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Impact of Node Speed and Transmission Range on the Hello Interval of AODV Routing Protocol

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ABSTRACT

In mobile ad-hoc networks (MANETs), nodes use hello messages to detect neighbour nodes and to maintain link connectivity. In a typical MANET routing, a node broadcasts hello messages at a fixed interval. However, a fixed hello interval causes a long delay of neighbour discovery (if hello intervals are too long) or greater bandwidth wastage due to unnecessary protocol overhead (if hello intervals are too short). In this study, we investigate the impact of node speed and transmission range on hello intervals with respect to network throughput. Through simulations of a MANET using ad hoc on-demand distance vector (AODV) routing protocol, we show that the hello interval required to maximize network throughput can be determined as a function of node speed and transmission range.

Key Words : MANETs, Adaptive hello message, Hello interval, Transmission range, AODV, mobility factor

Ⅰ. Introduction

Mobile ad-hoc networks (MANETs) are characterized by their dynamic network topology and resource constraints regarding bandwidth and battery power. In typical MANET applications, the connectivity of nodes changes frequently as a result of movement, link failure, or fading effects[1]. These factors cause a node to change its information about neighbour nodes frequently. Thus, a neighbour discovery scheme is one of the most critical challenges in MANETs.

In general, a neighbour discovery scheme is used to detect new neighbours and link breaks in MANET routing protocols. Traditional MANET routing protocols provide a mechanism to monitor neighbourhood changes (new neighbours or lost neighbours) by exchanging hello messages in fixed intervals[2]. For example, the hello interval is 1 s in ad hoc on-demand distance vector (AODV)[3], and 2 s in optimized link state routing (OLSR)[4]. Although the implementation of a fixed hello interval for neighbour detection is very simple, its routing performance in dynamic environments of MANETs has been critically debated. Use of hello messages also contributes to overall network traffic and affects performance. As hello messages are broadcast locally by the nodes, they contend with data packets for bandwidth. They may also increase the probability of collisions with data packets or other control messages in the network, which can lead to medium access control (MAC) layer backoff and buffer overflows at the interface queues. These factors lead to an overall reduction in network utilization and throughput as well as increase in the packet loss ratio.

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Many previous studies have observed that the routing performance is correlated to the link detection capabilities of the hello emission strategy[5,6]. With shorter hello intervals, new neighbours and link breaks are detected faster. However, hello intervals that are too short cause unnecessary protocol overhead. This reduces network throughput and increases the energy consumption of nodes. However, if a node sends hello messages less often, then congestion and resource waste will be alleviated, but neighbour tables will be inaccurate and broken link detection delay will increase. Such delay might lead to unnecessary packet drops because of route unavailability. Several adaptive algorithms were proposed in previous studies[7-12] to control the hello interval dynamically in order to achieve a good trade-off between resource waste and the broken link detection delay. The basic idea of these schemes is to modify the hello interval based on a node's moving distance[7] or speed[8,9] or the number of link changes[10-13] in order to decrease route setup and maintenance overhead. However, previous studies did not examine sufficiently the manner in which the node speed and transmission range affect the hello interval in routing performance.

In this study, we investigate the impact of node speed and transmission range on hello intervals with respect to network throughput. Through simulations of a mobile ad-hoc network (MANET) using an AODV routing protocol, we show that the hello interval necessary to maximize network throughput depends on node speed and transmission range.

The remainder of this paper is organized as follows. Section 2 outlines related works. Section 3 explains the manner in which speed and transmission range affect the hello interval and defines a mobility factor. Section 4 compares two types of mobility models and describes our simulation environment. In addition, through simulation results of network performance, we examine the correlation between the mobility factor and hello interval. Section 5 presents the conclusions of this study.

Ⅱ. Related Work

2.1 Control Schemes of the Hello Interval

Traditional MANET routing protocols use a fixed time interval to send hello messages, which is not optimal. For example, if the nodes in a network do not move, the links of the nodes will not change. Therefore, sending hello messages at a fixed rate will only cause unnecessary overhead in the network. By contrast, if the nodes are moving too fast, sending hello messages at a fixed rate might advertise the links too late. Thus, when a node sends a packet to a neighbour, that neighbour may no longer be in its transmission range, in which case the packet will simply be dropped. The node must then exchange additional messages to find a means to route the pending packets. Several adaptive algorithms were proposed in previous studies to control the hello interval dynamically. The basic idea of these schemes is to adapt the hello interval based on a node's moving distance[7] or speed[8,9] or the number of link changes[10-13].

Giruka et al.[7] proposed an adaptive hello scheme, in which a node emits hello messages at every constant distance it moves. Thus, nodes moving at higher speeds emit hello messages at higher rates. Similarly, nodes moving at slower speeds emit hello message at lower rates. To prevent too slow or too fast emission rates of hello messages, minimum and maximum rates are thus defined as MIN-BEACON-INTERVAL and MAX-BEACON-INTERVAL.

Jingwen et al.[8] proposed Adaptive Classified Hello Scheme (ACHS) for an improved hello message. ACHS distinguishes nodes into 2 classes such as nodes on the route and off the route. Then, speeds of nodes in each class are compared to determine proper optimum hello interval with threshold velocity and determination velocity.

Basagni et al.[9] proposed distance routing effect algorithm for mobility (DREAM), which considers mobility as a means to control the refresh timer to broadcast messages. In DREAM, a node broadcasts a control message according to its speed. The faster a node moves, the more often it broadcasts messages. Conversely, the slower a node moves, the fewer control messages it sends.

Huang et al.[10] proposed an algorithm based on the link change rate. A link is a local connection with a neighbour, and the link change rate measures the change in the set of links of a node over time. The link change rate is first measured by monitoring the number of acquired and lost links. If a node has a link change rate close to zero, its neighbourhood remains unchanged. Conversely, if a node has a high link change rate, its neighbourhood has changed. Based on this assumption, the hello timer can be set to an adequate value. In stable networks, the value of the hello timer can be higher so that no unnecessary overhead is incurred. In highly dynamic networks, the value should be small to monitor changes in the network.

In addition, other adaptive hello schemes exist that reflect link changes used to establish the emission rate of hello messages. Previous studies[11-13] suggest that a node broadcasts hello messages based on the number of link changes or neighbours. Ernst et al.[11] proposed an adaptive hello scheme that adapts the hello interval according to link changes and interval length coordination with neighbouring nodes. Hernandez-Cons et al.[12] proposed a dynamic hello/timeout timer based on link change rate as the number of new and lost links per time elapsed since the last measurement. Ingelrest et al.[13] proposed a turnover-based adaptive hello protocol. “Turnover” refers to the change based on the update to the neighbour table, meaning that whenever a neighbour table is updated, turnover occurs. Thus, the hello interval is regulated by the ratio of the number of current to the number of previous neighbours. The hello interval increases as the link change rate diminishes, whereas the hello interval decreases as link changes occur infrequently.

Previous studies proposed several dynamic control algorithms for the hello interval. However, they did not examine sufficiently the manner in which the node speed and its transmission range affect the hello interval in routing performance.

2.2 AODV Overview

The AODV is a reactive routing protocol, in which routes are determined only as needed. When a route is required, AODV uses a route discovery process to learn a route. Once a route is established, it is maintained as long as it is needed using a maintenance procedure. AODV maintains routes using a soft state approach: if a route is not used, it expires after a specified period. If a path is broken, a node that composes the path detects link disconnection using its neighbour information. The node then sends a route error message to neighbours and route recovery mechanisms work to locate a new route.

Two variables determine connectivity using hello messages: HELLO_INTERVAL and ALLOWED_HELLO_LOSS. HELLO_INTERVAL specifies the maximum time interval between the transmission of hello messages. ALLOWED_HELLO_LOSS specifies the maximum number of periods of HELLO_INTERVAL to wait without receiving a hello message before detecting a loss of connectivity to a neighbour. The recommended value for HELLO_INTERVAL is 1 s and for ALLOWED_HELLO_LOSS is 2 s[3]. HELLO_INTERVAL and ALLOWED_HELLO_LOSS are related to the period of data packets lost (neighbour lifetime) as shown in Fig. 1.

However, a node does not broadcast hello messages every interval in the network. Rather, a node should only use hello messages if it is part of an active route. It means that an initial path construction between the source and destination does not strongly depend on hello messages. After a path is constructed, a node in the path update its

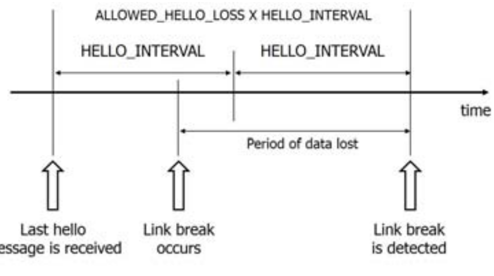


Fig. 1. Hello message operation in AODV.

neighbour table steadily with hello messages from neighbours. If the node does not receive any hello messages from neighbours after neighbour lifetime, it deletes the neighbours in its neighbour table. The node then informs other neighbours that the path is disconnected by sending a route error message, which begins the route recovery process.

2.3 Mobility Models

Network performance is affected by mobility models in MANET because links are disconnected or maintained according to node movement[14,15]. We introduce two mobility models, random waypoint and Gauss-Markov mobility models, for use in simulations[16].

The random waypoint mobility model was designed to apply simply to any mobile networks[17]. It has simple rules stipulating that nodes move independently and randomly. Nodes initially are set with a pause time and speed. They then choose any waypoint to the destination within the limit and travel to that destination in a straight line at a configured speed. After reaching the destination, the nodes pause before repeating the operation. Network conditions can be different according to the configuration of factors of random waypoint mobility.

By contrast, the Gauss-Markov mobility model[18] is inclined to move with specific patterns generally in contrast to random waypoint mobility, which changes direction sharply. In addition, the Gauss-Markov mobility model move unpredictably because it possesses a parameter to determine its randomness. Nodes are assigned speed and direction initially, but are changed according to the degree of the parameter at fixed intervals of time. Specifically, the current speed and direction are calculated based on the previous speed and direction with a random variable using the following equations:

$$s_n = as_{n-1} + (1-a)\bar{s} + \sqrt{(1-a^2)s_{x_{n-1}}}$$
$$d_n = ad_{n-1} + (1-a)\bar{d} + \sqrt{(1-a^2)d_{x_{n-1}}}$$

where n and $n-1$ indicate current and previous instances, respectively. Thus, the current speed and direction of the node are s_n and d_n, which are determined by other parameters. Among the parameters, previous conditions such as $s_n - 1$ and $d_n - 1$ represent the core of the mobility because the major characteristic of Gauss-Markov mobility is predictability of future conditions based on the previous speed and direction. Constant values $\bar{s}$ and $\bar{d}$ denote mean speed and direction. This means that when instances increase, the values of s_n and d_n are close to $\bar{s}$ and $\bar{d}$. $s_{x_{n-1}}$ and $d_{x_{n-1}}$ are determined from random Gaussian distribution. All other parameters are multiplied by tuning parameter α. Its range is $0 \le \alpha \le 1$ for adjusting randomness. Therefore, perfect randomness is obtained when $\alpha = 0$, whereas a linear model is obtained when $\alpha = 1$.

Ⅲ. Two Parameters of Neighborhood Changes and Mobility Factor

In MANETs, most routing protocols provide a mechanism to monitor neighbourhood changes (new or lost neighbours) by exchanging hello messages in fixed intervals. However, hello intervals that are too long cause a long delay of neighbour discovery and hello intervals that are too short cause unnecessary bandwidth overhead in the network. Thus, designing the hello interval properly according to node mobility is necessary. In this section, we investigate two parameters that affect neighbourhood changes: node speed and transmission range. Then, in order to incorporate two parameters, node speed and transmission range, we propose a mobility factor.

3.1 Node Speed

If the nodes in a network do not move, the neighbourhood of a node will not change. Because the movement of nodes affects neighbourhood changes, one crucial parameter is node speed. Fig. 2(a) and (b) show the neighbourhood changes of a node when the node moves at two speeds, V_1 and V_2 ($V_1 < V_2$), respectively. The transmission range of the node is assumed to be constant as R. The node

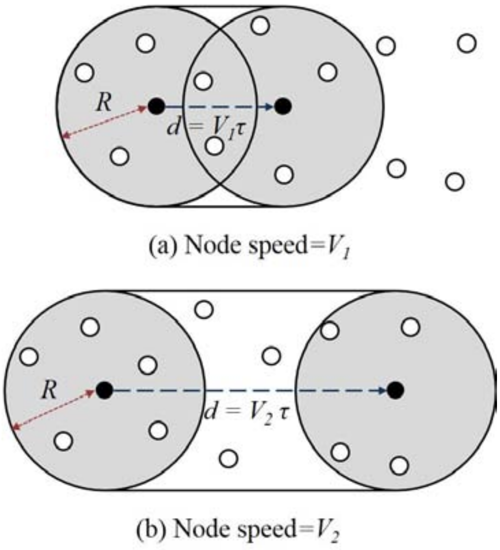


Fig. 2. Effect of node speed on neighborhood changes when V_1 < V_2.

at a higher speed travels a longer distance d during the same time τ. This means the more neighbours change during the same time. Thus, Fig. 2(b) at the node speed V_2 shows a greater number of neighbourhood changes than in Fig. 2(a) at the node speed V_1 during the period τ.

3.2 Transmission Range

Even though nodes move, if nodes are located within the transmission range of each other, the neighbourhood of a node does not change. Thus, another parameter that affects neighbourhood changes when nodes move is the transmission range of a node. Fig. 3(a) and (b) show the neighbourhood changes of a node when the node moves with two transmission ranges, R_1 and R_2 (R_1 < R_2), respectively. The node speed is assumed to be a constant V. In this example, Fig. 3(a) at the transmission range R_1 shows a greater number of neighbourhood changes than in Fig. 3(b) at the transmission range R_2 during the period τ.

3.3 Mobility Factor

In most previous studies, mobility is normally defined as node speed. For example, a node speed of 300 km/h indicates a high mobility and 30 km/h

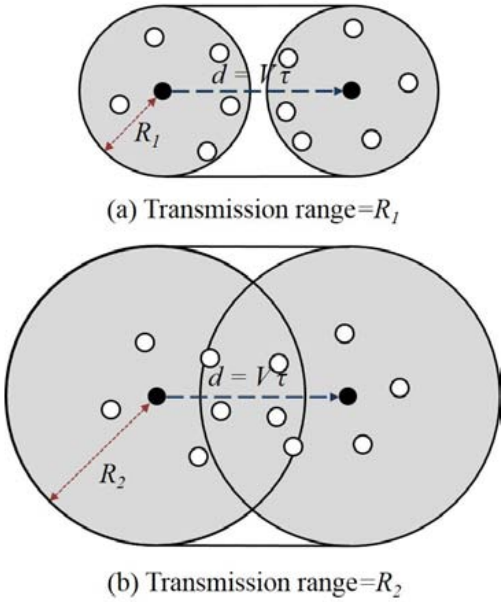


Fig. 3. Effect of transmission range on neighborhood changes when R_1 < R_2.

indicates a low mobility, regardless of their transmission range. As previously mentioned, both the node speed and transmission range affect neighbourhood changes when nodes move. When a node moves outside the transmission range of others, the link between them will break. Therefore, incorporating two parameters, node speed V and transmission range R, is necessary to define a mobility factor. Clearly, the time to link breaks depends on R over V. We define a new mobility factor μ as:

$$\mu = \frac{R(m)}{V(m/s)} \tag{1}$$

The mobility factor μ indicates the period (s) of a node to cross R (m) at the moving speed of V (m/s).

Ⅳ. Impact of Node Speed and Transmission Range on The Hello Interval

In this section, we investigate the impact of node speed and transmission range on the hello interval in network throughput by simulations. We evaluate the network throughput for different hello intervals by varying node speed and transmission range using the network simulator ns-3[19]. By analyzing the simulation results, we determine the relation between the hello intervals and mobility factor to maximize network throughput.

4.1 Simulation Environment

Our simulations were conducted on a network with 50 nodes, which were randomly positioned on a map. Based on transmission ranges, map sizes were made different, that is, 300x300 m^2, 450x450 m^2, and 600x600 m^2, by maintaining a transmission footprint at approximately 17%. The transmission footprint is the percentage of transmission range to the map. Each simulation is run for a period of 600 s. Ten pairs of nodes are selected randomly for source and destination nodes. Each source sends 4 packets/s at a constant bit rate to communicate with the destination. The packet size is 512 bytes; thus, the data rate is 16 kbps. All nodes move at a speed of 10 to 30 m/s and within a transmission range of 70 to 140 m. In addition, we assumed a wireless LAN interface of the IEEE 802.11b with a channel capacity of 1 Mbps. The simulation parameters are detailed in Table 1.

To investigate the effect of mobility patterns on a hello interval in network throughput, we used two types of mobility models for our simulation: random waypoint and Gauss-Markov. Fig. 4 shows an example of the trajectory of a mobile node, which has an average speed of 20 m/s during 600 seconds. Fig. 4(a) shows a moving pattern of a node using the random waypoint mobility model. The random waypoint mobility model is used typically for simulation in MANETs because it is very simple and assures randomness. Fig. 4(b) shows a moving pattern of a node using the Gauss-Markov mobility model. The Gauss-Markov mobility model can avoid travelling to an unexpected spot and making a sharp turn as characterized by the random waypoint mobility model. If we compare the trajectory of a mobile node for two mobility models, the node with the random waypoint mobility model moves in a wider range than the Gauss-Markov mobility model during the same period with the same average speed.

Table 1. Simulation parameters.

Parameters	Values
Map size	300x300 m^2, 450x450 m^2, 600x600 m^2
Simulation time	600 s
Number of nodes	50
Sources and destinations	10 pairs
Mobility model	Random waypoint, Gauss-Markov mobility models
Moving speed	10, 15, 20, 30 m/s
Transmission range	70, 105, 140 m
Transmission footprint	17%
PHY/MAC protocol	802.11b
Channel capacity	1 Mbps
Loss model	Friis propagation loss model
Traffic model	Constant bit rate model
Packet size	512 bytes
Source packet rate	4 packets/s

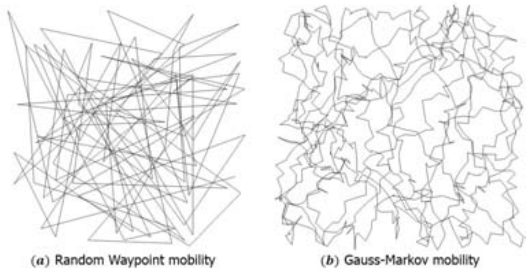


Fig. 4. Trajectory of a node when using the random waypoint and Gauss-Markov mobility models.

Parameters of each mobility model are presented in Table 2. In the random waypoint model, all nodes moved with a velocity of 10 to 30 m/s with no pause time. In the Gauss-Markov model, we set tuning parameter a to 0.75, which determines the randomness of mobility. Average velocity was set from 10 to 30 m/s, and average direction was randomly set from 0° to 360°.

Table 2. Parameters of mobility models.

Model	Parameter settings
Random Waypoint Mobility	Pause time = 0 s
	Velocity = 10, 15, 20, 30 m/s
Gauss-Markov Mobility	Degree of random (*a*) = 0.75
	Update period = 0.5 s
	Average velocity = 10, 15, 20, 30 m/s
	Average direction = 0° to 360° (random)

4.2 Impact of Node Speed

First, we investigated the impact of node speed on the hello interval with respect to network throughput. In all our graphs of simulation results, we indicate the 90% confidence interval. Fig. 5(a) and (b) show the network throughput according to the hello interval for different node speeds with the random waypoint and Gauss-Markov mobility models, respectively. In our simulations, all nodes were assumed to have the same transmission range of 140 m and an average speed of 10, 15, 20, or 30 m/s in the map size of 600x600 m^2. The graphs in Fig. 5 show that the total network throughput decreases as the node speed increases. For the same node speed, we also observed that the network throughput increased as the hello interval increased. However, after a certain value of the hello interval, it decreases. Therefore, an optimum value of the hello interval exists that maximizes the total network throughput. From these figures, we can observe that the optimum hello interval increases as the node speed decreases. By contrast, the optimum hello interval decreases as the node speed increases. This means that nodes moving at higher speeds require hello messages at shorter intervals. Similarly, nodes moving at slower speeds require hello messages at longer intervals in order to maximize the total network throughput. Also, these figures reveal that the Gauss-Markov mobility model yields a higher throughput with a longer optimum hello interval than does the random waypoint mobility model. This tendency is the result of the different characteristics of moving patterns with the two mobility models, which affect link change rate. The more neighborhood changes in the random waypoint mobility model than does in the Gauss-Markov mobility model during the same period with the same average speed.

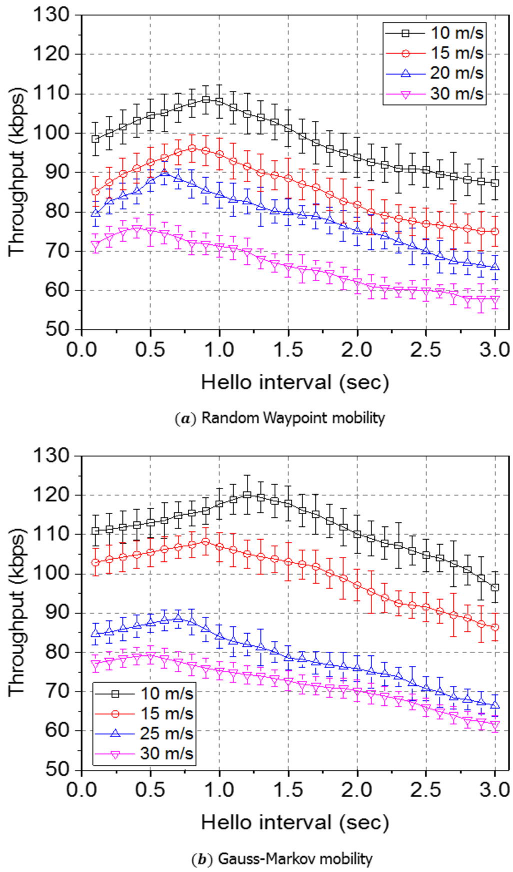
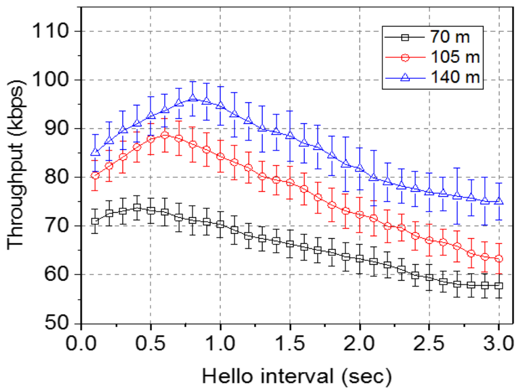


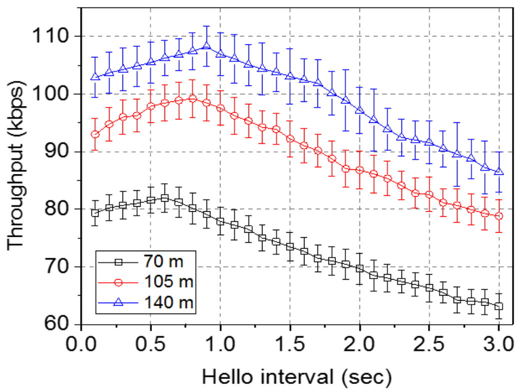
Fig. 5. Comparison of network throughput based on hello intervals for different node speeds.

4.3 Impact of Transmission Range

Second, we investigated the effect of the transmission range on the hello interval in terms of network throughput. In all our graphs of simulation results, we indicate the 90% confidence interval. Fig. 6(a) and (b) show the network throughput based on the hello interval for different transmission ranges with the random waypoint and Gauss-Markov mobility models, respectively. Simulations were conducted for transmission ranges of 70, 105, and 140 m with the same node speed of 15 m/s in the map size of 300x300 m^2, 450x450 m^2, and 600x600



(a) Random Waypoint mobility



(b) Gauss-Markov mobility

Fig. 6. Comparison of network throughput based on hello intervals for different transmission ranges.

m^2 for each transmission range. The graphs in Fig. 6 show that the total network throughput increased as the transmission range increased from 70 to 140 m. In addition, the optimum hello interval corresponding to the maximum throughput increased as the transmission range increased. This means that nodes with a longer transmission range must broadcast hello messages at a slower rate to increase the total network throughput and thus reduce the network overhead.

In Fig. 6, we compare the random waypoint and Gauss-Markov mobility models based on the total network throughput and optimum hello interval for the different transmission ranges. Due to the same reason as shown in Fig. 5, we note that the Gauss-Markov mobility model yields a higher throughput with a longer optimum hello interval than does the random waypoint mobility model.

4.4 Relationship of Mobility Factor to the Hello Interval

The aforementioned simulation results revealed that the optimum hello interval depends on two parameters: node speed and transmission range. For each graph in Fig 5 and 6, we first determined the optimum hello interval that maximizes the network throughput. We then determined the node-speed and transmission-range combination that corresponds to the optimum hello interval. We can represent this combination as the mobility factor defined in the (1). Fig. 7(a) and (b) show the relationship between the optimum hello interval and mobility factor μ with the random waypoint and Gauss-Markov mobility models, respectively. From Fig. 7, we observed that the optimum hello interval of the Gauss-Markov mobility model was longer than the random waypoint mobility model for the same mobility factor μ. These figures exhibit a high correlation between the optimum hello interval and mobility factor μ.

To fit the simulation results, we established a linear equation of the optimum hello interval, hello interval, and mobility factor μ as follows.

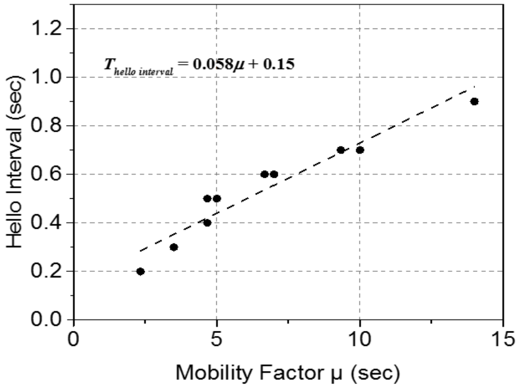
$$T_{hellointerval} = c_1\mu + c_2 \tag{2}$$

where c_1 and c_2 are constants. To determine the constants c_1 and c_2, we used 12 simulation points with combinations of four node speeds and three transmission ranges as follows.

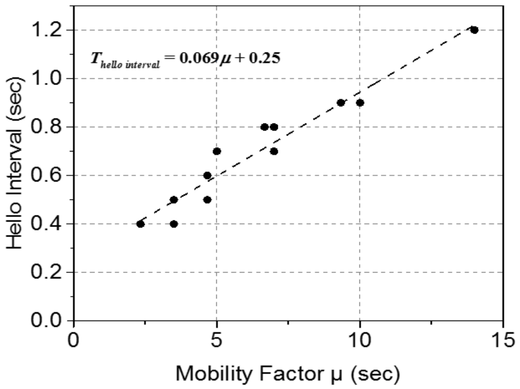
$$V(m/s) = \{10, 15, 20, 30\}$$
$$R(m) = \{70, 105, 140\}$$
$$\mu(=\frac{R}{V}) = \begin{Bmatrix} 2.33, 3.5, 4.67, 7, 3.5, 5, \\ 6.67, 10, 4.67, 7, 9.3, 14 \end{Bmatrix}$$

Using a linear regression analysis of the simulation results given in Fig. 7, we obtained a linear equation each for the random waypoint and Gauss-Markov mobility models as follows.

$$T_{hellointerval} = 0.058\mu + 0.15 \tag{3}$$



(*a*) Random Waypoint mobility



(*b*) Gauss-Markov mobility

Fig. 7. Relationship between the hello interval and mobility factor μ.

$$T_{hello\,interval} = 0.069\mu + 0.25 \tag{4}$$

Using (3) and (4), we can estimate the optimum hello interval according to the mobility factor.

V. Conclusion

In this paper, we investigated the impact of node speed and transmission range on hello intervals with respect to network throughput using two mobility models. Through simulations of a MANET using an AODV routing protocol, we showed that the hello interval to maximize the network throughput depends on node speed and transmission range. Specifically, with both random waypoint and Gauss-Markov mobility models, the optimum hello interval decreases as node speed increases, whereas it increases as transmission range increases. To incorporate node speed and transmission range, we defined a mobility factor μ as transmission range over node speed. Using the linear regression analysis of the simulation results, we showed that the optimum hello interval needed to maximize the network throughput could be expressed as a linear function of mobility factor μ. In future work, we will study a dynamic hello interval control algorithm using this relationship.

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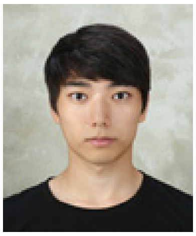

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