Impacts of Radio Propagation Model on Mobile Ad-hoc Network (MANET) Performance in Group Mobility Environments

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ABSTRACT

As the applications for Mobile Ad-hoc NETworks (MANETs) have varied, performance analysis has become one of the main research areas. They commonly offer only simple radio propagation models that neglect obstacles of a propagation environment. The radio wave propagation model has a strong impact on the results of the simulation run. In this paper we present the new experimental results of the impacts of the various propagation models on MANETs' performance. Intensive simulations have been presented using the group mobility which models typical ad-hoc situations such as military movements or disaster recovery activities under the supervision of a group leader. Comparisons of conventional simple models with more complicated models, i.e., shadowing, Raleigh, and Ricean models, show that, in spite of the models' popularity, the free space and two-ray ground models are too optimistic in describing real ad-hoc group mobility situations.

Keywords : MANETs, Radio Propagation Model, Group Mobility, Performance Analysis, Complicated Model

Ⅰ. Introduction

Mobile Ad-hoc NETworks (MANETs) configure independent networks to perform communication between nodes using a radio link without infrastructure. In addition, MANETs are highly dynamic because of

frequent nodes' movement, and therefore, there are limitations in resources, i.e., computing power, battery, and communication bandwidth, due to miniaturized equipment for node's mobility. In spite of these restrictions, MANETs have been widely deployed where network infrastructure supports are unavailable, i.e., emergency situations, natural disasters (e.g., backbone network breakdown due to flooding), military forces deployment, etc. Recently, the applications have diversified into various fields e.g., conferences, concerts, outdoor events such as festivals, and a ubiquitous sensor network

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접수일자 : 2010년 9월 2일, 수정일자 : 2010년 9월 9일, 심사완료일자 : 2010년 9월 17일

(USN). In typical MANET situations, such as military force deployment or disaster recovery activities, each node's movement is under a leader's supervision, not an each node's independent mobility, i.e., each node's movement is random but usually bounded in a group with a leader. Accordingly, many performance analysis studies for MANETs in group mobility environments have been conducted [1, 2, 3, 4, 5]. Most performance analysis done so far, however, has been based upon a very limited radio propagation model such as the free space model or the two-ray ground model. Since such a simple model cannot represent rather complicated nor practical outdoor environments that usually have radio propagation obstacles such as buildings or trees, it is expected that there are supposed to be some difference between the analysis using the simple model and the performance in real situation. To model the appropriate model which describes the real outdoor environments, we need comparative performance analysis under various radio propagation models; although similar topics have been dealt with each node's independent mobility assumption [11, 12], however, few analysis has been presented in group mobility environments. This paper presents new experimental results of the impacts on MANET performance by utilizing various radio propagation models. Accordingly, in this work, performance of routing protocol has been analyzed with the group mobility scenario based upon the Random Point Group Mobility (RPGM) model [8], which is generally accepted as a group mobility model. The rest of the paper is organized as follows. We discuss the radio propagation model and the group mobility model in the following Section 2. In Section 3, the impacts of radio propagation models on MANET routing protocol has been analyzed by means of computer simulations, and Section 4 concludes this paper.

Ⅱ. Radio Propagation and Group Mobility Models

1. Radio Propagation Model

One of the biggest limiting factors which restrict the performance in the radio communication system is the radio channel environment. Differing from the wired channel, which is static and predictable, a radio channel is quite irregular and hard to analyze precisely, which makes the radio channel one of the most difficult parts in radio communication system analysis. Key mechanisms that affect radio signal propagation in a radio channel are reflection, diffraction, and scattering [6]. In addition, channel characteristics can be classified into two types: large-scale, which occurs by moving over a large area, and small-scale, which radically changes the signal amplitude and phase according to a small position change between the transmitter (Tx) and the receiver (Rx) [7]. As shown in Fig. 1, in large-scale channels, there is mean path loss according to the distance and shadowing, which changes around the mean path loss due to radio wave obstacles even at the same distance. In addition, small-scale fading is also generated around shadowing due to wave scattering.

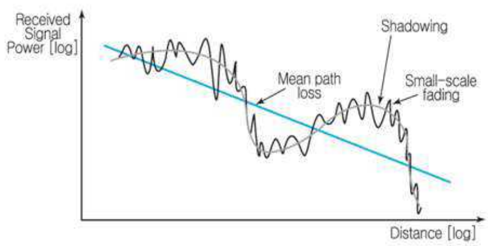

Fig. 1 Wave propagation models [8]

1.1 Free Space Model

The free space model represents the mean path loss in an open area. The free space model is used to model the received signal strength in a line-of-sight (LOS) environment where there is no obstacle between the Tx and the Rx, and is widely used in satellite communication systems or in typical LOS radio propagation environments. Similar to most other path loss models, this model can be expressed as a function of distance, d [m], between the Tx and the Rx. The analytical model for the receiving signal power according to the typical Friis free space equation is [9, 10, 11, 12, 13]

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \tag{1}$$

Where P_t and $P_r(d)$ are the transmitting power and receiving power at distance d between the Tx and the Rx, respectively. And G_t, G_r, λ and L indicate Tx antenna gain, Rx antenna gain, wavelength [m], and system loss coefficient ($L \geq 1$), which is independent of the propagation environment, respectively. The system loss coefficient includes attenuation in the transmission line, filter loss, antenna loss, etc. in a communication system. L is 1 when there is no loss in the system hardware. Equation (1) confirms that the receiving power decreases proportionally to the d's square.

1.2 Two-ray Ground Model

The two-ray ground model also represents the mean path loss in an open area. This model was developed to consider the direct path between the Tx and the Rx, and the ground surface reflected path between the Tx and the Rx as shown in Fig. 2, because it is rare for only an LOS path to exist. This model usually provides actual results compared to the free space model for long-distance communication. The receiving signal power is given by [10, 11, 12, 13]

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

Where h_t and h_r are the antenna height at the Tx and the Rx, respectively. Equation (2) shows that the receiving power decreases more rapidly than in the free space model as the distance increases between the Tx and the Rx. The two-ray ground model, however, cannot analyze accurate values for short distance communication because of interference between the two paths. That is the reason why the free space model is used when the distance d between the Tx and the Rx is short.

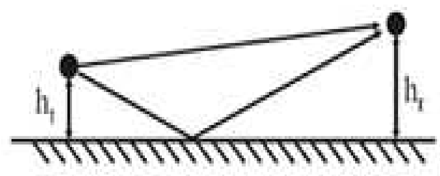

Fig. 2 Two-ray ground model with direct path and reflection [13]

1.3 Shadowing model

The shadowing model is often referred to log-normal shadowing model. This model also presumes that the mean receiving power between the Tx and the Rx decreases in an algebraic manner and Gaussian random variable is added to the path loss model according to the environment between the Tx and the Rx. The shadowing model consists of two parts. The first is the path loss model based upon the free space model which utilizes path loss exponents, β, for various environments, and is expressed as

$$\left[\frac{\overline{P_r(d)}}{P_r(d_0)}\right]_{dB} = -10\beta\log\left(\frac{d}{d_0}\right) \tag{3}$$

Where d_0 is the reference distance, and the path loss exponent, β, which has various values from 2 to 6 according to the environment as shown in Table 1. For example, the value of β is 2 in free space and the value is larger with obstacles [18]. The second is the Gaussian random variable model presuming that each path has a unique path loss in a real radio propagation environment because of different surrounding conditions according to the Rx locations even with the same distance between the Tx and the Rx. Therefore, the aggregated shadowing model is expressed as [10, 11, 12, 13]

$$\left[\frac{\overline{P_r(d)}}{P_r(d_0)}\right]_{dB} = -10\beta\log\left(\frac{d}{d_0}\right) + X_{dB} \tag{4}$$

where X_{dB} is the Gaussian random variable with a standard deviation of σ_{dB} and its mean value of 0. Equation (4) includes random shadowing impact over equation (3) to generate different path loss for the same distance, d, value. Here, σ_{dB} also has various values according to the environments as shown in Table 2.

Table 1. Typical values of path loss exponent β [10, 11]

Environment		β
Outdoor	Free Space	2
	Shadowed urban area	2.7 to 5
Inside	Line-of-sight	1.6 to 1.8
	Obstructed	4 to 6

Table 2. Typical values of shadowing standard deviation σ_{dB} [10, 11]

Environment	σ_{dB} (dB)
Outdoor	4 to 12
Office, hard partition	7
Office, soft partition	9.6
Factory, line-of-sight	3 to 6
Factory, obstructed	6.8

1.4 Ricean and Rayleigh Fading Models

These two models represent small-scale channel characteristics. Small-scale is often simply called fading and it is the variation in signal power received for a short time or through a short-distance radio channel. When more than two waves arrive at the receiving antenna with a slight timing difference, the wave power is increased if they are in-phase and decreased if they are out-of-phase. Fading is defined as this impact from the multi-path. Rayleigh fading occurs when multiple indirect paths exist only due to scattering between the Tx and the Rx, while Ricean fading occurs when indirect paths and an LOS path exist together [11, 12].

2. Group Mobility Model

In this paper, performance analysis based upon group mobility has been made according to the RPGM, which is adequate for typical MANETs application modeling. Each group in the RPGM has a logical leader node which decides the group mobility pattern. Initially, each node in the group is distributed randomly and uniformly around the group leader node. When the leader decides the destination, each node in the group moves to the destination which also randomly and uniformly distributed across the destination of the group leader. Thus, the speed and path of the mobility pattern for each node are decided according to the group leader's destination. Fig. 3 shows an example of single group RPGM model and multiple group mobility pattern is also followed in later of this paper.

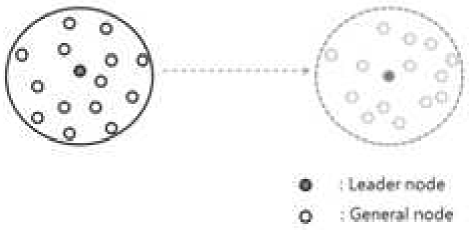

Fig. 3. Single group RPGM model

III. Numerical Results

A popular network simulator, ns-2 [15] is used for the performance analysis in this paper. The metrics used are throughput, average delay, and routing overhead. In addition, the numerical analysis is performed under three different scenarios; by varying the distance between the nodes, the number of nodes in the group, and the group mobility speed. The results are presented as two scenarios, i.e.,, the impact of radio propagation models with distance and the impact of radio propagation with the number of nodes in a group node and the moving speed.

1. Impact of Radio Propagation Models with Distance

1.1 Scenario and Simulation Setup

The numerical analysis is conducted to find the routing performance impacts according to the change in distance between the nodes for each radio propagation model. With one base station node and one mobile node, as shown in Fig. 4, the performance is measured by changing the distance between the nodes by 10 m up to 50 m, which is the maximum transmission range of the node. The two nodes are connected as a transmission pair using the user datagram protocol (UDP) with constant bit rate (CBR) traffic to transmit a 512-Bytes packet, four times per second for 200 seconds. Table 3 shows the detailed parameter setup for the simulation scenario according to the distance.

Fig. 4. Configuration for node-to-node distance simulation

Table 3. Parameter setup for the impact of the distance between the nodes

Parameter	Value
Protocols	AODV
Simulation Time	200 sec.
MAC Type	IEEE 802.11
Transmission Range	50 m
Traffic Type	CBR (UDP)
Packet Size	512 Bytes
Packet Interval	0.25 sec. (4 packets/sec.)
Number of Nodes	2
Number of Connections	1 pair

As mentioned in Section 2, the shadowing model requires the path loss exponent, β, and σ_{dB} to reflect the shadowing impact. We set 4 for the path loss exponent, β, and 8 for σ_{dB}, assuming an outdoor environment in this scenario. Since the Rayleigh model and the Ricean model are not implemented in the current ns-2, we have implemented these models with references [16, 17].

Throughput is defined as the ratio of the received packets to the transmitted packets. Average delay is defined as the elapsed time difference between the packet generation time at the Tx and the packet received time at the Rx. In addition, routing overhead is defined as the ratio of the routing packet to the sum of the routing packet and the transmitted packet.

1.2 Simulation Results

The simulation results for the radio propagation model with changing distances between the nodes are shown in Figs. 5, 6, and 7. Fig. 5 shows the throughput for each radio propagation model. As shown in Fig. 5, the free space and the two-ray ground model show 100% throughput because these models are assumed to be ideal environments. On the other hand, throughput decreases for the shadowing and fading models as the distance between the nodes increases, and the Rayleigh fading model has the biggest impact on the performance of MANETs. Fig. 6 shows the average delay with different radio propagation models. Average delay with the free space or the two-ray ground model shows a nearly zero second in average, which is also ideal. On the other hand, MANET with the shadowing model and the fading model demonstrates increased delay with the distance increases, and especially the Rayleigh fading model shows the largest delay. Fig. 7 shows the routing overhead. The routing overheads for the free space and two-ray ground models are also close to zero, while the Rayleigh fading demonstrates the largest overhead.

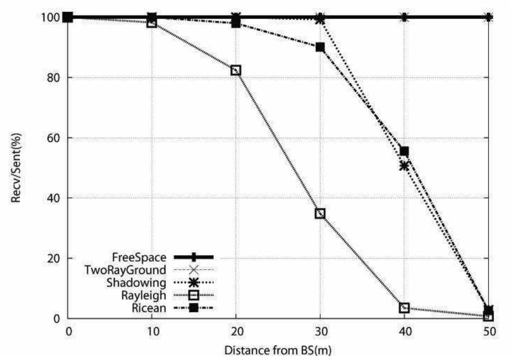

Fig 5. Throughput as a function of the distance between the nodes

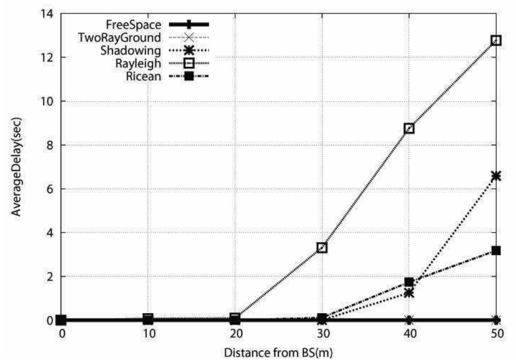

Fig 6. Average delay as a function of the distance between the nodes

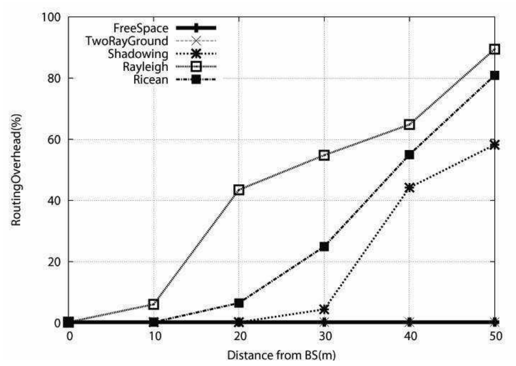

Fig 7. Routing overhead as a function of the distance between the nodes

2. Impact of the Radio Propagation Model with the Number of Group Nodes and Moving Speed

2.1 Scenario and Simulation Setup

Analysis of the impact of radio propagation models according to the number of group nodes and moving speed is performed with the group mobility scenario. The scenario is for one group to move forward in a zigzag fashion, as in Fig. 8, with randomly selected destination points. UDPs with CBR traffic connection are used for 10 transmission pairs to transmit a 512-Bytes packet, four times per second for 200 seconds. Table 4 and Table 5 show the detailed parameters according to the number of group nodes and moving speed.

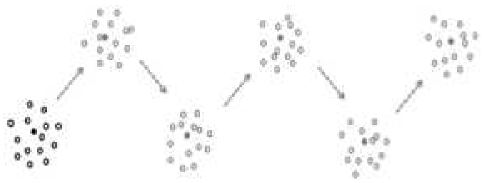

Fig. 8. Group mobility pattern

Table 4. Parameter setup for the impact of the number of nodes in a group

Parameter	Value
Protocols	AODV
Simulation Time	200 sec.
MAC Type	IEEE 802.11
Transmission Range	50 m
Traffic Type	CBR (UDP)
Packet Size	512 Bytes
Packet Interval	0.25 sec. (4 packets/sec.)
Number of Connections	10 pairs
Number of Nodes	10, 20, 30, 40, 50
Node Speed	5 m/s

Table 5. Parameter setup for the impact of the mobility speed of a group

Parameter	Value
Protocols	AODV
Simulation Time	200 sec.
MAC Type	IEEE 802.11
Transmission Range	50 m
Traffic Type	CBR (UDP)
Packet Size	512 Bytes
Packet Interval	0.25 sec. (4 packets/sec.)
Number of Connections	10 pairs
Number of Nodes	30
Node Speed	1, 10, 20, 30, 40, 50 m/s

Simulations have been performed five times for each of the different randomly generated mobility scenarios and show the mean value. The same radio propagation models are used as in previous analysis.

2.2 Simulation Results

Fig. 9, 10, and 11 show the simulation results according to the number nodes in a group. Fig. 9 shows the throughput according to the number of nodes in a group. The throughput increases as the number of nodes in a group increases. The maximum throughput for the free space model and the two-ray ground model is achieved above 80% due to ideal assumption, while the throughput of Rayleigh model is achieved below 20%. The average delay is significantly decreased as the number of nodes in a group increases for the free space and two-ray ground models, as shown in Fig. 10. On the contrary, for other models, the delay increases as the number of nodes in a group increases up to 20 nodes, but the other models a slight decrease with more than 20 nodes. Fig. 11 shows the simulation results for the overhead.

The overall overhead increases as the number of nodes in a group increases. Especially, the free space model and the two-ray ground model ideally show the lowest overhead value.

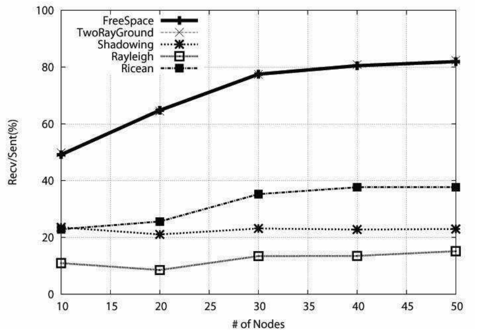

Fig 9. Throughput as a function of the number of nodes in a group

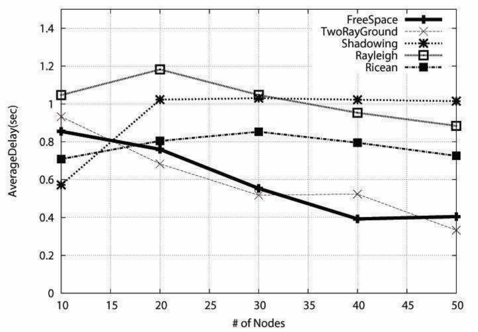

Fig. 10. Average delay as a function of the number of nodes in a group

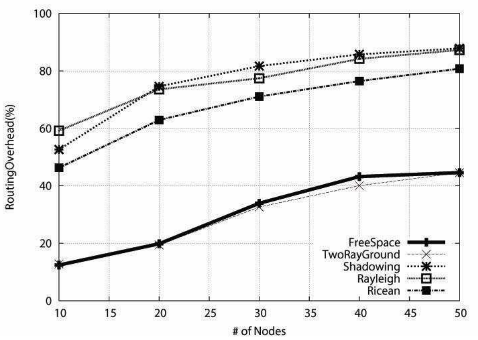

Fig. 11. Routing overhead as a function of the number of nodes in a group

Figs. 12, 13, and 14 show the simulation results according to group mobility. Fig. 12 shows that the throughput decreases as the moving speed for the free space and two-ray ground models increases. However, the throughput for the other models does not demonstrate any significant decrease or increase. Similar to the results in Fig. 5 and Fig. 9, throughput decreases in the order of the free space, the two-ray ground, the Ricean, the shadowing, and the Rayleigh model with the group moving speed. The average delay is shown in Fig. 13, the delay increases as the increase in moving speed, and the Rayleigh model demonstrates the largest delay. The routing overhead results shown in Fig. 14 are similar to that in Fig. 11.

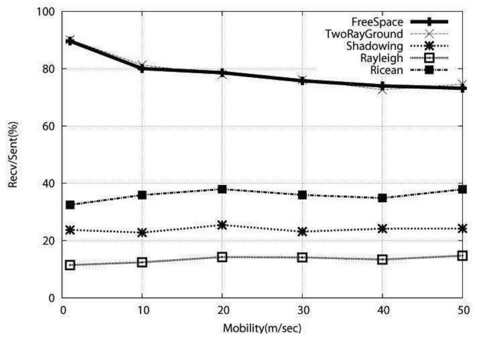

Fig. 12. Throughput as a function of the group mobility speed

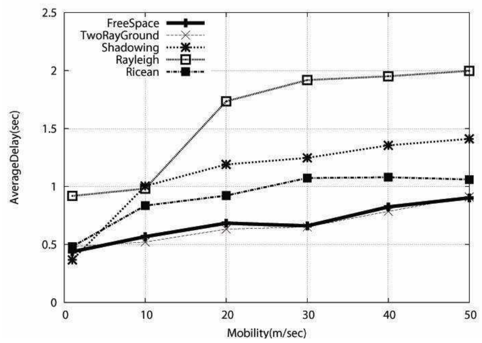

Fig. 13. Average delay as a function of the group mobility speed

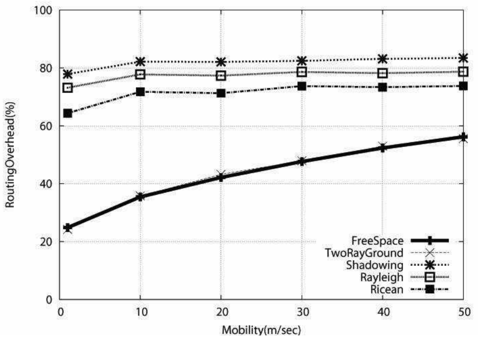

Fig. 14. Routing overhead as a function of the group mobility speed

Throughout our simulations, we found that the free space model and the two-ray ground model show the ideal performance for every metric, which indicates a very significant difference from the other models, such as the fading, the Ricean, and the Rayleigh models. Therefore, we conclude that the current research results which use simple models i.e., the free space and the two-ray ground models are too optimistic to apply to practical outdoor environments for MANETs.

Ⅳ. Conclusion

Most research on MANETs performance analysis in group mobility environments conducted so far have been largely based upon a simple radio propagation model i.e., the free space or two-ray ground propagation model, which assumes ideal situations. Although we can expect that these simple models cannot cover complicated practical outdoor environments, which usually have multiple radio propagation obstacles, few comprehensive comparative analyses using various models in group mobility environments has been reported.

This paper presents the impacts on MANETs performance analysis by utilizing various radio propagation models. Impacts on AODV routing protocol performance have been analyzed with the free space, the two-ray ground, the shadowing, the Ricean, and the Rayleigh radio propagation models under group mobility MANETs environments. The performance analysis is conducted with different scenarios, i.e., varying the distance between nodes, number of group nodes, and group mobility speed. The results confirmed that there are significant differences in performance between the often used free space and two-ray ground models, and the Rayleigh model, which represents a real outdoor MANETs environment. In most cases, the simulation results show that the results with the free space and the two-ray ground models are too optimistic to apply to a real MANET situation. Our results have shown that the choice of a radio propagation model can significantly affect the performance of MANETs in group mobility situation.

Only a single radio propagation model for each scenario has been applied in this paper. However, in a real situation, it would be more realistic to implement combined radio propagation models even in a single scenario, which will be our future study area. In addition, research on more varied group mobility models is also required.

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