.7144	7.97919	-0.2431	7.698	25.7378	9.70921
Taksim	2.88741	13.7049	2.33018	13.5482	29.2916	14.5018

It can be seen from Table I, all there path loss models give better result in Besiktas. Because standard deviation of error for each path loss model gives smallest value in Besiktas. The reason for better result in Besiktas may be the antenna deployment for Besiktas site. Since antenna heights of Besiktas are considerable higher than Taksim antennas, accuracy of path loss prediction is higher in Besiktas. Among all three models, Walfisch-Ikegami model works better in both Besiktas and Taksim sites.

B. Description of the Measurement Environment

Fig. 1 to 6, show simulation versus measurements and results for Besiktas and Taksim respectively.

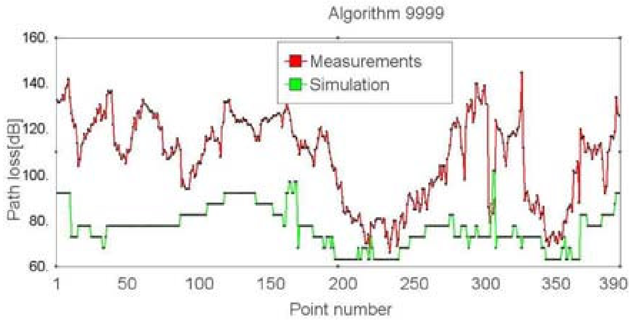

Fig. 1. Comparisons of Algorithm 9999 predictions results with measurements in Besiktas.

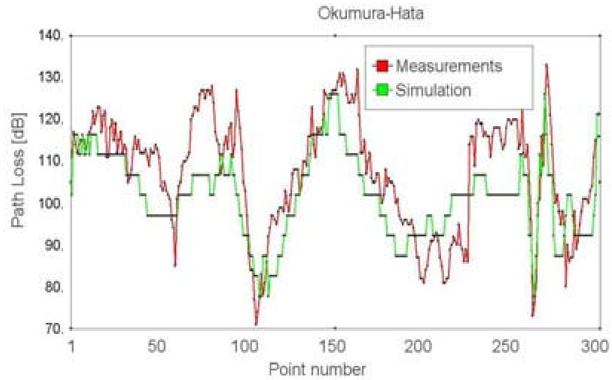

Fig. 2. Comparisons of Advanced Okumura-Hata model predictions results with measurements in Besiktas.

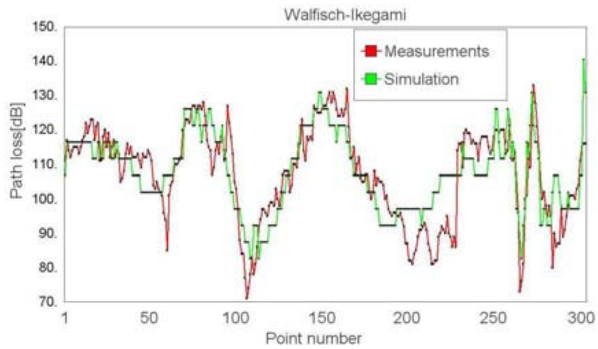

Fig. 3. Comparisons of Advanced Walfisch-Ikegami prediction results with measurements in Besiktas.

From Fig. 1 and Table I, it can be said that Algorithm 9999 underestimate the path loss. Real path loss values are higher than values that Algorithm 9999 predict for this area.

From Table I and Fig. 2, it can be seen that Advanced Okumura-Hata model also underestimate the path loss for that region. However, compared to the Algorithm 9999, Advanced Okumura-Hata gives better result in that region.

Table I and Fig. 3 indicate that simulation values and real values are generally similar. If all the graphics are examined, it can be concluded that Walfisch-Ikegami model is the best for Besiktas.

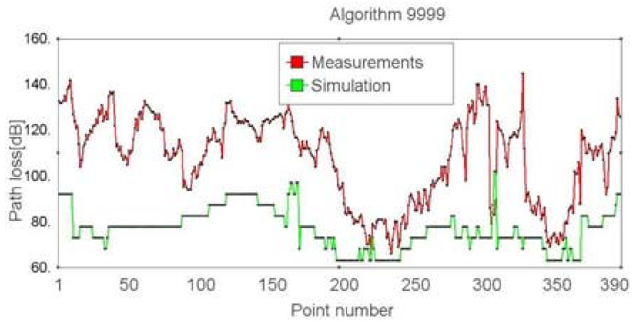

Fig. 4. Comparisons of Algorithm 9999 predictions results with measurements in Taksim

Simulation versus measurement results of Taksim site, Fig.4-6, indicate that Algorithm 9999 and Walfisch-Ikegami underestimate path loss values in Taksim. Among there models, Walfisch-Ikegami gets the best result in Taksim, too.

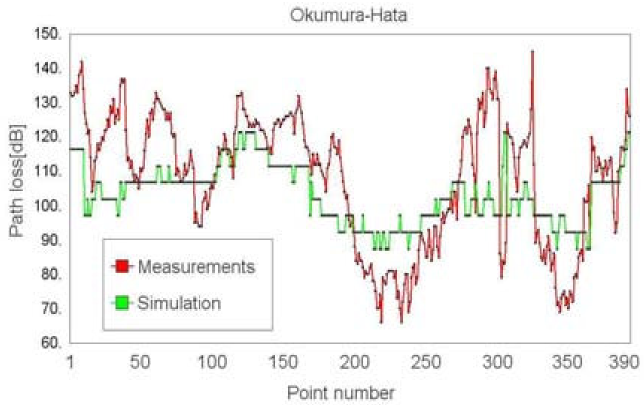

Fig. 5. Comparisons of Okumura-Hata predictions results with measurements in Taksim.

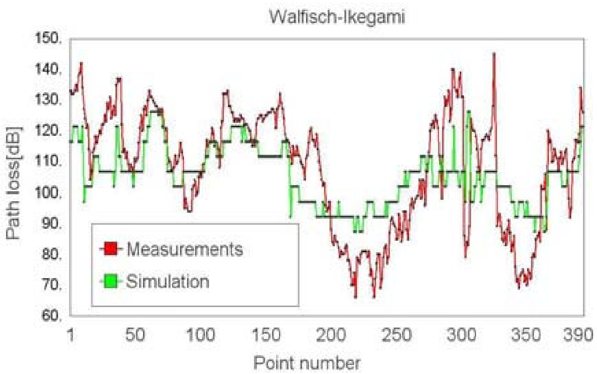

Fig. 6. Comparisons of Walfisch-Ikegami predictions results with measurements in Taksim.

C. Error in Clutters

Path loss prediction errors according to clutter are presented Table II for Besiktas site.

From Table II, it can be seen that models performs differently in different clutters. This analysis is especially important in model tuning studies.

TABLE II
ERROR IN CLUTTERS IN BESIKTAS SITE

	Algorithm 9999	Okumura Hata	Walfisch Ikegami
Openland	μ =25.71 σ =9.73	$\mu = -0.59$ σ =11.90	$\mu = -5.43$ σ =11.56
DenseUrban	μ =25.48 σ =10.33	μ =7.46 σ =7.61	μ =0.94 σ =7.06
Openinurban	μ =22.80 σ =8.48	μ =5.50 σ =7.23	μ =1.28 σ =7.27
Industrial Commer cial	μ =28.69 σ =2.74	$\mu = -2.555$ σ =3.94	$\mu = -5.58$ σ =4.99
Parks	μ =12.78 σ =1.41	$\mu = -5.26$ σ =1.2	$\mu = -19.78$ σ =4.84

V. CONCLUSION

This paper presented three path models and comparative study with measurements. Nowadays, ray tracing models also are used in order to predict path loss in UMTS system [3]. However ray-tracing models need accurate 3D topographic databases with building data. So next step of this work can be using ray tracing models in path loss prediction in UMTS systems.

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