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Adaptive Hello Control Using Link Change Ratio in Mobile Ad Hoc Networks

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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 excessively long) or greater bandwidth wastage due to unnecessary protocol overhead (if hello intervals are overly short). In this study, we define a link change ratio based on the information of neighbour nodes and investigate the relationship between the link change ratio and the hello interval in terms of total throughput. The simulation results demonstrate that the link change ratio normally increases as the hello interval increases. However, hello intervals that maximize the network throughput exhibit a constant range of link change ratios, even though node mobility changes. Using this result, we propose an adaptive hello control scheme based on the link change ratio. Simulation results confirm that the proposed scheme can significantly enhance the total network throughput compared with existing adaptive schemes using a link change rate.

Key Words : MANETs, hello interval,, adaptive hello control,, link change ratio

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 because of movement, failure, or fading effects[1]. Further, because the moving speeds and directions of each node may be different, links between nodes can be broken frequently. Different transmission ranges of each node can also affect the link connectivity between neighbours; link connectivity affects network performance directly[2]. 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[3]. Although the implementation of a fixed hello interval for neighbour detection is simple, its routing performance in the dynamic environments of MANETs has been critically debated. The use of hello messages also contributes to overall network traffic and affects performance. As hello messages

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are broadcast locally by the nodes, they contend with data packets for bandwidth. They can also increase the probability of collisions with data packets or other control messages in the network. These factors, among others, lead to an overall reduction in network utilization and throughput, and increase the packet loss ratio[2,3].

Many previous studies have observed that routing performance is correlated to the link detection capabilities of the hello emission strategy [4,5]. With shorter hello intervals, new neighbours and link breaks are detected more quickly. However, hello intervals that are overly short cause unnecessary protocol overhead. This reduces network throughput and increases the energy consumption of the nodes. However, if a node sends hello messages less frequently, then congestion and resource waste will be alleviated; however, neighbour tables will be inaccurate and link detection delay will increase. Our previous study investigated the impact of node speed and transmission range on hello intervals in network throughput[6]. Through simulations in a MANET, we demonstrated that the hello interval to maximize the network throughput depends on node speed and transmission range.

Several adaptive algorithms have been proposed in previous studies to control the hello interval dynamically to achieve an effective trade-off between resource waste and link detection delay. The basic idea of these schemes is to adjust the hello interval based on a node's moving distance[7], speed[8,9], or the number of link changes[10-13] to decrease the route setup and maintenance overhead.

In this study, we first define link change ratio and investigate the impact of the link change ratio on hello intervals with respect to network throughput. Through simulations of a mobile ad hoc network using the ad hoc on-demand distance vector (AODV) routing protocol[14], we demonstrate that the hello intervals to maximize the network total throughput exhibit a constant range of link change ratios, even though node mobility changes. Using this result, we propose an adaptive hello control scheme based on the link change ratio. The proposed adaptive hello scheme focuses on maximizing the network throughput, even though the overhead is increased. Simulation results demonstrate that the proposed scheme can significantly enhance the total network throughput compared with existing adaptive schemes using a link change rate. The part of this study was presented at a conference[15].

The remainder of this paper is organized as follows. Section 2 outlines related works. In Section 3, we define link change ratio and investigate the impact of the link change ratio on hello intervals in network throughput. In Section 4, we propose an adaptive hello control scheme based on the link change ratio to enhance the total network throughput. Section 5 presents the conclusions of this study.

Ⅱ. Related Works

Links between nodes are disconnected frequently in MANETs because of independent node mobility. 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 do not change. Therefore, sending hello messages at a fixed rate only generates unnecessary overhead in the network. Conversely, if the nodes are moving quickly, sending hello messages at a fixed rate may not notify the links in a sufficiently timely fashion. When a node sends a packet to a neighbour, the neighbour node may no longer be in its transmission range, which results in packet drops. The node must then exchange additional messages to locate a means to route the pending packets. Several adaptive algorithms have been proposed in previous studies to control the hello interval dynamically. The basic idea of these schemes is to adjust the hello interval based on a node's moving distance[7], speed[8,9], or the number of link changes[10-13].

2.1 Schemes based on node moving distance

Giruka et al.[7] proposed an adaptive hello scheme where a node emits hello messages every time it moves a constant distance. 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 overly slow or overly fast emission rates of hello messages, minimum and maximum rates are defined as MIN-BEACON-INTERVAL and MAX-BEACON-INTERVAL.

2.2 Schemes based on node speed:

Jingwen et al.[8] proposed Adaptive Classified Hello Scheme (ACHS) for an improved hello message. ACHS divides nodes into two classes, nodes on the route and nodes off the route. Then, the speeds of the nodes in each class are compared to determine a 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 frequently it broadcasts messages. Conversely, the slower a node moves, the fewer control messages it sends.

2.3 Schemes based on the number of link changes

Many adaptive hello schemes have been proposed to control the emission rate of hello messages based on the number of link changes[10-13]. Ingelrest et al.[10] 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.

Huang et al.[11] proposed an algorithm based on the link change rate for low overhead. It determines the hello message sending rate by comparing the previous link change rate and current link change rate. The link change rate is first measured by monitoring the number of new 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 changes. 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 such that no unnecessary overhead is incurred. In highly dynamic networks, the value must be small to monitor changes in the network.

Hernandez-Cons et al.[12] proposed a dynamic hello/timeout timer based on the link change rate as the number of new and lost links per time elapsed since the last measurement. Specifically, the scheme uses the average link change rate over a time, which considers the previous average link change rate multiplied by a weighted value. There is a threshold of the link change rate that is a value used to decide to increase or decrease the hello interval. If the average link change rate is lower than the threshold, the hello interval is increased by multiplying by the increase coefficient for reducing overhead. If the average link change rate is higher than the threshold, the hello interval is decreased by multiplying by the decrease coefficient for fast link recovery. Thus, link change rate in the scheme is used for detection of the relative mobility with neighbours.

Ⅲ. Link Change Ratio vs Link Change Rate

Many adaptive hello schemes have been proposed to control the hello interval dynamically based on the number of link changes per period [10-13]. In these schemes, the link changes consider new or lost neighbours during a hello interval; however, they do not consider maintained neighbours. In this section, we define a link change ratio that reflects new, lost, and maintained neighbours.

3.1 Definition of Link Change Ratio

We define a link change ratio as follows.

$$Link\,Change\,Ratio = \frac{N_a + N_d}{N_m + N_a + N_d} \qquad (1)$$

where N_a is the number of added (or new) neighbours, N_d is the number of deleted (or lost) neighbours, and N_m is the number of maintained neighbours, which are measured by monitoring the neighbour table during a hello interval τ. These notations are defined in Table 1. The link change ratio is calculated for every τ period and has a value between zero and one. A value of zero indicates no neighbour changes (no mobility) and a value of one indicates no maintained neighbours (highest mobility) during τ.

Fig. 1 illustrates added, deleted, and maintained neighbours. N_a, N_d, and N_m can be calculated based on the updates to the neighbour table. In Fig. 1(a), there are five neighbour nodes around a node S within its transmission range at time T. Thus, the neighbour table of node S includes nodes C, D, F, G, and H. Fig. 1(b) displays the neighbourhood changes of node S at time $(T+\tau)$ due to node mobility. Node S updates its neighbour table continuously; hence, nodes C and H are deleted and nodes A, B, and E are added. Nodes D, F, and G are maintained in the neighbour table. In this example, because N_a = 3, N_d = 2, and N_m = 3, the link change ratio is calculated as 0.625.

Table 1. Simulation parameters.

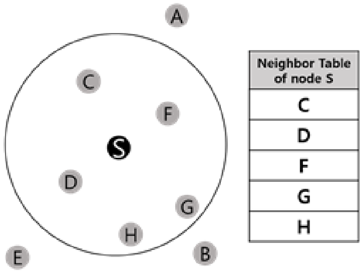
Variable	Definition
τ	Hello interval
N_a	Number of added neighbours during τ
N_d	Number of deleted neighbours during τ
N_m	Number of maintained neighbours during τ

3.2 Link Change Rate vs Link Change Ratio

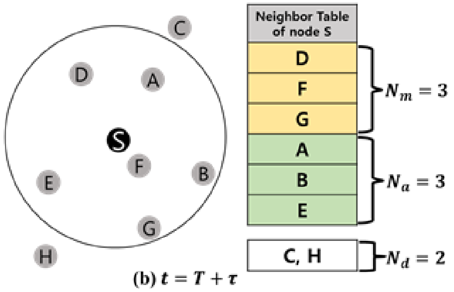
The link change rate used in many adaptive hello schemes considers the number of link changes per period as follows.

$$Link\ Change\ Rate = \frac{N_a + N_d}{\tau} \tag{2}$$

Figs. 2(a) and 2(b) describe the difference between link change rate and link change ratio for two different transmission ranges $R1$ and $R2$ $(R2 > R1)$. In Fig. 2(a), a mobile node with transmission range $R1$ moves a distance d during

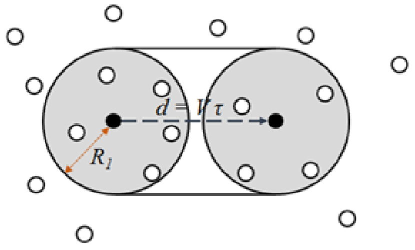


(a) $t = T$

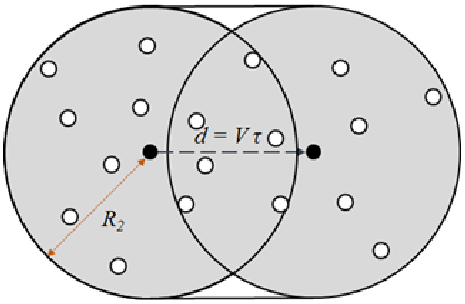


(b) $t = T + \tau$

Fig. 1. Illustration of added, deleted, and maintained neighbours.



(a) *Transmission range=R_1*



(b) *Transmission range=R_2 ($>R_1$)*

Fig. 2. Link change rate vs Link change ratio.

time τ with a velocity of Vm/s. In this example, during τ, the number of deleted neighbours is five and the number of added neighbours is four. Hence, the link change rate is calculated as $\frac{4+5}{\tau}=\frac{9}{\tau}$. However, in Fig. 2(b) for transmission range $R2$, during τ, the number of deleted neighbours is seven and the number of added neighbours is five. Thus, the link change rate is $\frac{5+7}{\tau}=\frac{12}{\tau}$, which is a higher value than the link change rate of the narrower transmission range $R1$.

In this case, the link change ratio exhibits a different tendency than the link change rate because it also considers maintained neighbours. In Fig. 2(a), there are no maintained neighbours; hence, the link change ratio is calculated as $\frac{4+5}{0+4+5}=1$. In Fig. 2(b), there are six maintained neighbours; hence, the link change ratio is $\frac{5+7}{6+5+7}=\frac{12}{18}$, which is less than the link change rate of the narrower transmission range $R1$.

Many adaptive hello schemes using the link change rate control the length of the hello interval by comparing the current and previous link change rates. Mobile nodes with a longer transmission range can have a higher link change rate than nodes with a shorter transmission range. Thus, there exists an inequality between mobile nodes with different transmission ranges.

Ⅳ. Relationship between Link Change Ratio and Hello Interval

In this section, we investigate the impact of the link change ratio on network throughput using simulations. Further, we investigate the relation between the link change ratio and the hello interval to maximize the total network throughput.

4.1 Simulation Environment

Our simulations were conducted on a network with 50 nodes initially positioned randomly on a map. Based on transmission ranges, the map sizes were different; that is, 300×300 m^2, 450×450 m^2, and 600×600 m^2, by maintaining a transmission footprint at approximately 17%. The transmission footprint is the ratio of transmission range to the map. Each simulation was executed for a period of 600 s. Ten pairs of nodes were selected randomly for source and destination nodes. Each source sent four packets/s at a constant bit rate to communicate with the destination. The packet size was 512 bytes; thus, the data rate was 16 kbps. All nodes moved at a speed of 5-30 m/s and within a transmission range of 70-140 m. We assumed a wireless LAN interface of the IEEE 802.11b with a channel capacity of 1 Mbps. We used AODV for the routing protocol[14] and ns-3.24 as a network simulator[16]. The simulation parameters are detailed in Table 2.

Network performance is affected by mobility models in MANET because links are disconnected or maintained according to node movement[17]. To investigate the effect of mobility patterns on the hello interval in network throughput, we used two types of mobility models for our simulation: random waypoint and Gauss-Markov[18].

Table 2. Simulation parameters.

Parameters	Values
Map size	300x300m2, 450x450 m2, 600x600 m2
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
Routing protocol	AODV

The random waypoint mobility model was designed to apply simply to any mobile networks [19]. 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[20] 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 moves unpredictably because it possesses a parameter to determine its randomness.

The parameters of each mobility model are presented in Table 3. In the random waypoint model, all nodes moved with a velocity of 5-30 m/s with no pause time. In the Gauss-Markov model, we set the tuning parameter σ to 0.5, which determines the randomness of mobility. The average velocity was set from 5-30 m/s and average direction was randomly set from 0-360°.

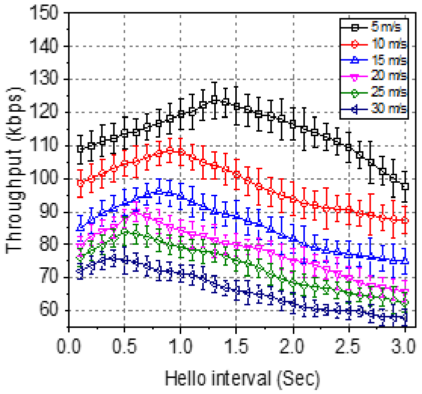
Table 3. Parameters of mobility models.

Model	Parameter settings
Random Waypoint Mobility	Pause time = 0 s
	Velocity = 5, 10, 15, 20, 25, 30 m/s
Gauss-Markov	Degree of random $(\sigma) = 0.5$
	Update period = 0.5 s
	Average velocity = 5, 10, 15, 20, 25, 30 m/s
	Average direction = 0-360° (random)

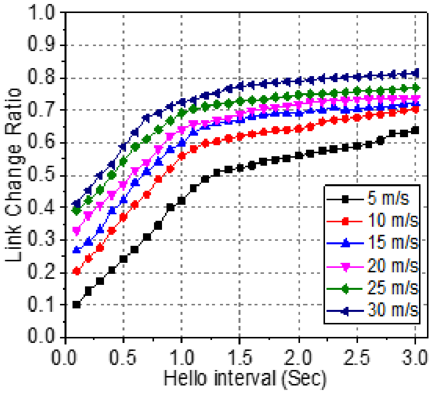
4.2 Simulation Results

In all our graphs of the simulation results for the network throughput, we indicate the 90% confidence interval. In Fig. 3, we investigate the impact of the hello interval on the network total throughput and link change ratio under the random waypoint mobility model.

Figs. 3(a) and 3(b) indicate the network throughput and link change ratio based on the hello interval for different node speeds, respectively. In this simulation, all nodes were assumed to have the same transmission range of 140 m and an average speed of 5, 10, 15, 20, 25, or 30 m/s. The graphs in Fig. 3(a) indicate that the total network throughput decreases as the node speed increases at the same hello interval. For the same node speed, we also observe that the network throughput increases as the hello interval increases. 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 graphs, we can observe that the optimum hello interval increases as the node speed decreases. Conversely, the optimum hello interval decreases as the node speed increases. This



(a) Throughput



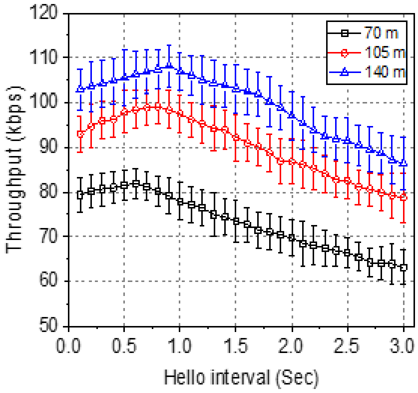
(b) Overhead

Fig. 3. Performances according to hello interval under random waypoint mobility with 140m tx-range.

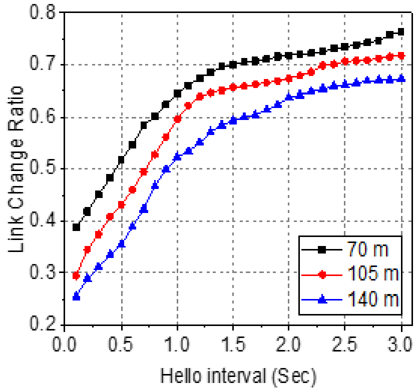
means that nodes moving at higher speeds require hello messages at shorter intervals. Similarly, nodes moving at slower speeds require hello messages at longer intervals to maximize the total network throughput.

The graphs in Fig. 3(b) indicate that the link change ratio increases as the hello interval increases. Further, we can observe that the link change ratio increases as the node speed increases at the same hello interval. This is natural because the number of added or deleted neighbours is increased and the number of maintained neighbours is decreased as the hello interval increases or the node speed increases when the transmission range of nodes is fixed.

In Fig. 4, we investigate the impact of hello interval on the network total throughput and link change ratio under the Gauss-Markov mobility model.



(a) Throughput

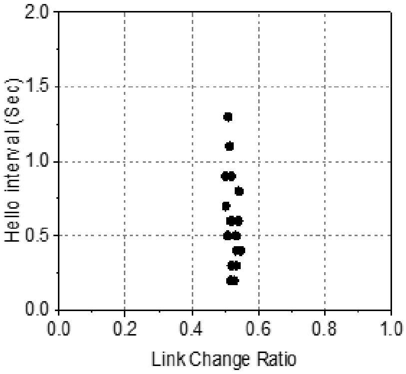


(b) Overhead

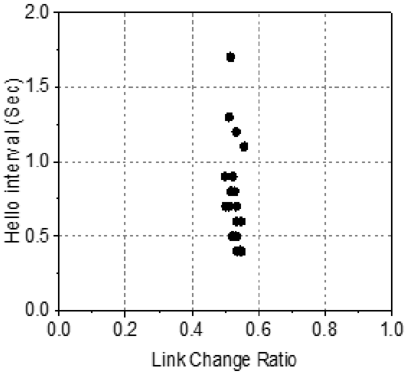
Fig. 4. Performances according to hello interval under Gauss-Markov mobility with 15m/s speed.

Figs. 4(a) and 4(b) display the network throughput and link change ratio based on the hello interval for different transmission ranges, respectively. Simulations were conducted for transmission ranges of 70, 105, and 140 m with the same node speed of 15 m/s. The graphs in Fig. 4(a) indicate that the total network throughput increases as the transmission range increases from 70-140 m. Further, the optimum hello interval corresponding to the maximum throughput increases as the transmission range increases. This means that nodes with a longer transmission range can broadcast hello messages at a slower rate to increase the total network throughput and thus reduce the network overhead. The graphs in Fig. 4(b) indicate that the link change ratio decreases as the transmission range increases at the same hello interval. This is because the number of maintained neighbours is increased as the transmission range increases when the node speed is fixed as illustrated in Section III.

We investigated the relationship of hello interval and link change ratio at the maximum throughput points under the random waypoint mobility and Gauss-Markov mobility models. From the graphs in Fig. 3(a), we can determine the values of the hello interval that maximize the network throughput for each node speed. Then, from the graphs in Fig. 3(b), we can determine the corresponding values of the link change ratio at the optimum hello intervals. Similar to this approach, in Figs. 5(a) and 5(b), we have plotted 18 points for the link change ratio and hello interval in the x-y plane for node speeds of 5, 10, 15, 20, 25, and 30 m/s at transmission ranges of 70, 105, and 140 m, under the random waypoint mobility and Gauss-Markov mobility models, respectively. From these figures, we observe that most points of the link change ratio are clustered in the range of 0.5-0.55, even though the optimum hello interval has different values based on the node speed, the transmission range, and the mobility models. From this result, we conclude that network throughput can be maximized if the link change ratio can be controlled in the range of 0.5-0.55 under the proposed scenario.



(a) Random waypoint mobility model



(b) Gauss-markov mobility model

Fig. 5. Link change ratio vs optimum hello interval.

V. Adaptive Hello Control Scheme

In this section, we propose an adaptive hello control scheme in order to maximize the network total throughput based on the link change ratio (LCR).

Basically, our adaptive hello control scheme adjusts the hello interval dynamically in order that the LCR could be maintained within a certain range to maximize the network throughput. To control the hello interval, we adopt the MIMD (Multiplicative Increase Multiplicative Decrease), because the MIMD is more capable to increase or decrease the hello interval rapidly for dynamically changing networks than other additive schemes[11].

Table 4 presents the definition of the parameters used in the proposed adaptive hello control scheme. We define τ as a hello interval that is dynamically adjusted by the algorithm. The algorithm is executed every τ period. To adjust the hello interval by measuring the link change ratio, we define two thresholds, $Thr_{\min}$ and $Thr_{\max}$, which indicate the minimum and maximum values of the threshold range. Also, $\alpha\,(\alpha>1)$ and $\beta\,(0<\beta<1)$ are defined as constants to increase or decrease the hello interval.

The flow chart of the proposed adaptive hello control algorithm based on the link change ratio is displayed in Fig. 6. Each node maintains a hello timer, which is set to its current hello interval τ. Whenever a node receives a hello message from neighbours, the node updates its neighbour table. The neighbour table maintains the list of its current neighbour nodes. When the hello timer expires, the node broadcasts a hello message for neighbour discovery and calculates the number of added neighbours, N_a, the number of deleted neighbours, N_d, and the number of maintained neighbours, N_m, using its neighbour table. Then, it calculates the link change ratio using (1). The node verifies if the current link change ratio value is within the threshold range, $Thr_{\min}$ and $Thr_{\max}$. If the link

Table 4. Definition of parameters in proposed algorithm.

Parameter	Definition
$Thr_{\min}$	Minimum threshold of link change ratio
$Thr_{\max}$	Maximum threshold of link change ratio
α	Increase coefficient $(\alpha>1)$
β	Decrease coefficient $(0<\beta<1)$

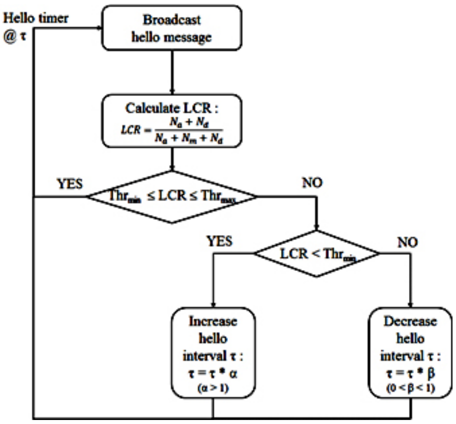


Fig. 6. Hello interval control algorithm.

change ratio value is within the threshold range, the next hello interval τ is maintained without change. If the link change ratio value is less than $Thr_{\min}$, the next hello interval τ is increased by multiplying by a constant $\alpha\,(>1)$ to increase the link change ratio; the link change ratio will be increased if the hello interval is increased. If the link change ratio value is greater than $Thr_{\max}$, the next hello interval τ is decreased by multiplying by a constant $\beta\,(0<\beta<1)$ to decrease the link change ratio. That is, the hello interval τ is adjusted dynamically based on the measured link change ratio value. Then, the node sets its hello timer to the next hello interval τ.

In this scheme, each neighbour node may have a different value of hello interval. In order to implement the proposed adaptive hello scheme in the original AODV, we add a field to notify sender's hello interval in the hello message. Also, in the neighbour table, one entry of hello interval is added for each neighbor. Whenever a node receives a hello message from its neighbor, it updates the hello interval for the corresponding node in the neighbor table. Thus, a node can detect a link disconnection for each neighbour using the corresponding hello interval.

Ⅵ. Performance Evaluation

In this section, we compare the performance of the proposed scheme in terms of the network throughput and the protocol overhead with the existing adaptive schemes, in which the hello intervals are dynamically adjusted using the link change rate[10,11].

6.1 Simulation Environments

Our simulations were conducted with the same environment as in Section IV. The values of the two thresholds, $Thr_{\min}$ and $Thr_{\max}$, to adjust the hello interval by measuring the link change ratio, were assumed to be 0.5 and 0.55, respectively, which were obtained from the simulation results to maximize the network throughput in Section IV.

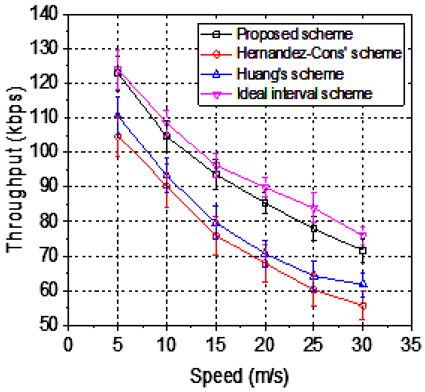
Table 5. Values of parameters used in simulations.

Parameter	Value
$Thr_{\min}$	0.5
$Thr_{\max}$	0.55
α	1.3
β	0.7

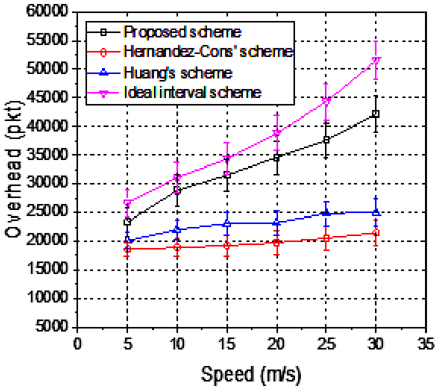
Further, the two constants α and β, used to increase or decrease the hello interval dynamically, were assumed to be 1.3 and 0.7 through simulations. The simulation parameters are detailed in Tables 2, 3, and 5.

6.2 Simulation Results

We compared the proposed adaptive hello control scheme to two existing schemes and an ideal interval in terms of the network throughput and protocol overhead according to node speed and



(a) Throughput



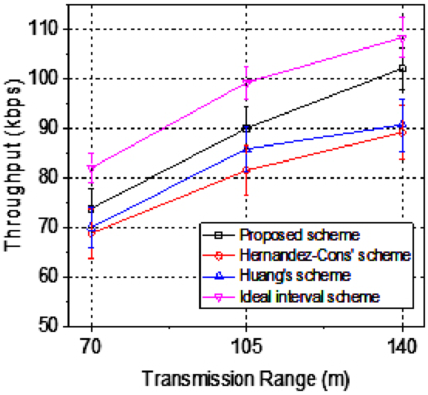
(b) Overhead

Fig. 7. Performance comparison according to node speed under the random waypoint mobility with 140m tx-range.

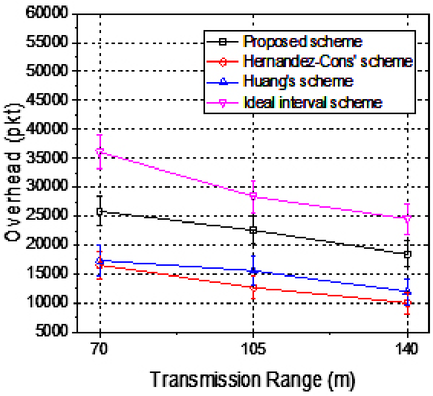
transmission range. For the two existing schemes, we considered Huang's scheme[11] and Hernandez-Cons' scheme[12], which are both adaptive hello schemes based on the link change rate. Ideal interval indicates a scheme with a hello interval that maximizes the network throughput and was determined using the throughput-hello interval curves in Figs. 4-7. Protocol overhead includes control messages such as hello message for neighbor discovery, route request/route reply for route recovery, and route error for route maintenance. In our simulation, we considered the random waypoint mobility and Gauss-Markov mobility models. In all our graphs of the simulation results, we indicate the 90% confidence interval.

We compare the network throughput and protocol overhead under the random waypoint mobility model in Fig. 7. In Fig. 7, the node speed varied from 5-30 m/s when the transmission range was fixed at 140 m. From Fig. 7(a), we observe that the network throughput in all schemes decreases as the node speed increases. The ideal interval indicates the highest throughput compared with the other schemes. The proposed scheme had the second highest throughput, marginally less than the ideal interval scheme; however, it demonstrated greater than 10% improvement in throughput compared with both Huang's scheme and Hernandez-Cons' scheme. From Fig. 7(b), we can observe that the protocol overhead in all schemes increases as the node speed increases. In terms of the protocol overhead, Hernandez-Cons' scheme demonstrated the lowest overhead; Huang's scheme had the second lowest. The ideal interval scheme indicates the highest overhead. The hello interval dynamically controlled by Hernandez-Cons' scheme and Huang's scheme was significantly greater than the ideal interval; hence, the overhead due to hello messages was significantly reduced compared to the ideal interval scheme. Thus, Hernandez-Cons' scheme and Huang's scheme can reduce the overhead due to hello messages; however, the proposed scheme outperformed these two existing schemes in terms of throughput.

In Fig. 8, we varied the transmission range from 70-140 m when the node speed was fixed at 15 m/s under the Gauss-Markov mobility model. From Fig. 8(a), we can observe that the network throughput in all schemes increases as the transmission range increases. In terms of the network throughput, the four schemes indicate similar tendencies in Fig. 7(a). The ideal interval demonstrates the highest throughput compared with the other three schemes. The proposed scheme had the second highest throughput and produced a greater than 10% improvement in the throughput compared to Huang's scheme and Hernandez-Cons' scheme. From Fig. 8(b), we can observe that the protocol overhead in all schemes decreases as the transmission range increases. In terms of the protocol overhead, the four schemes demonstrated similar tendencies in Fig. 7(b). The Hernandez-Cons' scheme had the lowest overhead; the Huang's scheme had the second



(a) Throughput



(b) Overhead

Fig. 8. Performance comparison according to node speed under the Gauss-markov mobility with 15m/s speed.

lowest overhead. The ideal interval scheme indicated the highest overhead. This can be explained using the same reason as in Fig. 7(b).

From the results under the random waypoint mobility and Gauss-Markov mobility models, we can observe that the proposed adaptive hello scheme based on the link change ratio can improve network throughput by greater than 10% compared with Huang's scheme and Hernandez-Cons' scheme. Even though Hernandez-Cons' scheme and Huang's scheme can reduce the overhead due to hello messages, the objective of the proposed scheme is to enhance the network throughput.

Ⅶ. Conclusion

In this study, we defined a link change ratio based on the information of neighbour nodes and investigated the relationship between the link change ratio and hello interval in terms of total throughput. The simulation results demonstrated that the link change ratio normally increased as the hello interval increased. However, the hello intervals that maximize throughput exhibited a constant range of link change ratios, even though node speed, transmission range, and node mobility model changed. Using this result, we proposed an adaptive hello control scheme where the link change ratio could be controlled within the proper range by adjusting the hello interval dynamically. Simulation results confirmed that the proposed scheme could enhance the total network throughput by greater than 10% compared with Hernandez-Cons' scheme and Huang's scheme, which are adaptive hello schemes using the link change rate.

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