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Comparative Analysis of Channel Fading Models in Wireless Sensor Networks

KEYWORDS: Small-scale Fading, Rayleigh Fading Distribution, Ricean Fading Distribution, Fast-Rayleigh Fading Distribution.

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ABSTRACT *Fading and interference are the major performance degrading factors in wireless/mobile communications. In order to improve and test the system's effectiveness to resist fading, we significantly need to model and simulate the communication scenario under some fading channel for designing of a communication system. The characteristic of fading channel is diverse and complex for different propagation environments. Therefore, appropriate fading model for a particular communication scenario is essential in this regard. Rayleigh fading and Ricean fading models are the most commonly used small scale models in wireless communication till date.*
But after the advent of mobile radio communication, the design of a scenario has been changed to implement mobility of transmitter or receiver. Thus we need to change the fading model as well. This paper helps to compare different fading models- Rayleigh fading, Ricean fading and fast- Rayleigh fading using QualNet Developer 4.5.1. The simulation results show that Fast Reyleigh Fading model is best suited for mobile radio environments which suffer dense fading

1. Introduction

In one of the most common examples of wireless communication, i.e. mobile communication systems, the transmitting antenna or Base Station are located on top of a tower and radiate at maximum allowed power. Whereas, the receiving mobile station may either be movable and is present below some surrounding building. Thus, the channel is affected by the surrounding structures- cars, buildings, etc. (Belloni, 2012). This creates some degradation in the received signal strength. The behavior of any radio channel between a transmitter and a receiver can be a due to any of the following phenomena:

Path loss: These losses are due to free-space loss, absorption of the transmission medium (i.e. the atmosphere) and scattering of signals themselves when they are obstructed. This path loss is usually degrading with square or forth power of the distance between transmitter and receiver.

Shadowing: In this case, the received signal power fluctuates due to large objects obstructing the propagation path between transmitter and receiver. The shadowing effect is usually characterized by log-normal distribution.

Fading: Fluctuations in the amplitude of a radio signal over a short period of time or travelled distance. It is caused by interference between two or more versions of the transmitted signal which arrive at the receiver at slightly different times. These waves, called multipath waves, combine at the receiver antenna to give a resultant signal which can vary widely in amplitude and phase. Phenomenon of fading is subdivided as follows:

Large-scale fading: It results due to motion over large areas. It helps in computing path loss as a function of distance. This is often described in terms of a mean-path loss and a log normally distributed variation about the mean.

Small-scale fading: It is due to small changes in position. Small-scale fading refers to changes in signal amplitude and phase which may be due to small changes in the spatial positioning between a receiver and a transmitter. Below figure gives a graphical description of the above mentioned fading phenomena. Fig.1. about here.

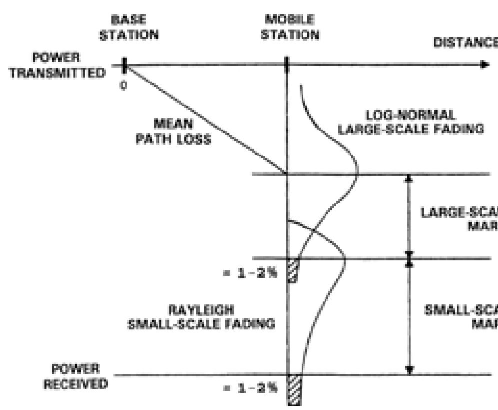

Fig.1. Link Budget consideration for a Fading Channel. [6]

In the next section, we will discuss the existing fading models for different environments.

2. Fading Models

Following section includes three generalized fading models that are basically used to describe small-scale fading in QualNet Developer 4.5.1.

Rayleigh Fading Model

Rayleigh fading occurs when there is no line of sight between the transmitter and receiver. The fading speed is affected by how fast the receiver and/or transmitter or the surrounding objects are moving. Pdf of Rayleigh Fading Distribution is represented by: (Sklar & Theodore S. Rappaport (1996) Wireless Communications, Principles and Practice, Dorling Kindersley (India) Pearson Education, Prentice Hall)

$$p(r) = \frac{r}{\sigma^2}\exp[-\frac{r^2}{2\sigma^2}] \qquad 0 <= r <= \infty$$

$$= 0 \qquad \text{otherwise}$$

Where, r is the envelope magnitude of received voltage and is variance in data. The Rayleigh pdf curve shows that it is the worst case of fading per mean received signal power (Sklar,

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2012). A typical Rayleigh fading envelope at 900MHz is shown in fig. 2. The carrier receiver speed here is 120Km/hr.

Ricean Fading Model
In small-scale fading, when the signal arrives at the receiver by several paths and one of them, typically a line of sight (LOS) signal is much stronger than the others, then such channel is termed as Ricean Fading Channel and the amplitude of received signal is said to be Rice Distributed. Fig.2. about here.

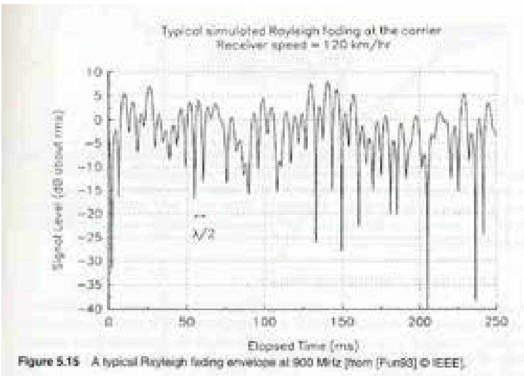

Fig. 2. Typical Rayleigh Fading Envelope.

Probability Density Function (pdf) of Ricean Fading Distribution is given by: (Sklar, 2012).

$$p(r) = \frac{r}{\sigma^2} \exp[-(\frac{r^2+A^2}{2\sigma^2})] * I_0(\frac{Ar}{\sigma^2})$$

for A >= 0 and r>=0
= 0 for r < 0

Where, is the modified Bessel function of the first kind and zero-order and A is the peak amplitude of the dominant signal. Ricean Distribution is more described in terms of a parameter, K called as Rice factor. It is defined as the ratio between signal power and variance of the multipath.

$$K = \frac{A^2}{2\sigma^2}$$

As dominant path becomes weaker, value of K decreases. Fig.3. about here.

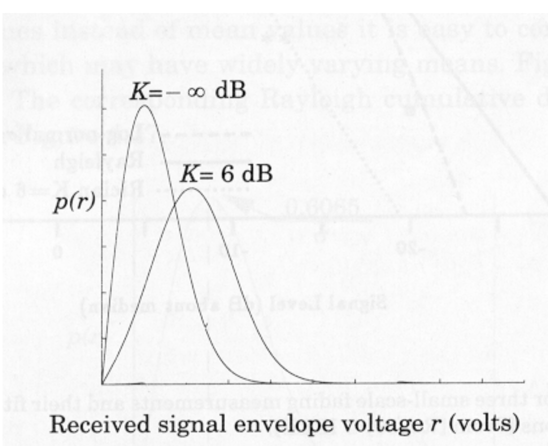

Fig. 3. Rayleigh and Rice distribution PDFs

For K = 0, Ricean Distribution degenerates to Rayleigh Distribution, i.e. when dominant component fades away. For K, the fading becomes deterministic giving rise to an AWGN channel.

Fast Rayleigh Fading Model
This model is used for networks where either the transmitter or receiver is mobile with very high velocity, then the fading gets severe and how rapidly the channel fades, will be affected by how fast they are moving. Due to relative motion between the transmitter and the receiver, each multipath wave experiences apparent shift in the frequency. This shift in the received signal frequency is called as Doppler's shift. In such a scenario, small-scale fading itself is categorized as Time-Variance of channel and Time-Spreading of signal. This is briefly demonstrated below in a fig. 4. The terms slow and fast fading refer to the rate at which magnitude and phase change imposed by the channel on the signal changes.

Slow fading arises when the coherence time of the channel is large relative to the delay constraint of the channel. Fast fading occurs when the amplitude and phase change imposed by the channel varies and is not constant. It occurs when the coherence time of the channel is small relative to delay constraint of the channel. Fig.4. about here.

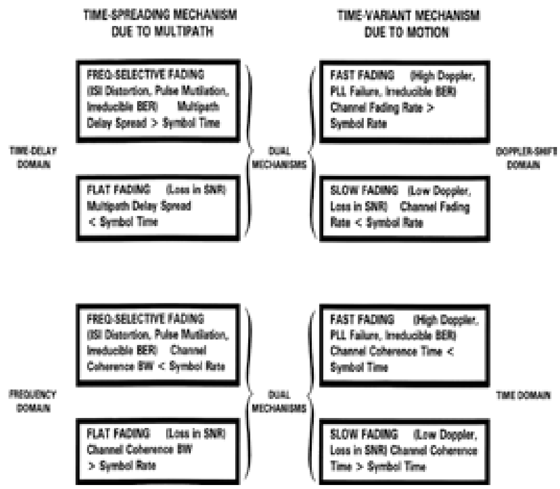

Fig. 4. Small scale fading manifestation

Practically, it has been seen that, such a characteristic is noticed in specific, highly dense and highly dispersive areas. In most advanced networks like Wireless Sensor Networks, the fading effect is even more severe and such a fading is then modeled using Hyper-Rayleigh Fading Model.

3. Simulation Environment
This section gives the details of the simulation environment used to simulate the results and description of parameters set. Simulation environment used here is QualNet® Developer 4.5.1.

Here, a scenario is created that consists of 7 nodes, out of which node1 is the PAN coordinator (Full Function Device) while the other three, node2 to 7 are transmitters (Reduced Function Devices). Now, we have applied different fading models in this scenario. A snapshot of the same is given below. Fig.5. about here.

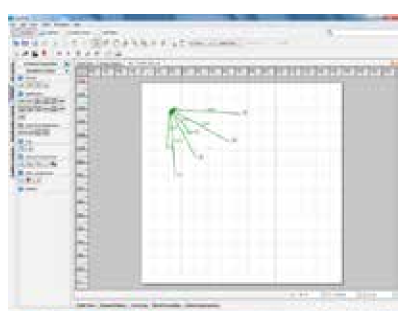

Fig. 5. Simulation Scenario

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Simulation parameters are set as shown in table. Table.1. about here.

Simulation Parameters	Value/ Settings
Simulation Time	1000 sec
Routing Protocol	AODV
Network Protocol	IPv4
Packet Reception Model	PHY802.15.4
Device Type Node1	FFD (PAN Coordinator)
Device Type Node2-7	RFD
Path loss Model	Constant
Fading Model	Rayleigh, Ricean, Fast Rayleigh

Table.1. Simulation Parameters

In the next section, results based on this simulation shall be discussed.

4. Results

On the basis of the above simulation, following results are achieved with few application layer parameters, in form of bar graphs.

Average Jitter

Jitter is used as a measure of the variability over time of the packet latency across a network.

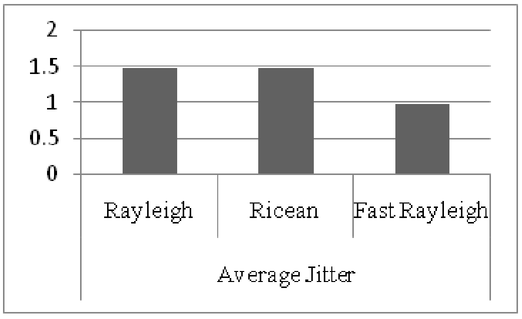

Fig.6. Average Jitter for different models

So, jitter in any communication scenario should be least. Now since the scenario taken here is highly faded (WSN or any other highly dense network) it will suffer high jitter. So, among all the three available fading models- Rayleigh, Ricean, Fast Rayleigh, Fast Rayleigh gives maximum jitter because Fast Rayleigh can model such networks in the best way. So it accurately measures the effect of fading than Rayleigh or Ricean models.

Total Packets Received

This graph shows that during transmission, out of all transmitted packets only a total of 14 packets could reach in Rayleigh and Ricean model. But in case of Fast Rayleigh model, 57 packets reached. This shows that Fast Rayleigh model has better performance than other models.

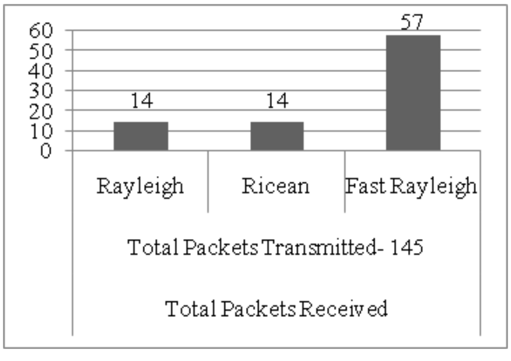

Fig.6. Total packets received for different models

Average end to end Delay

Average end-to-end delay refers to the time taken for a packet to be transmitted across a network from source to destination. For any network, it should be as low as possible. Fast Rayleigh Model shows less end-to-end delay value than the other two models. Thus we can say that Fast Rayleigh model adapt severe fading scenarios better that the other two models.

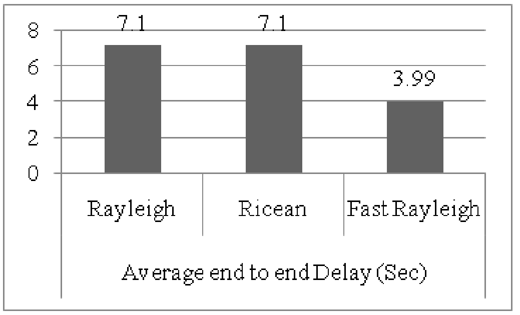

Fig.6. Average End to end delay for different models

Throughput

Throughput is the average rate of successful message delivery over a communication channel. Therefore, in any network, throughput should be high. In the simulated scenario, total input throughput was 2500 bits/sec.

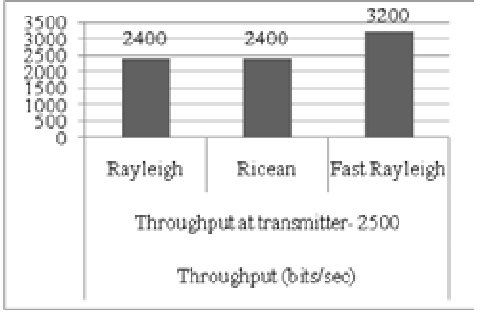

Fig.6. Throughput for different models

But due to the effect of fading, the packets suffered loss and the overall throughput is decreased. Here since the modeled scenario is highly prone to fading, it is best modeled by Fast Rayleigh Model than Rayleigh or Ricean models giving maximum throughput value of 3200 bits/sec comparatively.

5. Conclusions

On the basis on above results, following conclusions can be drawn.

I. Since the scenario consists of 7 nodes placed in close vicinity. This represents primarily a dense scenario.
II. Application layer parameters- jitter, total packets received, end to end delay and throughput shows optimum values for fast Rayleigh model only.
III. This means, out of all the three fading models, fast Rayleigh fading model shows better results than the other two. So, we can say that fast Rayleigh fading is best suited for such dense networks.

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