Effective Analysis of various Radio Propagation Models in Wireless Sensor Network Scenario using Qualnet 6.1 Simulator

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Abstract: *In the recent years, extensive amount of research have been done by researchers to solve and upgrade various design and application issues in Wireless Sensor Networks (WSN). WSN is a network of devices that has the ability to communicate through wireless links and can exchange useful information gathered during monitoring. The monitored data is forwarded through multiple nodes, and reaches the gateway node, through which it is further forwarded to the main base station. The features of WSNs, such as small size, low cost, wireless networking and smart deployment in a physical areas, makes it helpful for a variety of applications, for example, battlefield surveillance, weather and environmental monitoring, as well as industry process control systems. In this paper we have focused on comparative analysis of various Radio Propagation models used in WSN. We have used Qualnet 6.1 Simulator for simulating the considered WSN environment.*

Index Term: *Propagation Models, WSN, Path loss Modeling*

I. INTRODUCTION

RADIO PROPAGATION MODEL

Radio propagation model [1] is basically defined as a mathematical formulation for the characteristic modeling of radio wave propagation as a function of frequency, distance and other conditions. The basic development of these models are used for formalizing the performance of radio waves which are propagated from one place to another; these models are typically used to analyze the performance of path loss along a link and the effective coverage area of a transmitter. [2]
There are many types of radio propagation models [3] [7] defined by the researchers in the initial and previous era of research. Such as; friis- or free space model [4], two ray ground model [5] [6], shadowing model, log normal model [8] [9], etc.

Many researchers have used these models to simulate the performance of Wireless Sensor Networks [10] [11], but a proper simulated comparison of these models is yet to be done. This can give a brief idea about the performance of the considered radio propagation models.

In this paper we have considered the three prominent and the most important radio propagation models used nowadays by researchers. These are, Friis or Free Space Model, Two Ray Ground Model and Log Normal Shadowing Model.

II. OVERVIEW ON WIRELESS SENSOR NETWORKS

Wireless Sensor Network (WSN) [10] [11] commonly comprises of countless cost, low - power, and multi-utilitarian sensor hubs that are conveyed in a specific district for monitoring. These sensor nodes are little in size, yet are very much furnished with detecting highlights, information preparing and additionally correspondence abilities. The sensor hubs convey by means of a remote medium and team up to process a given errand, for instance, condition observing, battlefield observation, and industrial process control. As contrasted and customary remote correspondence systems, for example, cell frameworks and MANET [12], sensor systems have the following unique qualities and imperatives, for instance, thick hub sending, Battery control, Energy utilization, information calculation and processing. Sensor hubs are generally thickly sent in a fields of interest [13] [14] [15]. The number of sensor hubs in a sensor arranges more, as contrast with MANET. Sensor nodes are usually powered by battery, and in most situations WSN is deployed in a harsh or hostile environment, where it is very difficult or even impossible to change or recharge the batteries. [16] Therefore energy consumption, data processing and its storage needs a better and sustainable processing system to minimize the power consumption. In reference to these constraints many important research features have been implemented by the researcher to overcome the short comings of WSN. One of the most important research areas in the field of WSN is Radio Propagation Model.

For practical development of WSN topologies in simulation, can only be possible if the path-loss values used among the sensor nodes are properly computed via a genuine propagation model. The design of WSN routing protocols by employing simplistic path-loss models would not perform as expected under realistic scenarios, and the characterizations of these protocols under such unreliable assumptions would wrong and questionable results. The correct modeling of the path loss is of the utmost importance in determining the signal-to-noise ratio, which, in turn, is the determining factor in transmission power control. The WSN lifetime is significantly affected by the optimal assignment of transmission power levels and the extent of retransmissions due to packet failures, which are all dependent on the correct modeling of the path loss. Therefore, the path loss is not deterministic. Instead, it is stochastic, and it can be different over time and may change rapidly under different frequencies and scenario.

III. PATHLOSS MODELLING AND ITS IMPORTANCE IN WIRELESS SENSOR NETWORK

Path loss modeling [17] [18] provides the most important, reliable and accurate analysis of wireless sensor networks [19]. Researchers have conducted distinction studies in WSN in the previous and current era based on route loss modeling, but the use of an inadequate and simplistic route loss model can lead to an unrealistic assessment of the problems in the wireless networks considered.

Path loss models are basically used to abstract the actual propagation characteristics of the use of electromagnetic waves to transmit information in a network, even with a limited number of parameters. Therefore, correct modeling of radio wave propagation and trajectory loss is the most important phenomenon used in the implementation and analysis of the Wireless Sensor Network system. The use of propagation models directly affects most of the performance metrics used to analyze the WSN. However, in many studies on WSN, too simplistic and unreliable propagation models are used, so the use of such inappropriate and unreal propagation models creates a lack of knowledge in the study and implementation of the WSN.

IV. MATHEMATICAL MODELLING OF PROPAGATION MODEL IN WSN

The propagation models are mainly focused on the estimation of the mean signal intensity drop at different transmitter-receiver separations (T-R) and the variability of the signal intensity in the immediate vicinity of the specific separation T-R. The variation in the signal strength is due to changes in the propagation path between a transmitter and a receiver. [17] The relative movements of the transmitter and / or the receiver cause signal intensity variations. In addition, even if the transmitter and the receiver are static, the signal strength may also vary due to the moving and scattering of objects or the shading of objects that affect the propagation environment. With respect to spatial and temporal scales, propagation models can be grouped into two classes, namely large-scale and small-scale propagation models. Large scale propagation models characterize the mean signal intensity due to long range T-R displacements. The free space propagation model can be used when there are no obstacles that can create paths, except for the line-of-sight (LOS) path between the transmitter and the receiver (for example, communications by satellite). [17] Thus, the model of free space propagation is accurate when there is no object other than the transmitter and the receiver, because the existence of any other object could lead to reflected paths. This model is applicable only when the receiver is in the far field of the transmitter antenna (e.g., the transmitter receiver distance is larger than the Fraunhofer distance). The Fraunhofer distance, $d\,f$, is given by

$$d_f = \frac{2D^2}{\lambda} \qquad \text{(i)} \quad [17]$$

Where D is the largest dimension of the transmitter antenna and m is the wavelength. The model is based on the Friis transmission equation, [20] in which spherical propagation is considered and the total received power is equal to the power density times the effective area of receiver antenna

$$\mathrm{Pr} = \frac{P_{tot}}{4\pi d^2}\,\mathrm{Ae}, \qquad \text{(ii)}$$

Where Ptot = $PtGt$, Pt is the transmitter power, Gt is the transmitter antenna gain, and d is the T–R distance. The effective area of receiver antenna, Ae, is related to the physical size of the antenna and given by

$$\mathrm{Ae} = \frac{\lambda^2}{4\pi}\,\mathrm{Gr} \qquad \text{(iii)}$$

Where Gr is the receiver antenna gain and m is the wavelength. Substituting (iii) into (ii), we get the free-space propagation model as

$$\mathrm{Pr} = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2} \qquad \text{(iv)}$$

Equation (iv) shows that the received power falls off with the square of the T–R distance. Besides clear LOS propagation, obstacles may exist (e.g., reflecting surfaces) in between transmitter and the receiver that necessitate the inclusion of other propagation mechanisms affecting signal propagation.

Basic propagation mechanisms can be grouped into reflection, scattering, and diffraction. The importance of these mechanisms comes from the fact that they result in multiple copies of the transmitted signals, each having different amplitudes and phases, when they reach the receiver. The composite signal obtained at the receiver is the sum of the copies arriving from different paths. This may improve or degrade the LOS signal depending on the phases of each signal received from different paths, and the amplitudes of the signals define the level of improvement or degradation. Reflection occurs when a propagating wave is incident on an object that has large dimensions compared to the wavelength (i.e., a relatively smooth surface).

V. FRIIS OR FREE SPACE PROPAGATION MODEL

The free space propagation model assumes the ideal propagation condition that there is only one clear line-of-sight path between the transmitter and receiver. H. T. Friis presented the following equation to calculate the received signal power in free space at a considered distance from the transmitter. [21]

Free space propagation model is use to derive the free space path loss formula.

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \qquad \text{(v)}$$

Where Pt is the transmitted signal power and Pr is the received signal power. Gt and Gr are the antenna gains of the transmitter and the receiver respectively. L(L >= 1) is the system loss, and λ is the wavelength. The free space model basically represents the communication range as a circle around the transmitter. If a receiver is within the circle, it receives all packets. Otherwise, it loses all packets.

VI. TWO RAY GROUND PROPAGATION MODEL

The Two-Rays Ground Model is a radio propagation model which predicts the path losses between a transmitting antenna and a receiving antenna when they are in LOS (line of sight). Generally, the two antennas each have different height. The received signal having two components, first, the LOS component and second is the multipathcomponent formed predominantly by a single ground reflected wave. [17]

A single line of sight path between two sensing nodes is seldom the only means of propagation. The two Ray ground model considers both the direct path and a ground reflection path. Two Ray Ground model gives more accurate prediction at a long distance than the free space model. The received power at distance is predicted by [22]

$$P_r(d) = \frac{P_t G_t G_r {h_t}^2 {h_r}^2}{d^4 L} \qquad \text{(vi)}$$

In equation 7 Pt is the transmitted signal power, Gt and Gr are the antenna gains of the transmitter and the receiver respectively. L is the system loss and h_t and h_r are the heights of the transmitter and receiver Antennas respectively. The equation shows a faster power decrease with increases in distance. However, the two-ray model does not give a good result for a short distance due to the oscillation caused by the constructive and destructive combination of the two rays. Instead, the free space model is still used.

VII. LOG NORMAL SHADOWING MODEL

Log Normal Shadowing model is a generic model and an extension to Friis or Free space model. It is used to predict the propagation loss for a wide range of environments, whereas, the Friis Free space model is restricted to unobstructed clear path between the transmitter & the receiver. [23]

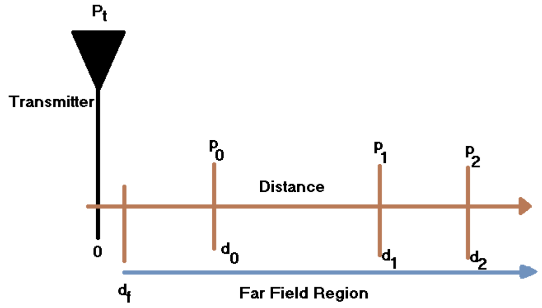

Fig 1.

In the far field region of the transmitter ($d \geq df$), if $PL(d0)$ is the path loss measured in dB at a distance $d0$ from the transmitter, then the path loss (the loss in signal power measure in dB when moving from distance $d0$ to d) at an arbitrary distance $d>d0$ is given by

$$PLd_{0\to d}(dB) = PL(d_0) + 10nlog_{10}\left(\frac{d}{d_0}\right) + Xd_f \leq d_0 \leq d \quad \text{(vii)}$$

$PL(d0)$ = Path Loss in dB at a distance $d0$
$PLd>d0$= Path Loss in dB at an arbitrary distance d
n = Path Loss exponent.
See the table below that gives the path loss exponent for various environments. χ = A zero-mean Gaussian distributed random variable (in dB) with standard deviation – σ. This variable is used only when there is a shadowing effect. If there is no shadowing effect, then this variable is zero. Usually to model real environments the shadowing effects cannot be neglected. If the shadowing effect is neglected, the Path Loss is simply a straight line. To add shadowing effect a zero-mean Gaussian random variable with standard deviation – σ is added to the equation. The actual path loss may still vary due to other factors. Thus the path loss exponent (modeling the slope) and the standard deviation of the random variable should be known precisely for a better modeling. [24]

VIII. DIFFERENT ENVIRONMENTS AND THERE IMPORTANCE IN RADIO PROPAGATION MODEL

Many researchers have focused on various network scenarios in the previous years, but the results of their work were based on simplistic result, where no obstruction or reflection of radio waves was typically considered. Only few studies have addressed the subject of wireless channel modeling of WSN. For free space environments, most of the researchers have relied on free space propagation model and two ray ground model. But in realistic scenarios these propagation model cannot be considered, as they do not focus on the basic environmental conditions such as obstruction and reflection of the signals.

Therefore on this basis we have focused on two important network environments, firstly the rural environment, where the obstruction and reflection of the radio waves will be least, and secondly the urban environment where the radio waves obstruction and reflection will be high. The main objective of our research is basically focused to provide schematic ideology of how propagation models may work with different WSN Scenarios.

IX. RURAL ENVIRONMENT FEATURES AND TOPOLOGY

Reflection diffraction and scattering are three important propagation mechanisms. Radio transmission in a communications system often takes place over irregular terrain. The terrain profile of a particular area needs to be taken into account for estimating the path loss. The terrain profile may vary from a simple curved earth profile to a highly mountainous profile. The presence of trees, buildings, and other obstacles also must be taken into account. On this basis, a rural environment may be describe as an environment where the three important radio propagation mechanism that are, reflection, diffraction and scattering are considered to be less as compare to any other physical environment.

In our scenario we have considered rural environment as a flat surface where no obstacles or clutters are installed, therefore the radio wave will not face any obstruction during communication.

X. SEMI-URBAN ENVIRONMENT FEATURES AND TOPOLOGY.

Main ideology and features behind semi urban environment based sensor network, we have considered a flat surface environment consist of sensor nodes which are placed in a grid and the obstacles and clutters are minimum, the main objective behind this environment is to see what happens when a network is introduced with very less obstructions.

In our scenario we have taken the same rural environment as discussed above but the main difference over here is that, in this scenario we have introduce very less obstacles, which may affect the radio waves propagation.

XI. URBAN ENVIRONMENT FEATURES AND TOPOLOGY

Main ideology and features behind an urban environment based sensor network is that, in realistic conditions no environment can be considered where radio waves obstacles and clutter can be neglected, in other words an urban environment may be called as an environment where reflection diffraction or scattering of radio waves may be very high as well as changes with time.

In our scenario we have just considered the same environment as above two, with just one difference that is the radio waves obstacles and cluttering may be very high as compare to the other two environments.

XII. MAIN IDEOLOGY BEHIND THE CONSIDERED WORK

The main feature and ideology behind our consider work is as follows:

1. We have used Qualnet Simulator 6.1, a network simulator basically used to simulate Sensor based network.
2. To provide researchers a schematic importance of Radio Propagation Model in WSN.
3. To provide the importance of Log Normal Propagation model in WSN.
4. To help the researchers to understand the quality implementation and analysis of Radio Propagation Model in WSN

XIII. SIMULATION DESCRIPTION

Simulation Parameter

S.No	Parameter	Value
1	Number of Nodes	Varying from 25 Nodes to 200 Nodes
2	Simulation Area	1500 X 1500 m^2
3.	Radio Propagation Model	a. Free Space Model b. Two Ray Ground Model c. Log Normal Shadowing Model
4	Nodes Transmit Power	1 Watt
5	Nodes Receiver Power	1 Watt
6	Initial Nodes Energy	0.01 J
7	Routing Protocol	AODV
8	Nodes Placement	Random
9	Application	CBR
10	Number of Packets	1000
11	Packet Size	1024 Bytes
12	Interval between the packet	1 Second
13	Simulation Time	1500 Second

Simulation has been conducted in three phases:

(a) *For Rural Environment* we have considered that once the nodes have been deployed in the area, they are all trying to be in contact with each other, the nodes have been placed at 250m from each other.

In this scenario it has been further taken in consideration that no obstacles are present in the network so that the signals may not face any type of obstruction during transmission, for this reason the path loss mean is consider to be none as given in Qualnet simulator. For simulation purpose the number of nodes has been varied from 25 nodes to 200 nodes so that we may check how the network behaves from a simple network environment to a congestion based network environment.

(b) *For Semi urban environment* we have considered that all the nodes when deployed in an area at a distance of 250m apart from each other, they are facing a slight amount of signal deflection, which can be considered due to the involvement of obstacles such as uneven surface, or buildings which may cause the signals to face obstruction during transmission, for this purpose we have considered the value of path loss mean as (3dB) as given in the Qualnet Simulator.

(c) *For Urban Environment* we have considered similar issues as taken in the above mentioned semi urban environment but the value of path loss mean has been considered to be the highest that is (10dB) as mentioned in Qualnet Simulator.

For the entire above environment we have varied the number of nodes and checked the performance of the network, the performance matrices considered are, throughput, end to end delay, jitter and packet delivery ratio.

XIV. RESULT AND DISCUSSION

(A) RURAL AREA NETWORK:

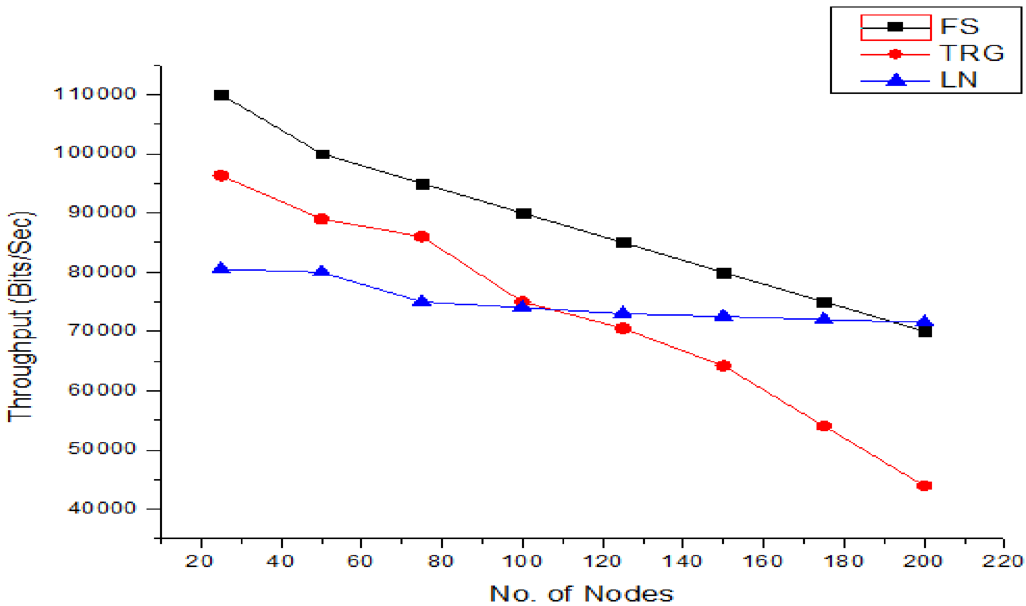

Fig 2: Throughput Vs No. of Nodes

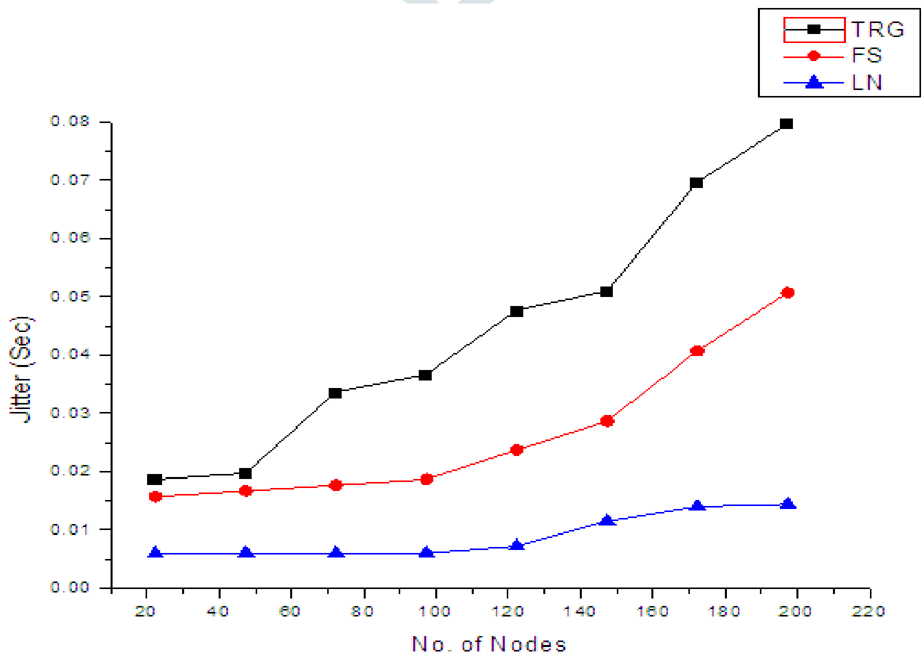

Fig 3: Jitter Vs No of Nodes

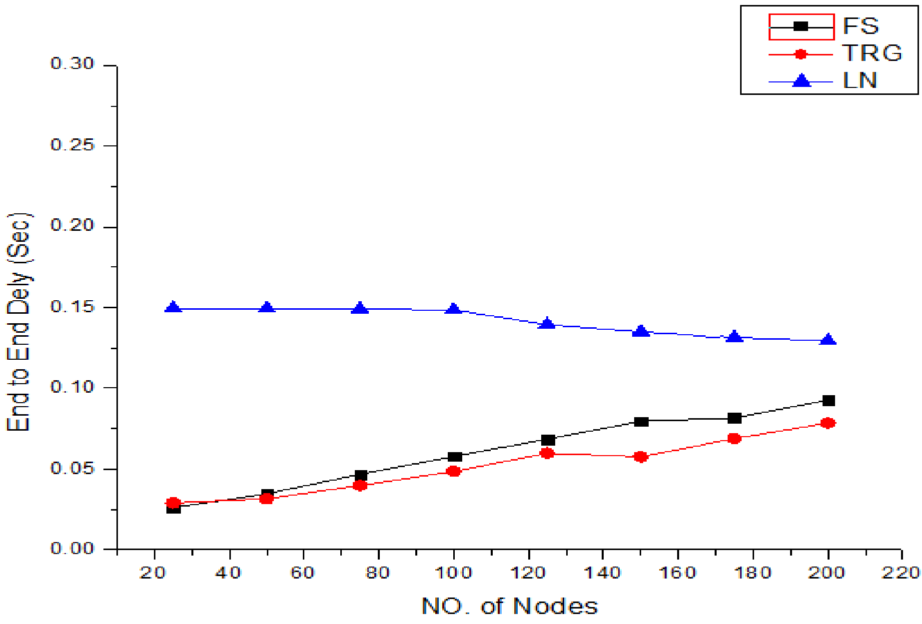

Fig 4: End to End Delay Vs No of Nodes

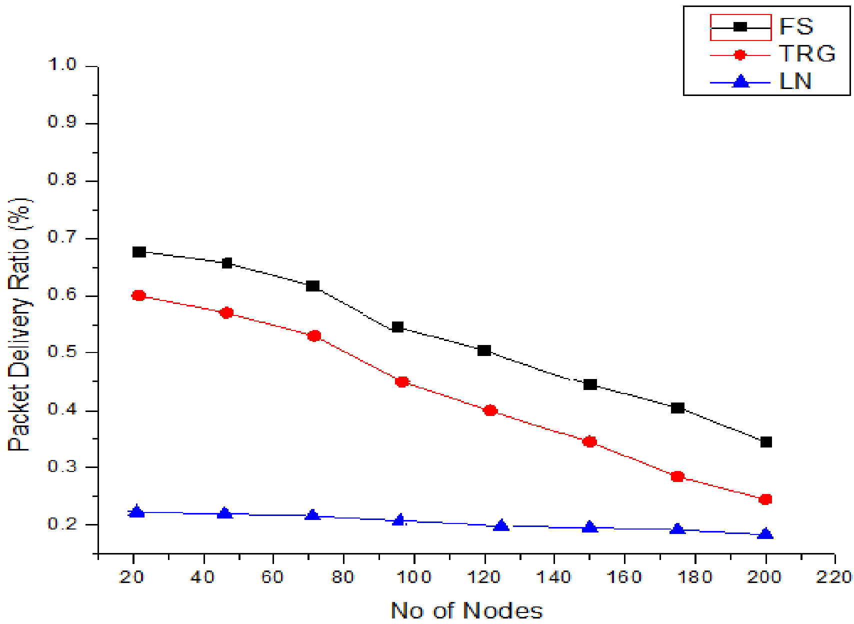

Fig 5: Packet Delivery Ratio Vs No of Nodes

The above mentioned graphs are showing the performance of Rural Environment. From the graphs we can observe that throughput is very much high as minimum signal drop is occurring in the network. Similarly the jitter and end to end delay are also considered to be low. But as the number of nodes is increasing, the value of all the performance matrices drops.

Free space (FS) and two ray ground (TRG) are showing fairly high outputs for the performance matrices till 100 nodes but their values decreases once the number of nodes are increased fro 100 nodes. Log normal shadowing (LN) is showing substantially similar output.

(B) SEMI URBAN AREA NETWORK:

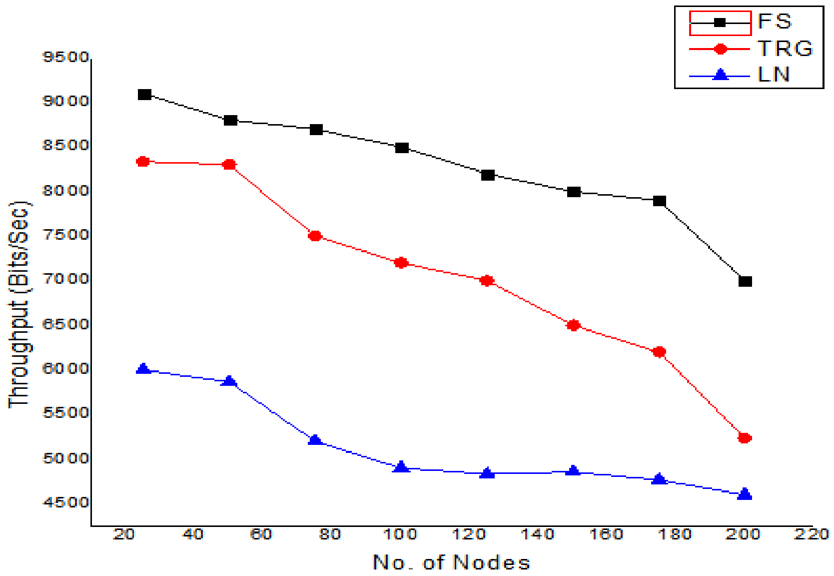

Fig 6: Throughput Vs No. of Nodes

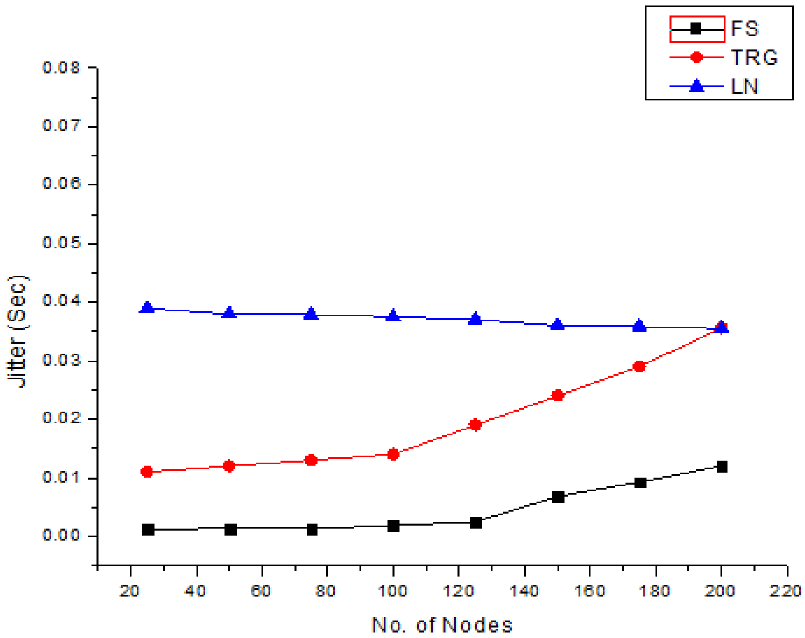

Fig 7: Jitter Vs No of Nodes

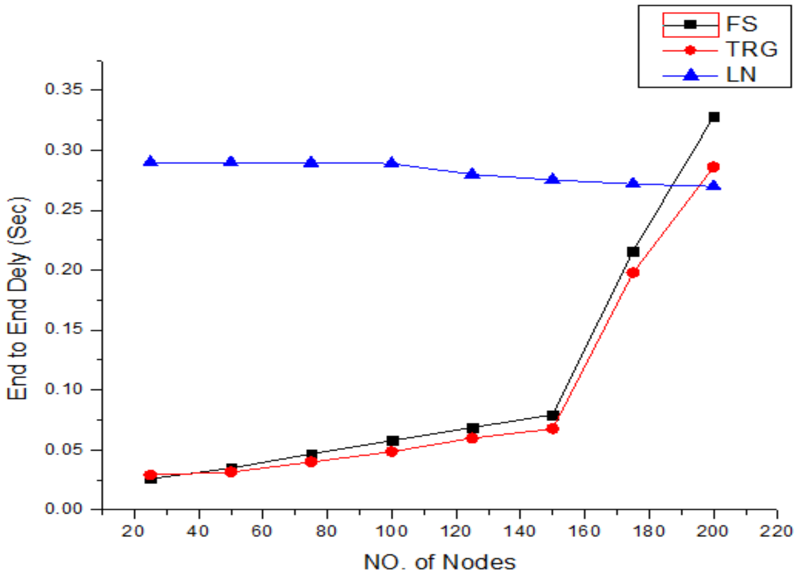

Fig 8: End to End Delay Vs No of Nodes

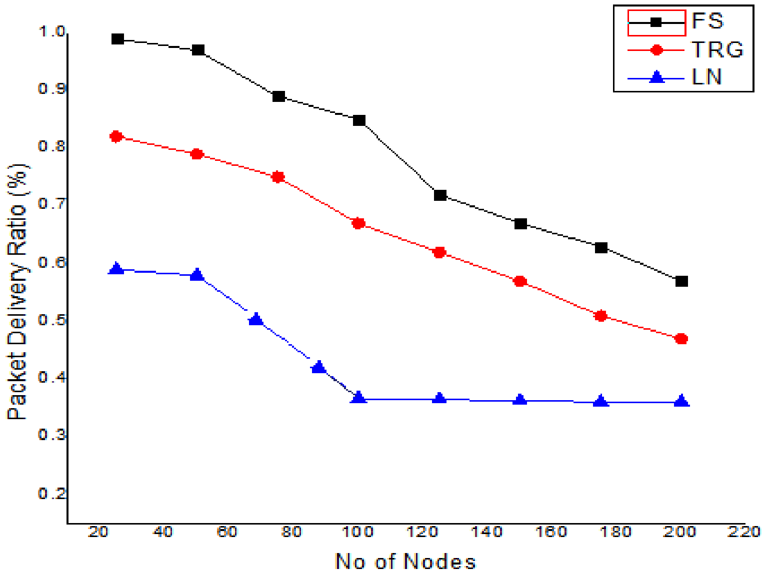

Fig 9: Packet Delivery Ratio Vs No of Nodes

The above mentioned graphs are showing the performance of Semi urban Environment. From the graphs we can observe that throughput decreases as the number of nodes are increasing. Similarly the jitter and end to end delay are getting increased as the number of nodes is increases. Packet delivery radio is also decreased as the number of nodes is increased.

Free space (FS) and two ray ground (TRG) are showing fairly high outputs for the performance matrices when the nodes are less in numbers, but their values decreases once the number of nodes are increased. Log normal shadowing (LN) is showing substantially similar output.

(C) URBAN AREA NETWORK:

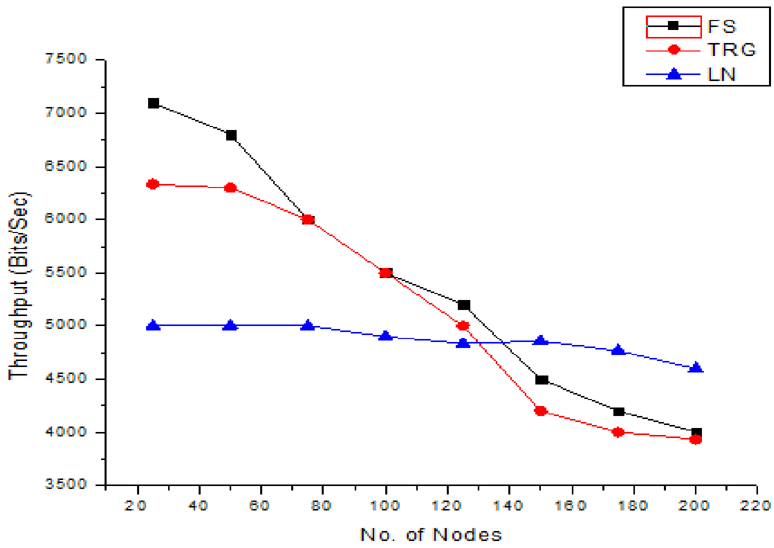

Fig 10: Throughput Vs No. of Nodes

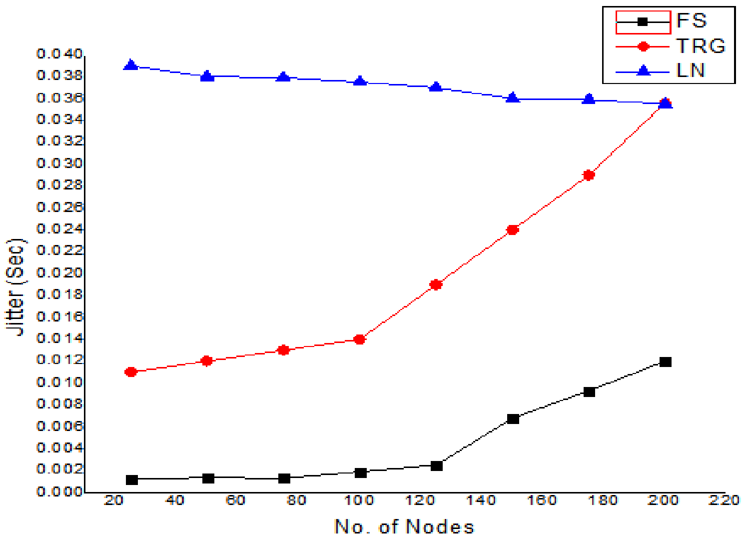

Fig 11: Jitter Vs No of Nodes

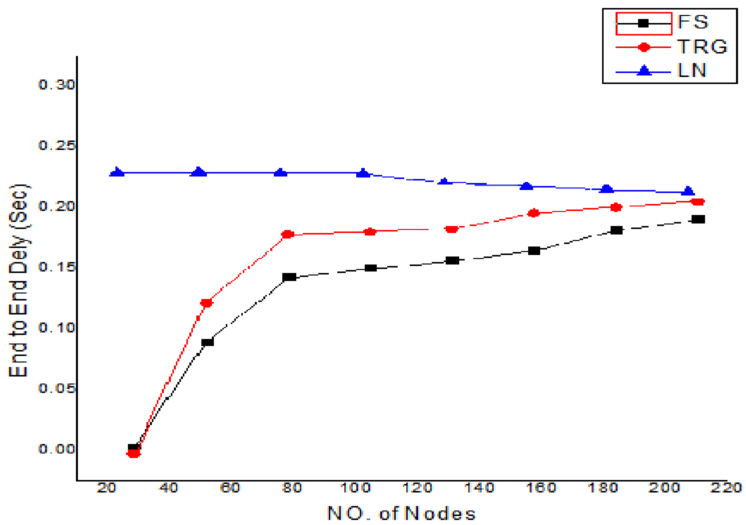

Fig12: End to End Delay Vs No of Nodes

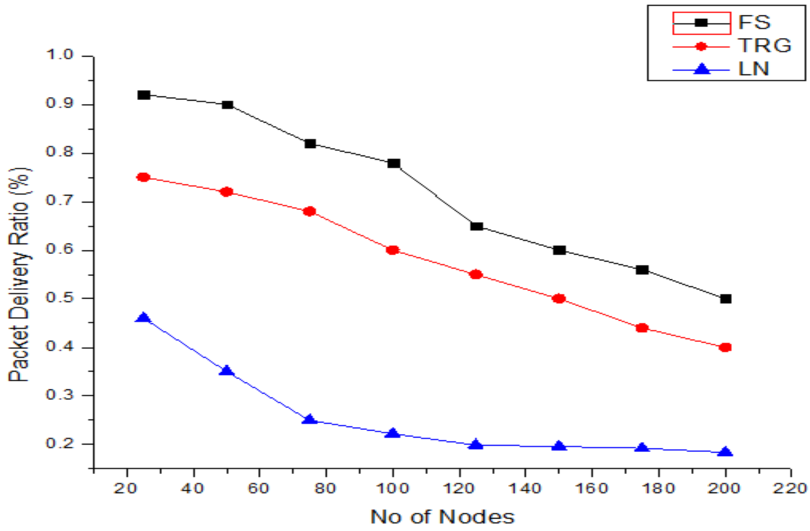

Fig 13: Packet Delivery Ratio Vs No of Nodes

The above mentioned graphs are showing the performance of Urban Environment. From the graphs we can observe that throughput is very much low as compared to the other considered network environment, because in our scenario we have considered the path loss mean to be the highest in the case of Urban environment, due to this, the performance matrices are showing their lowest capabilities. The signal drop is considered to be very high in this case

Free space (FS) and two ray ground (TRG) are showing fairly good outputs for the performance matrices when the numbers of nodes are low, but their performance decreases once the numbers of nodes are increased. Log normal shadowing (LN) is showing substantially similar output.

XV. CONCLUSION

The main motive behind this article is to provide an idea about how the propagation models work, the results which is provided, may not be accurate in real or practical environments, because in real environments the deflection of signals may occur very abruptly.

From the above simulation it is very much clear that the performance of the considered propagation models changes in different environments. The performance of free space model is showing to be the best model, but here it should be taken in consideration that this model may work only when the transmitter and receiver nodes are very much in line of sight.

From our result we would like to encourage the researchers to look over the performance of Log normal shadowing, as the propagation model basically focus toward a realistic environments. The performance of Log normal shadowing may be low as compare to the other considered propagation models, but still it has higher chances of performing better in realistic environments.

In future the authors of this article would like to check the performance of the considered propagation models in practical set up. This main give a clear picture of how the propagation models work in case of sensor network.

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18. REFERENCES

[1] https://en.wikipedia.org/wiki/Radio_propagation_model.

[2] Rath, H. K., Verma, S., Simha, A., & Karandikar, A. (2016). "Path Loss model for Indian terrain - empirical approach". 2016 Twenty Second National Conference on Communication (NCC). doi:10.1109/ncc.2016.7561183.

[3] Klozar, L., & Prokopec, J. (2011). Propagation path loss models for mobile communication. Proceedings of 21st International Conference Radioelektronika 2011. doi:10.1109/radioelek.2011.5936478

[4] https://www.gaussianwaves.com/2013/09/friss-free-space-propagation-model/.

[5] https://en.wikipedia.org/wiki/Two- ray_ground-reflection_model.

[6] Loyka, S., & Kouki, A. (2001). Using two ray multipath model for microwave link budget analysis. IEEE Antennas and Propagation Magazine, 43(5), 31–36. doi:10.1109/74.979365.

[7] https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-P.2345-2015-PDF-E.pdf

[8] http://shodhganga.inflibnet.ac.in/bitstream/10603/24868/15/05_chapter%203.pdf

[9] https://www.csie.ntu.edu.tw/~hsinmu/courses/_media/wn_11fall/path_loss_and_shadowing.pdf

[10] Potdar, V., Sharif, A., & Chang, E. (2009). Wireless Sensor Networks: A Survey. 2009 International Conference on Advanced Information Networking and Applications Workshops. Doi:10.1109/waina.2009.192

[11] I.F.Akyildiz, W. Su, Ysankarasubramaniam, E. Cayirci “Wireless sensor networks: a survey” 1389-1286/02/$ - see front matter Ó.2002 Published by Elsevier Science B.V.PII: S1389-1286(01)00302-4

[12] Anjum, S. S., Noor, R. M., & Anisi, M. H. (2015). Survey on MANET Based Communication Scenarios for Search and Rescue Operations. 2015 5th International Conference on IT Convergence and Security (ICITCS). doi:10.1109/icitcs.2015.7293023

[13] Yong-Min, L., Shu-Ci, W., & Xiao-Hong, N. (2009). The Architecture and Characteristics of Wireless Sensor Network. 2009 International Conference on Computer Technology and Development. doi:10.1109/icctd.2009.44

[14] Tennina, S., Kartsakli, E., Lalos, A., Antonopoulos, A., Mekikis, P.-V., Di Renzo, M., … Verikoukis, C. (2013). WSN4QoL: Wireless Sensor Networks for quality of life. 2013 IEEE 15th International Conference on e-Health Networking, Applications and Services (Healthcom 2013) doi:10.1109/healthcom.2013.6720683

[15] Islam, K., Shen, W., & Wang, X. (2012). Wireless Sensor Network Reliability and Security in Factory Automation: A Survey. IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), 42(6), 1243–1256. doi:10.1109/tsmcc.2012.2205680

[16] Jenkins, L. (2014). Title: Challenges in deployment of wireless sensor networks. 2014 9th International Conference on Industrial and Information Systems (ICIIS). doi:10.1109/iciinfs.2014.7036467

[17] Kurt, S., & Tavli, B. (2017). Path-Loss Modeling for Wireless Sensor Networks: A review of models and comparative evaluations. IEEE Antennas and Propagation Magazine, 59(1), 18–37. doi:10.1109/map.2016.2630035

[18] Alsayyari, A., Kostanic, I., & Otero, C. E. (2015). An empirical path loss model for Wireless Sensor Network deployment in a concrete surface environment. 2015 IEEE 16th Annual Wireless and Microwave Technology Conference (WAMICON). doi:10.1109/wamicon.2015.7120311

[19] Raheemah, A., Sabri, N., Salim, M. S., Ehkan, P., & Ahmad, R. B. (2016). New empirical path loss model for wireless sensor networks in mango greenhouses. Computers and Electronics in Agriculture, 127, 553–560. doi:10.1016/j.compag.2016.07.011

[20] https://en.wikipedia.org/wiki/Friis_transmission_equation

[21] https://ieeexplore.ieee.org/document/1697062

[22] https://en.wikipedia.org/wiki/Two-ray_ground-reflection_model

[23] https://pdfs.semanticscholar.org/8453/9ed2d2e8f3252fe925ee662db3fa2d0a2af6.pdf

[24] https://www.gaussianwaves.com/2013/09/log-distance-path-loss-or-log-normal-shadowing-model/