Available Online at www.ijcsmc.com

International Journal of Computer Science and Mobile Computing

A Monthly Journal of Computer Science and Information Technology

ISSN 2320–088X

IJCSMC, Vol. 2, Issue. 3, March 2013, pg.41 – 45

RESEARCH ARTICLE

Signal Strength and System Operating Margin Estimation for Vehicular Ad-Hoc Networks in Rayleigh Fading Environment

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Abstract: In this paper, signal strength and system operating margin (SOM) are estimated for vehicular ad-hoc networks in absence and presence of Rayleigh fading. The free space propagation model and Ad-hoc IEEE 802.11 models are discussed and later has been used to estimate signal strength and system operating margin. Rayleigh fading was then simulated and signal strength and system operating margin are estimated in Rayleigh fading environment.

Keywords: Vehicular Ad-hoc network; propagation models; IEEE 802.11 model; system operating margin; Rayleigh fading

I. Introduction to Vehicular Ad-hoc Network

Vehicular Ad-hoc Network (VANET) is a subset of Mobile Ad-hoc Network (MANET). In VANET, vehicles act as transceiver and are able to send, receive and forward the information at the same time. VANET has a lot of applications that increase traveller safety, improve traveller mobility, decline travelling time, preserve energy and protect the environment, enlarge transportation system efficiency and boost on-board luxury [1]. It involves relatively short radio multihops (between 200 - 1000m), low cost antennas deployed in each car, and low transmitter power (around 32 mW) [2]. In vehicular ad-hoc networks, there is no restriction to communicate with neighbouring vehicles travelling within a specific transmission range. In VANET system multi-hop communication takes place [3]. Ad-hoc networks are beneficial for deploying these networks in the areas where it is not practicable to install the needed infrastructure [4].

II. Propagation Models

Two propagation models are discussed below.

A. Free Space Propagation Model

The Free Space Propagation model (FSP) is used to predict the received signal strength having a clear, unobstructed line-of-sight path between a transmitter and receiver. The received signal power is calculated by the following equation given by Friis.

$$P_r(d) = P_t\, G_t\, G_r\, \lambda^2 / (4\pi)^2\, d^2 \qquad (1)$$

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where, $P_r(d)$ is the received power which is a function of the transmission-receiver separation, P_t is the transmitted power, G_t is the transmitter antenna gain, G_r is the receiver antenna gain, λ is the wavelength and d is the transmitter-receiver separation[5].

Free-Space Loss does not include factors such as the gain of the antennas used at the transmitter and receiver, nor any loss allied with hardware imperfections; it is solely based on the LoS (Line of Sight) path through free space air [6].
The equation of free space path loss is as follows:

$$FSPL\ (dB) = 20*\log_{10}(d) + 20*\log_{10}(f) + 92.45 \quad (2)$$

where f is frequency measured in GHz, d is distance measured in Km and 92.45 is the reference loss constant.
This reference loss constant varies by varying the measured units of frequency and distance.
If d is measured in meters and f in KHz, then the FSPL equation becomes

$$FSPL\ (dB) = 20*\log_{10}(d) + 20*\log_{10}(f) - 87.55 \quad (3)$$

For d in meters and f in MHz, then equation is as follows

$$FSPL\ (dB) = 20*\log_{10}(d) + 20*\log_{10}(f) - 27.55 \quad (4)$$

If d is measured in Km and f in MHz, then the free space path loss equation becomes [7]

$$FSPL\ (dB) = 20*\log_{10}(d) + 20*\log_{10}(f) + 32.45 \quad (5)$$

Equation (5) can be simplified for 2400 MHz frequency band [3].

$$FSPL\ (dB) = 40 + 20*\log_{10}(d) \quad (6)$$

B. IEEE 802.11 Model for Ad-Hoc Network

An Ad-Hoc network is a decentralized type of wireless network. Due to this type of nature, the scalability of the network may be improved. It does not rely on pre-existing infrastructure such as access points in managed wireless networks [8]. An ad hoc network is made up of multiple nodes (e.g. transmitter power) connected by links (e.g. length of link, signal loss). Ad hoc network often refers to a mode of operation of IEEE 802.11 which is wireless local area networks in frequency bands 2.4, 3.6, 5 GHz [9].

The path loss equation is quite accurate for free space path loss model and mobile wireless local area network system typically operate with antennas that are between one to two meters above the ground. Basically this model is the extension to the free space model and can be analysed using the equations as follows [3]:

$$P_{loss} = 10*n*\log_{10}(d) + 20*\log_{10}(f) - 20*\log_{10}(h_t\ h_r) \quad (7)$$

where f is the frequency in GHz, h_t is the transmitter antenna height in meters, h_r is the receiver antenna height, d is the distance and n is the path loss exponent. Equation (7) can also be simplified for 2.4 GHz frequency band.

$$P_{loss} = 7.6 + 20*\log_{10}(d) - 20*\log_{10}(h_t\ h_r) \quad (8)$$

Here by using this model, the path loss and signal strength is calculated for different values of n (path loss exponent).

C. Rayleigh Fading

Fading is variation of the signal strength that affects the signal over a certain transmission medium. The fading may vary with time, environmental location or radio frequency and is often modelled as arbitrary process. In wireless systems, fading may either be due to multipath propagation, or due to shadowing from obstacles affecting the wave propagation, referred to as shadow fading. The presence of reflectors in the environment surrounding a transmitter and receiver create multiple paths that a transmitted signal can traverse [10].

Rayleigh fading is caused by multipath reception. The mobile antenna receives a large number, say *N*, reflected and scattered waves. Because of wave cancellation effects, the instantaneous received power seen by a moving antenna becomes a random variable, dependent on the location of the antenna. Rayleigh fading is a geometric model for the effect of a propagation situation on a radio signal. Rayleigh fading is described as a realistic model [10].

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Rayleigh fading is a practical model when there are various objects in the environment that spread the radio signal before it comes at the receiver. If there is no dominant component to the scatter, then such a process will have zero mean and phase evenly distributed between 0 and 2π radians. This random variable has a probability density function:

$$P(r) = r / \sigma^2 \exp(-r^2 / 2\sigma^2); \qquad (0 \le r \le \infty) \tag{9}$$

where, σ is the rms received voltage signal before envelope detection and σ^2 is the time average power of the received signal before envelope detection [5].

III. Problem Formulation

To estimate the signal strength in vehicular ad-hoc network the following parameters are considered. Frequency (f) is considered as 2.450 GHz and distance is varied upto 1000 meters. The path loss exponent is considered to vary from 2 to 6. For free space propagation the path loss exponent is 2 and may increase upto 6 in urban area. The transmitter and receiver antenna heights are taken as 2 meters. The transmitted power is assumed as 15 dBm. The transmitter and receiver antenna gain are assumed to have a value of 5 dBi and the cable and connector loss to be 1.2 dB. The average vehicular speed is considered as 40km/hr in Indian scenario. On the basis of these parameters the signal strength is estimated without and with Rayleigh fading.

IV. Estimation of Signal Strength

Signal strength is estimated with the parameters discussed in the previous section and shown in Fig 1. In this figure, signal strength is compared for different values of path loss exponent (n) which ranges for 2 to 6 depending on the propagation environment. The signal strength decreases with increasing distance and with increasing n, the signal strength becomes poorer.

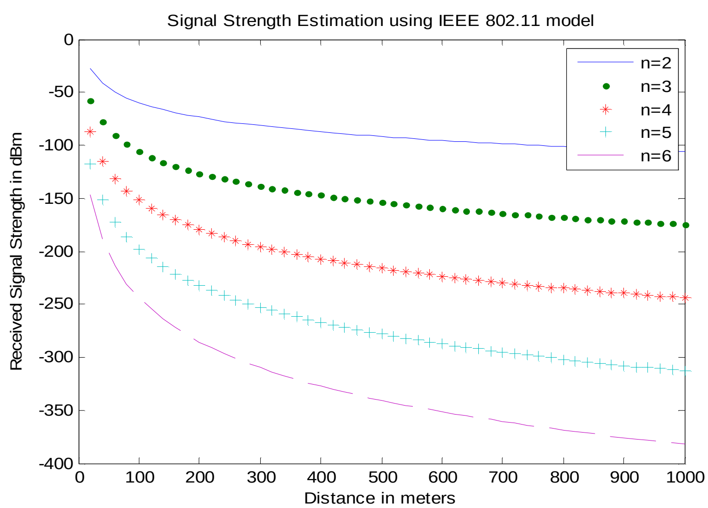

Figure 1. Signal Strength Estimation for VANET

Rayleigh fading was then simulated using MATLAB. The following parameters were considered during simulation –
Number of multipath = 5
Carrier frequency = 2.45 GHz
Sampling frequency = 9.8 GHz
Sampling time = 102.04 microseconds.

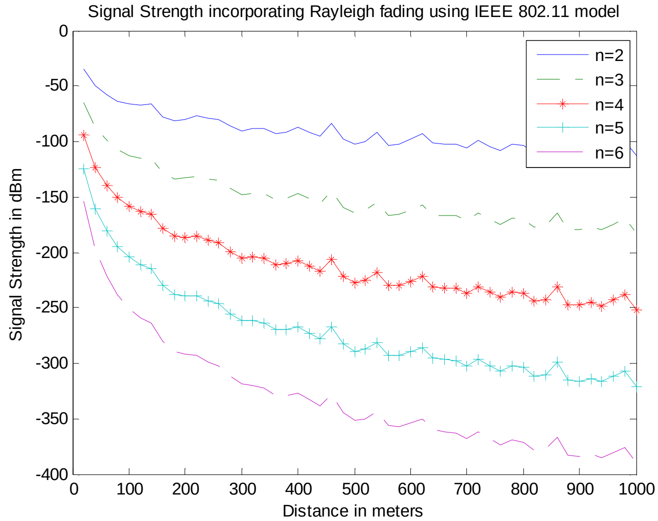

Figure 2. Signal Strength Estimation under Rayleigh fading for VANET

Figure 2 shows the signal strength estimation incorporating Rayleigh fading for different values of path loss exponent. The graph shows similar nature as without fading. But the signal strength with Rayleigh fading shows fluctuations in comparison to signal strength without Rayleigh fading. This shows that in practical systems, Rayleigh fading must be considered for proper system design.

V. ESTIMATION OF SYSTEM OPERATING MARGIN (SOM)

System Operating Margin (SOM) is defined as the difference between the received signal level and the receiver sensitivity which is needed for error free reception. System Operating Margin can be calculated using equation (10) [2]. SOM, basically, is the difference between the signals a radio actually receives versus the signal quality required for adequate data recovery (receiver sensitivity). SOM can be defined as

$$SOM = P_r - S_r \quad (10)$$

where, P_r is the received power in dBm, S_r is the receiver sensitivity in dBm and SOM is the system operating margin [6].
The System Operating Margin predicts the area of optimal reception between the transmitter and receiver. For optimum operation, an ideal System Operating Margin would be 20dBm or more than that however these values are not always achievable but a value lower than 10dBm is usually considered unacceptable [3].

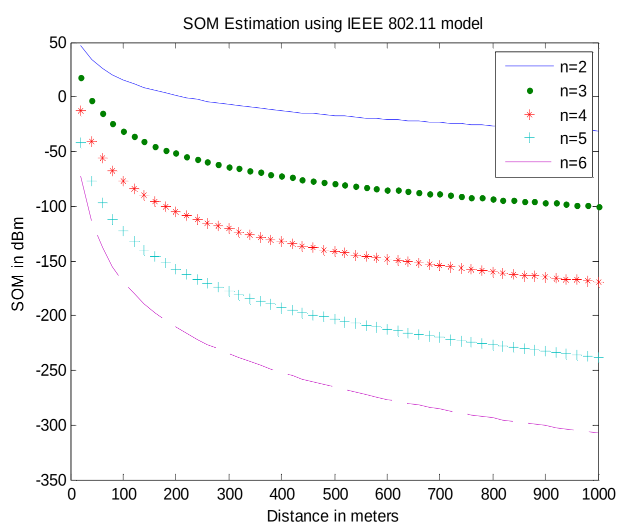

Figure 3. SOM Estimation for VANET

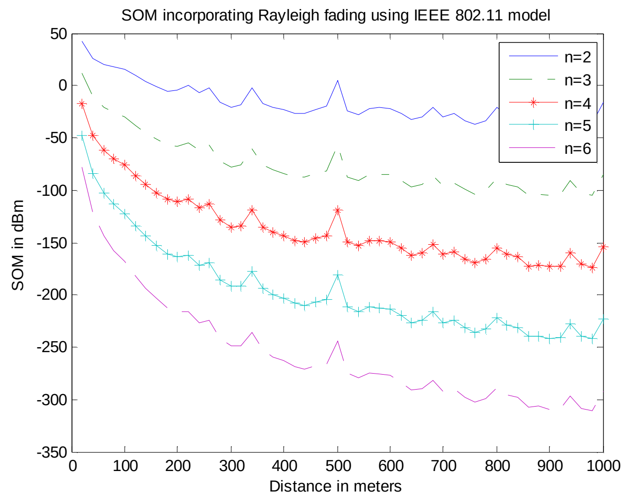

Figure 4. SOM Estimation under Rayleigh fading for VANET

In this work, the receiver sensitivity has been chosen to be -75 dBm. Figures 3 and 4 show the system operating margin with and without Rayleigh fading respectively for different values the path loss exponent. The system operating margin decreases with increasing distance. The effect is much more pronounced for increasing values of n. Under Rayleigh fading environment, SOM fluctuates. The value of system operating margin below 10 dB is normally not acceptable. So the maximum range can be calculated for different environments.

VI. Conclusions

The signal strength and system operating margin are estimated with and without Rayleigh fading for a typical vehicular ad-hoc network. From the estimated results, it may be concluded that the signal strength decreases with increasing path loss exponent. The system operating margin also decreases with increasing path loss exponent. In Rayleigh fading environment, the signal strength and SOM show fluctuations which must be taken into account for system design. The range of operation can also be found out from these estimations.

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