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AN IMPROVED 5G WIRELESS PROPAGATION MODEL USING 3-D RAY-TRACING TECHNIQUE

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ABSTRACT
The wireless communication system has grown dramatically in the last few years. According to global cellular data demand projections, the volume of wireless data expected by 2021 will be 143 Exabytes per quarter, which is 7 times higher than the regular demand in 2016. The 5G network is the hope for the future network because it has the capacity to satisfy the network demands in terms of speed and bandwidth of this projection. There are several 5G propagation models however they have a relatively small bandwidth which results in inefficient communication especially with mobile/cellular data usage. Another challenge is that measuring the 5G propagation using the current techniques are time consuming, less accurate and insufficient information on simulation parameter configurations. In this work a. model of propagation in future 5G wireless networks using ray-tracing has been proposed. The model was developed to check the propagation quality of the 5G network using 3-D ray tracing technique. The model was implemented using the Matrix Laboratory (MATLAB) software. The results from our performance evaluation showed that our model was able to produce a better 5G propagation quality over a wider bandwidth in lesser time. Our model had an overall performance score of 98.8%, while the existing system had 70.5%. This work could be beneficial network administrators and to the research communities.

Key Words: Propagation, 5G, Wireless Networks, Ray Tracing.

1. INTRODUCTION

In recent years, the wireless communication system has grown dramatically. According to global cellular data demand projections, the volume of wireless data expected by 2021 will be 143 Exabytes per quarter, which is 7 times higher than the regular demand in 2016 [1]. As a result, network operators are currently dealing with massive traffic for mobile data demand, and existing 4G/LTE cellular network service providers are approaching theoretical maximum capacity. Furthermore, current networks will almost certainly be incapable of acquiring such high capacities [1].

The 5G networks which are the latest emerging network generation will require a better network design and technologies in order to meet with the ravaging demand for cellular data in this present age. However, heterogeneity will make cognition and coordination handling complicated in 5G networks and beyond. One of the solutions to this will be the introduction of higher frequencies such as the 24 GHz, 26 GHz and 28 GHz respectively. The aim of these higher frequencies was to achieve a wider bandwidth for the new 5G networks for better communication using this network. The fruitful planning, design, analysis, and implementation of wireless networks systems require deeper understanding about the radio wave propagation modeling.

Because of the large propagation area borders with regards to increase frequencies, ray tracing (RT) is regarded as the best technique for small wavelength frequency of 5G. It solves high traditional computational time in relation to upper operative frequency, resulting in slower ray-optics estimation and undefined efficiency in achieving results [2]. It is extremely useful in indoor radio wave propagation channel categorization because it drastically reduces the time-consuming and site-specific measurement campaign.

1.1.Statement of the Problem

The problem with the current 5G propagation models is that they have a relatively small bandwidth which results in inefficient communication especially with mobile/cellular data usage. Another challenge is that measuring the 5G propagation using the current techniques are time consuming, less accurate and insufficient information on simulation parameter configurations.

1.2.Goal and Objectives

The goal of this study is to use 3-D ray-tracing to create a better 5G wireless propagation model. The specific objectives are to:

i. develop a model using 3-D ray tracing technique to propagate 5G.
ii. implement using MATLAB Simulation software.
iii. evaluate our results with other existing system performance.

2.0 Literature Review

This section of the research shed light on some related literatures by various scholars.

2.1. Related Work

Hosain et al. [1] proposed a 3-D ray tracing method for radio propagation prediction. Their research demonstrated a more accurate method for modeling radio wave propagation in an indoor scenario using computerized simulation. The method was focused at reducing the number of RL effectively in the ray tracing procedure based on some environmental criteria.

Hossain et al [2] presented a study to experiment the radio propagation rate at 28ghz indoors. They created an effective 3-D ray tracing (ETRT) method. The simulation software based on the ETRT was validated using measurement data. The received signal strength and path loss demonstrated a synergy between measurement and simulation.

Ferrand et al. [3] presented a study on wireless channel modeling trends and challenges for evolving radio access. They conducted an analysis of the primary drivers of the new modeling tools, their challenges, and current methods/solutions for addressing these challenges.

Khawaja et al. [4] conducted research on the temporal and spatial characteristics of mmWave propagation channels for UAVs. They investigated the spatial and small-scale temporal characteristics of 28GHz mmWave air-to-ground (AG) line-of-sight (LOS) propagation channels in various environmental scenarios. They distinguished between persistent and non-persistent received multipath components (MPC). They discovered that the scatterer properties influenced the small-scale temporal and spatial characteristics of the AG propagation channel (number, distribution and geometry).

Geok et al [5] provided a comprehensive review of efficient Ray-Tracing (RT) wireless communication techniques. The conventional techniques were described in terms of the current challenges and solutions. They demonstrated ray tracing techniques for overcoming the constraints of the uniform geometrical theory of diffraction (UTD) and geometrical optics (GO). The primary motivation for this was to reduce computational time while increasing accuracy. They also provided a concise overview of RT, described the elemental methods, reviewed several RT progressive methods, and presented hybrid RT methods that made use of physical optics.

Lee et al [6] presented 5G small cell propagation characterization based on geographic location variation. They used a channel sounder in a microcell environment with a 90.5Km radius in Korea to measure changes caused by variation. In order to analyze the propagation characteristics, they developed the best distribution model reflecting the characteristics of the location. A comparison of actual measurements and 3-D RT simulation results validated their measurement results.

Oliveira et al [7] proposed ray tracing 5G channels from scenarios involving vehicle and pedestrian mobility control. In order to generate realistic data, they proposed a refined methodology for virtual measurements of 5G channels that combined a simulation of urban mobility with a ray tracing simulator. The urban mobility simulator was in charge of movement, positioning pedestrians and vehicles throughout each scene, while the ray tracing simulator was used to simulate interactions between receivers and transmitters. Both simulators were built using Python software.

Hossain et al [8] presented PL and RSSI modeling validation by measurement at 4.5GHz, an indoor 3-D RT radio wave propagation prediction method. A simulation was carried out using a software tool developed in-house. 3-D shooting bouncing ray tracing (SBRT) and 3-

D RT simulation were carried out independently on a specific layout where the measurement was carried out. The comparison results showed that the RSSI and PL of the proposed RT had better agreement with measurement than those of the conventional SBRT outputs.

Azpilicueta et al [9] presented 5G mmWave spatial channel characterization for system analysis in urban environments. They presented a channel characterization in terms of large-scale propagation, small-scale propagation, statistical and interference analysis of Fifth-Generation (5G) MillimeterWave (mmWave) bands for wireless networks at 28, 30, and 60 GHz in both an outdoor urban complex scenario and an indoor scenario, in order to consider a multi-functional, high-density 5G network operation. For that purpose, an in-house deterministic 3-D Ray-Launching (3D-RL) code was used, which took into account all of the material properties of the obstacles in the scenario at the frequency under consideration, with the help of purpose-specific implemented mmWave simulation modules.

Li et al. [10] used ray tracing to model a directional antenna channel in an urban environment. They clustered the incident rays based on the azimuth direction of arrival at the receiver and extracted features such as the number of clusters, cluster center distribution, and cluster power ratio. The proposed DACM was derived using the ray tracing method and was feasible within a few hundred meters for a typical urban scenario. They used ray tracing and numerical simulations to validate the proposed model.

Hossain et al [11] presented a study demonstrating an efficient 3-D Ray tracing method for indoor radio propagation prediction at 28 GHz in a 5G network. They used measurement data to validate the simulation software based on the ETRT model. The indication of received signal strength and path loss showed significant agreement between simulation and measurement. The proposed ETRT method outperformed the conventional shooting bouncing ray tracing method in terms of agreement with measurement data. Based on the comprehensive comparison, they were able to reach an acceptable agreement for their proposed method.

3.1 Methodology

The design tool for modeling in this study is the Unified Modeling Language (UML) notation. The UML diagrams used in the research are as follows: Use Case diagrams, Sequence diagrams, and Class diagrams.

3.1 Analysis of the Existing Model

The current system is based on a model developed by Hossain et al. [12]. They created an adaptive 3-d ray tracing method for predicting indoor radio wave propagation. A university departmental office room, a mini shopping mall, and a small library layout were selected for simulation. On the mention unique layouts, 3 scenarios were designed by placing the Tx, Rx over the layout. For each particular scenario, RT was performed using conventional SBRT method. Each and every necessary configurable parameter was similar for these methods. Rx ID, total received by Rx, path loss, propagation period, and total number of launching rays were all explained in the results data. For the conventional SBRT method, the step size for vertical and azimuth angles was 1 for RL.

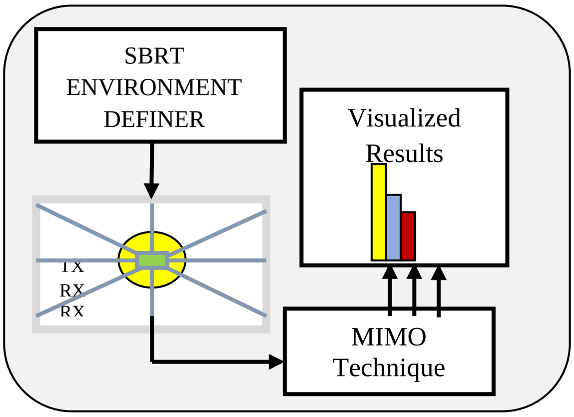

Figure 1: Existing Model Architecture (**Source:** Hossainet al. [12])

There were three different portions in this section. The first section discusses the university departmental office room, where Tx is located in the center. The second section, Tx, is located in the center of a mini-mall. Tx was placed in the center of the small library at the end of the third section. The term investigation is synonymous with the number of rays captured in Rx, path loss, propagation time, and total number of rays initiated, which is the active dimension of overall output comparison.

3.1.1 Disadvantages of the Existing Model

The existing system has the following disadvantages:

i. The existing model operates within a low bandwidth, i.e. within a single building.

ii. The existing model had lower transmission, distance and lower inference.

iii. The existing model used the SBRT algorithm for its implementation, hence the poor results.

iv. The existing model

3.1.2 Algorithm of the Existing Model

Step I:

Define SBRT scenario.

Step II:

Emit SBRT rays in multiple directions with lower angle difference dimension based on the scenario.

Step III:

Trace the rays for successive directions by only calculation.

Step IV:

Predefine wider direction wise SBRT ray emission.

3.2 Analysis of the Proposed Model

The proposed model is an enhancement of the existing system by Hossain et al [12]. The main purpose of this research is to produce a better 5G propagation quality over a wider bandwidth in lesser time by ensuring packet delivery within an environment from a transmitter to the receiver using the 5G network topology and techniques. A building environment is simulated for this purpose. In application environment, the simulation condition was created using a geographic information system map. Packets in form of radio signals were transmitted from one point in the building to another point outside the building in the forest area. The simulation environment, including the building and the forests surrounding it, was set up in the same way as the real one. The height of the building, width of the road, density of the building, and materials (asphalt, metal, cement, wood, etc.) were assigned different reliability values based on permittivity, conductivity, and transmission of each material (e.g., the permittivity of wood is 1.99, its conductivity is 0.012, and it does not transmit electricity). The Rx antenna stood 2m tall, while the Tx antenna stood 7.3m tall. The 3D simulation was carried out by including radio wave information such as diffraction, reflection, and scattering.

The building was beamed to find the direction that best transits signal and the least transmitting part. Directional antennas were simulated to achieve higher frequency band above 6 GHz. i.e. higher transmission distances, higher performance and lower inference is achieved by the proposed system using this technique. This tool accomplishes this by boosting signal strength in a specific direction while suppressing signal strength in other directions. A directional antenna improves propagation quality by directing the beam in the desired direction.

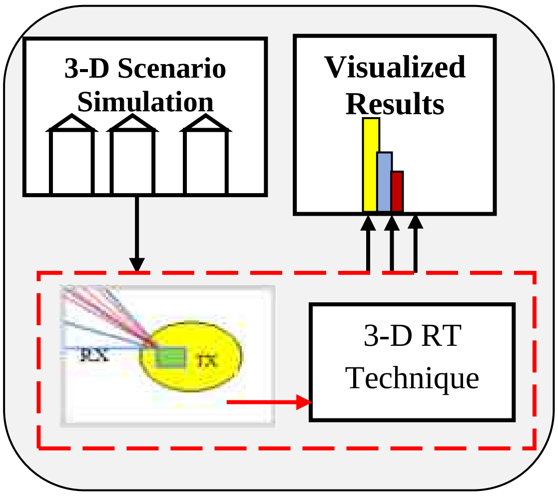

Figure 2: Architecture of the Proposed Model

3.2.1 The RT technique adopted in this approach is the 3-D RT method. The building used as the environment is passed through the six phases of the 3-D RT. **Algorithm of the Proposed Model**

Step I:

Declare Variable;
R = Ray;
Rx = Receiver;
Tx = Transmitter;

Step II

Define 3-D scenario.
3-D Scenario = Assign values to features;

Step III:

Launch R;
R = Rx ⟶ Tx

Step IV:

IF Rx ⟶ Tx = 1;
THEN
$R1 = R1_i , R1_{ii} , R1_{iii} , \ldots , R1_n$

Step V:

$R = \sum_{R1i\text{-}n} + R1$

Step VI:

Trace R;

4 IMPLEMENTATION

The proposed model was simulated using the MATLAB simulation software. MATLAB is the short form of mathematical laboratory. This tool is used for executing advanced mathematical and geometrical solutions as well as for simulating environments and carrying out other network based solutions.

4.2 Discussion of Results

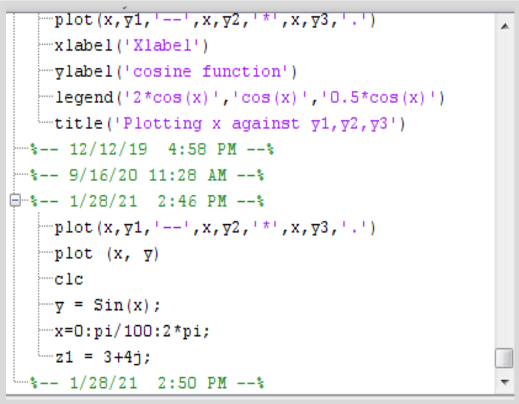

Figure 3: Code History page of MATLAB Simulator

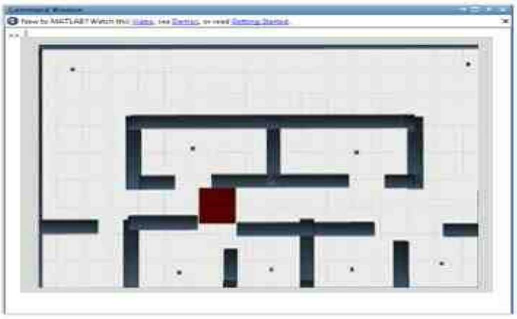

Figure 4: 3-D Scenario Definition

Figure 3 shows the coding environment of the MATLAB software. The building scenario simulated in the model is similar to the actual building it represents. The same dimensions as the actual building were also used to define the scenario in the simulation. This is shown in Figure 3. The red object in the output window represents the building which is the object being projected. The external part of the building serves as the transmission point labeled as Tx. This is where the simulated transmission antenna with height of 7.3 m is located. 5G signals are sent in forms of rays to the receiver antenna with a bandwidth of 28GHz to the receiver antenna at the forest close to the building environment. This is labeled as Rx.

Figure 5: 3-D Ray Tracing from one Tx to Multiple RXs

The rays are channeled to the forest location alone, i.e. Tx, this is a key feature of the 3-D ray tracing technique. More rays are generated from each individual ray after

the first launch. The multiple red lines represent the line of sight (LOS) between the Rx and the Tx, while the green lines represent non-line of sight (NLOS). Figure 7 shows that there are more lines of sight than there are non-lines of sight. This is a proof of successful transmission at a wide bandwidth using the 5G network.

4.3 Performance Analysis

Table 1 represents the parameters for evaluating the performance of our proposed model against the existing model. Our model achieved a higher propagation quality by creating more rays after the initial launching than the existing system.
During the tracing of the rays, more lines of sight were visible in our model than in the existing model. Also, our model was able to transmit rays over a wider bandwidth (28 GHz) than the existing system (26 GHz).

1	Model Efficiency (ME)	10%	13.4%	Model Efficiency (ME)
2	Propagation Quality (PQ)	5%	8	Propagation Quality (PQ)
3	No. of Successful Traces (ST)	7	10	No. of Successful Traces (ST)
4	Time Complexity (TC)	3 minutes	4 Minutes	Time Complexity (TC)
5	Cross Platform Adaptability (CPA)	10%	12%	Cross Platform Adaptability (CPA)
6	Size of Scenario (SS)	10 m	12 m	Size of Scenario (SS)
7	Bandwidth (B)	26 Ghz	28 Ghz	Bandwidth (B)
8	No. of Ray Launches (RL)	1	2	No. of Ray Launches (RL)
9	Receiver Antenna Height (RAH)	1.5m	2m	Receiver Antenna Height (RAH)
10	Transmitter Antenna Height (TAH)	4m	7.3m	Transmitter Antenna Height (TAH)

Table 1: Performance Evaluation Table

Total Performance Score = ∑Parameters' Values

Existing System = 10+5+3+10+10+26+1+1.5+4
= 70.5%

Proposed System = 13.5+8+10+4+12+12+28+2+2+7.3
= 98.8%

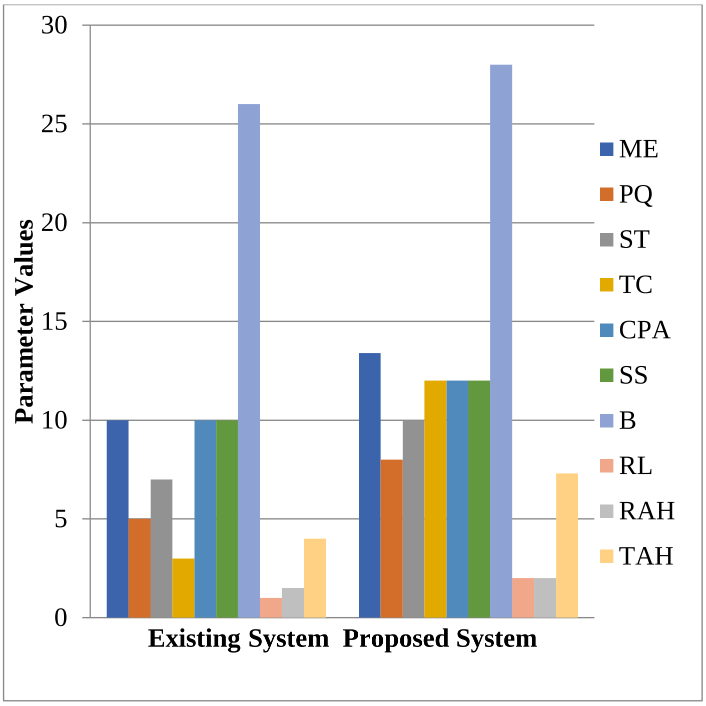

Figure 6: Performance Evaluation Chart

5 CONCLUSION

5G is the latest innovation in the network category and come with a lot of promising features such as larger bandwidth, better propagation and ability to satisfy the traffic of network users especially the cellular network. We have proposed a model that can be used to trace packet transmission within 28GHz range using the 3D ray tracing technique. Our proposed model out performs the existing model in terms of bandwidth and propagation quality.

6 CONTRIBUTION TO KNOWLEDGE

This study proposes an improved 5G wireless propagation model based on a 3-D ray-tracing technique. The proposed model outperforms existing 5G propagation models.

7 SUGGESTION FOR FUTURE WORK

For future work, we suggest that a hybrid 5G propagation model that combines two or more ray tracing techniques be developed.

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