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A^{2}OMDV : AN ADAPTIVE AD HOC ON-DEMAND MULTIPATH DISTANCE VECTOR ROUTING PROTOCOL USING DYNAMIC ROUTE SWITCHING

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Abstract

Based on the reactive routing protocol, the AOMDV protocol extends the AODV protocol to discover multiple paths. However, the AOMDV based on static route selection can not handle the dynamic change of the network such as congestion and contention. In this paper, we propose A^{2}OMDV to resolve the problem through dynamic route switching method. Based on the delay of the multiple paths, a source node selects its route dynamically and checks the quality of the alternative routes according to the change of the ad hoc network. The results from our analysis and simulation show performance enhancements of the proposed scheme with respect to end-to-end delay and throughput.

Keywords: hoc networks, AOMDV, Multipath routing

1. Introduction

Ad hoc networks are composed of wireless mobile nodes without any centralized management. Since each node has to find routes to its destinations through collaboration with other nodes, routing protocols play an important role in ad hoc networks. In addition, due to the constraints of ad hoc networks such dynamic topology and limited battery life, efficiency is a significant factor in the routing protocol.

The routing protocols in ad hoc networks are classified into two approaches: *proactive routing protocol* and *reactive routing protocol* [1]. In the proactive routing protocol, which is also called *table-driven approach*, each node maintains routing information to every other node in the same network. The information is

Nomenclatures

C_i	Priority of R_i
D	Destination node
P_i	Penalty that occurs at switching of routes
Q_i	i-th queue of the numerical model
R_i	i-th route of the node
T_i	RTT of R_i
S	Source node
W_i	Expected waiting time in Q_i
Z	Average of T_i for all routes
Greek Symbols	
α_i	Throughput that can be expected by a packet in Q_i
β	Total average throughput of A^2OMDV during a period T
λ_i	Arrival rate of Q_i
μ_i	Service rate of Q_i
Subscripts	
o	initial condition
i	Random condition
Abbreviations	
AODV	Ad hoc On-demand Distance Vector
AOMDV	Ad hoc On-demand Multipath Distance Vector
A^2OMDV	Adaptive Ad hoc On-demand Multipath Distance Vector
DSDV	Destination Sequenced Distance Vector Routing
DSR	Dynamic Source Routing
MANET	Mobile Ad hoc Network
NS-2	Network Simulator 2
RERR	Route Error
RREP	Route Response
RREQ	Route Request
RTT	Round Trip Time
TCP	Transmission Control Protocol

generally kept in a routing table, which are updated at every change of the network topology. Since no additional route discovery process is required, the proactive routing protocol has rapid session initiations. To maintain the routing table, however, periodical exchanges of topology information among nodes produce huge routing overhead. Otherwise, in the reactive routing protocol, each node does not need to maintain the routing table. When a source node has data to send, it initiates the route discovery procedure and maintains its routes only. Hence, in spite of the delayed session initiation resulted from the route discovery, the reactive routing protocol minimizes the routing overhead and it is also called *on-demand approach*.

The AODV [2] protocol based on the reactive routing discovery uses three different kinds of messages: Route request (RREQ), Route Reply (RREP) and Route Error (RERR). In addition, destination sequence numbers are used to ensure loop freedom at all times. In AODV, each source node finds a new route by the limited flooding of RREQ with the ring expansion and obtains a route to its destination through RREP. The AOMDV [3] protocol expands AODV to a multipath routing protocol, in which the source node keeps several different routes from multiple RREPs. The static route selection of AOMDV, however, can not handle the dynamic change of the network such as severe congestion caused by biased traffic.

In this paper, we address the problem of the AOMDV routing protocol and propose an adaptive approach for AOMDV, called **A^2OMDV**, through dynamic route switching. In the proposed scheme, a source node maintains a group of multiple disjoint paths to its destination and keeps monitoring the quality of the routes. If the performance of the selected route drops below a certain threshold, the source node picks another route from the group of the candidate routes considering their round trip time (RTT).

The rest of this paper is organized as follows. In Section 2, we briefly review the previous ad hoc routing protocols with regard to the multipath routing. In Section 3, we introduce the AOMDV routing protocol and address the problem of AOMDV. The proposed scheme, A^2OMDV, is presented in Section 4. To show the effectiveness of the proposed scheme, we analyze and evaluate the performance of our scheme with respect to throughput and delay in Sections 5 and 6. This paper is concluded in Section 7.

2. Related Work

Recently, many multipath routing protocols are researched in the ad hoc network to improve the network performance. When unexpected events such as congestion and unreachable nodes occurs from the dynamic characteristics of the ad hoc network, the multipath routing protocol keeps the connectivity to its destination by selecting an alternative route that detours the problems. Hence, the selection process determines the performance of the multipath routing protocol.

Li and Cuthbert [4] proposed a node-disjoint multipath routing protocol. They modified and extended AODV to discover multiple node-disjoint routing paths with the low routing overhead. When a RREQ is generated or forwarded by the node, each node appends its own address to the RREQ. Each node checks the information of route from the RREQ and records the shortest route in the reverse routing table. When the destination node receives the RREQ, it compares every node in the whole route record of the RREQ with all the existing node-disjoint paths in its routing table. If the new route satisfies the node-disjoint requirement, then the route is recorded in the routing table. Hence, the multiple Node-disjoint paths are obtained with reduced routing overhead.

Most of the proposed routing protocols [5] for the MANET (Mobile Ad hoc Network) do not take fairness into consideration. They cause a heavy load on the hosts along the primary route between a source and a destination. As a result, heavily loaded hosts may exhaust power energy quickly, which will lead to network partitions and failure of sessions. Additionally, due to the interference of the radio transmission in MANET, the advantage of the multipath routing is not obvious. Wu and Harms [6] proposed an on-demand method with low control overhead to efficiently search for multiple node-disjoint paths and presented the criteria for selecting the multiple paths. They used a heuristic method to redirect RREP messages through multiple paths. Their route selection criteria in MANETs include three properties: node disjointedness, length difference between the primary route and the alternative routes, and correlation factor between any two of the multiple paths.

There are two types routing protocol for wireless network. First, proactive type is operating routing path before sending data. If it changes topology of nodes, this information sends neighbor nodes. And neighbor nodes updated it. The well-known proactive routing protocol is DSDV.

Second, reactive type is setting routing table on demand, and it maintains active routes only. The well-known reactive routing protocols are DSR and AODV.

Wireless Network makes frequent movement. So it needs supporting movement of reactive routing protocol. In this section, we study well-known reactive routing protocol.

3. Problems and Motivation

3.1. Overview of AOMDV

Figure 1 shows an example of the MANET. In AOMDV, the route discovery procedure is initiated by RREQ when source nodes have some data for sending to the specific destination. In Fig. 1, the source node *S* broadcasts RREQ

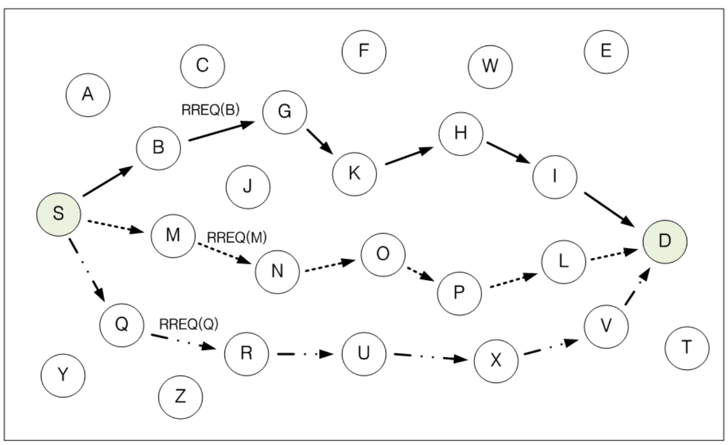

Fig. 1. Route Discovery Procedure in AOMDV.

messages for the destination node *D* and then waits for RREP. When the nodes *B*, *M*, and *Q* receive the RREQ, they mark it in the last hop field to distinguish multiple paths. For example, the RREQ passed through the node *B* is marked as RREQ(*B*). In addition, each RREQ message has its own sequence number and each node maintains the highest sequence number for a destination among received RREQ messages to prevent loops. When receiving a RREQ message, the intermediate nodes compare the destination sequence number between RREQ with their routing table and then floods the RREQ to others. Finally, if the RREQ reaches its destination, the destination node generates a RREP and sends it back along the reverse route. In order to form multiple paths, it generates RREP messages for every RREQ comes through disjoint path.

In AOMDV, the route recovery process is required in two cases as follows. First, when a link is broken due to the change of the network topology, intermediate nodes inform the route unreachability by sending a RERR message to the source node. Second, each node has a timeout field in its routing table in AOMDV. That is, AOMDV uses soft-state routes. Each node checks its routing table periodically and it rediscover a route when the route is expired. The value of the timeout is in relation of trade-off. Too small timeout causes unnecessary route discovery processes and too large timeout causes obsolete routes. Additionally, each node sends hello messages periodically in order to check the validity of the route.

3.2. Problem of AOMDV

1) *Congestion and Contention*: The MANET consists of various nodes in capacity. Since the route discovery selects the route has the least delay as the primary route, the nodes of high performance are easier to be included as a member of routes. For example, in Fig. 1, we assume that the node *G* has high capacity than others in the network. Thus, since RREQ(B) passes the route including the node *G*, RREQ(B) reaches to the node *D* at first and then the route of the node *G* is selected as a member of the primary route between *S* and *D*.

   However, as the number of primary routes that includes the node *G* increases, the node *G* can be bottleneck of the routes because traffic loads are focused on it. Figure 2 shows the case that three routes, (*S*, *D*), (*C*, *U*) and (*F*, *Z*), are intersected at the node *G*. In addition, due to the characteristics of wireless communications, the more active nodes are within the communication range, the more severe contention is caused. Thus, it also degrades the performance of the bottleneck node.

2) *Limitation of static route switching*: Multiple paths have various performances in terms of response time and bandwidth. The best of them is selected as the primary route and the others are used as alternative routes. In AOMDV, when the primary route is broken, the source node selects one of the alternative routes in order to prevent additional route discovery process. However, it has the following problems. First, since the route switching in AOMDV occurs only in case of a route error, it can not adapt to the dynamic change of the MANET. The network condition of the MANET changes frequently and routes that have better performance than the primary route can be available any time. However, the static route switching can not obtain the benefit of the change. In addition, since the route switching is performed without information on current status of alternative, the performance of the alternative route can not be guaranteed. Second, there is no method to prioritize the alternative routes. Since AOMDV has no field in the routing table suitable for managing information on the routes, the selection of the alternative routes performed without comparison of performance.

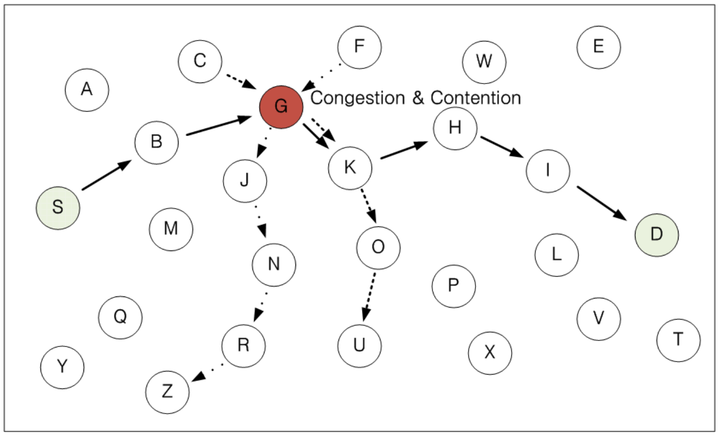

Fig. 2. Congestion due to Intersected Routes.

4. A^{2}OMDV Routing Protocol

In order to resolve the problems described in Section 3.2, we propose an Adaptive AOMDV, A^{2}OMDV, routing protocol, which supports dynamic route switching.

4.1. Route selection

In A^{2}OMDV, each source node prioritizes its routes obtained from the route discovery procedure and transmits data through the route of the highest priority at that time. The priority of a route is determined based on the RTT of the route and it is periodically recalculated in order to find the optimal route in the dynamic change of the network condition. We define the route of the highest priority as *primary route* and the other routes as *alternative routes*.

When a source node has N multiple paths to its destination, let R_i be the i-th route of the node and T_i the RTT of R_i. Additionally, we use Z to denote the average of T_i for all routes: $Z = \sum_i^N T_i / N$. Then, we define C_i as the priority of R_i and

$$C_i = \frac{Z - T_i}{Z} P_i \qquad (1)$$

where P_i is a penalty that occurs at switching of routes such as the performance degradation of TCP caused by fluctuation of RTT. Since C_i is a normalized form of RTT among the routes, P_i is represented the performance degradation in portion. Among the routes, we select the primary route R as the route of the highest priority. That is,

$$\arg\left(\max_{iC_i}\right) \qquad (2)$$

where $i = 1, \dots, N$. Furthermore, in order to avoid the unwilling overhead caused by the frequent route switching, we set $P_k = 0$ of the primary route.

4.2. Maintaining the status of routes

For the dynamic priority measurement, each source node has to maintain RTT of its routes. The RTT values are initialized as the end-to-end delay between RREQ and RREP at the route discovery procedure and updated periodically. In the RTT measurement for a route, the source node sends a probe packet to its destination through the route at every probing interval. Each measured RTT is stored in the entry corresponding to the route of the routing table.

Although many candidates for the probe packet are available, we consider an ICMP packet is suitable. Since the source node can verify the availability of its routes, the timeout field used in AOMDV is no longer needed in A^2OMDV. For the RTT measurement for the primary route, we apply a cross-layer approach. If the active session between the source node and the destination uses TCP, then the source node can obtain the estimated RTT from its TCP without generating any probe packet. Hence, it reduces unnecessary control overheads in A^2OMDV.

5. Numerical Analysis

In this section, we analyze A^2OMDV through numerical modeling. When we assume that a source node has N disjoint route to the destination, we can model each route as a queue Q_i, which has a service rate μ_i and two arrival rates, λ and λ'_i. The arrival rate λ represents the traffic from the source node and λ'_i is for the traffic load on the route R_i. Since a route consists of a number of nodes, the buffer capacity of each route is the sum of buffers in all nodes. Hence, we use the $M/M/1$ queue model under the assumption that each queue has an enough buffer for traffic. Figure 3 shows the queue model used in our analysis.

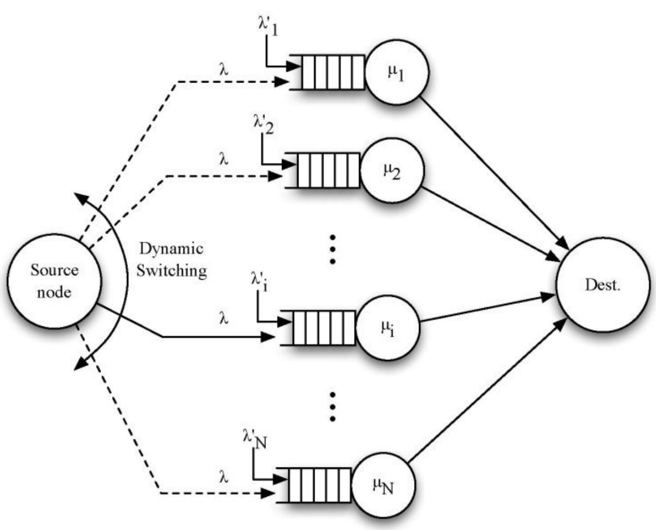

Fig. 3. Queue Model for A^2OMDV.

In A^2OMDV, the primary route is selected as a route that has the smallest RTT using the dynamic route switching. Hence, A^2OMDV should be modeled as a time variant system, in which λ and λ'_i are the function of time. That is, $\lambda(t)$ and $\lambda'_i(t)$ are used instead of λ and λ'_i. From this model, the total expected waiting time W_i in Q_i is

$$W_i(t) = \frac{1}{\mu_i - \left(\lambda(t) + \lambda'_i(t)\right)} \quad (3)$$

Let $\alpha_i(t)$ be the throughput that can be expected by a packet in Q_i and

$$\alpha_i(t) = \frac{MTU}{W_i(t)} = MTU\left(\mu_i - \lambda(t) - \lambda'_i(t)\right) \quad , \quad (4)$$

where MTU is the size of the maximum transfer unit. Let $W'_i(t)$ be $1/\{\mu_i - \lambda'_i(t)\}$. Then, we can define the throughput of A^2OMDV as a time variant function $\alpha(t)$:

$$\alpha_i(t) = \frac{MTU}{W(t)}, \text{ where } W(t) = W_k(t), \quad k = \arg\left(\min_{i\, W'_i(t)}\right)$$

Now, we can obtain β the total average throughput of A^2OMDV during a period T as follows:

$$\beta = \frac{1}{T}\int_0^T \alpha(t)\,dt \quad (5)$$

For example, when a source node has two routes, R_1 and R_2, and the best route is flipped between them at time T_1 and T_2,

$$\beta = \frac{1}{T}\left\{\int_0^{T_1} \frac{MTU}{W_1(t)}dt + \int_{T_1}^{T_2} \frac{MTU}{W_2(t)}dt + \int_{T_2}^{1} \frac{MTU}{W_1(t)}dt\right\}$$

With the varied network load, λ'_i, Fig. 4 depicts throughput improvement, $\beta/\alpha(t)$, when two routes, R_1 and R_2, have $\mu_1 = 10.0$, $\mu_2 = 8.0$ and $MTU = 1400$ bytes. In the model of Fig. 4, β and $\alpha_1(t)$ represent the throughput of A^2OMDV and AOMDV, respectively, because only R_1 is used in AOMDV. We can observe that A^2OMDV has little advantage in throughput when the network load is low because the performance of the primary route is enough to handle the load. That is, the benefit of A^2OMDV increases as the network load is heavy and as total traffic $(\lambda + \lambda'_i)$ is large.

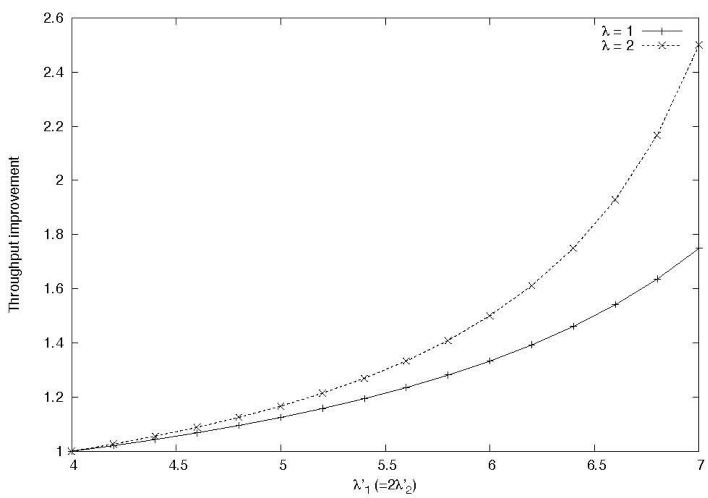

Fig. 4. Throughput Improvement of A^2OMDV.

6. Performance Evaluation

6.1. Simulation environment

Comparing to AOMDV, we evaluate A^2OMDV through ns-2 [7] simulation. In our simulation, we use an AOMDV model based on its recent protocol specification of [3].

Figure 5 shows the network configuration in the simulation, which consists of three routes with different bandwidth. The primary route in Fig. 5 has the highest bandwidth than others. In order to simulate various network conditions, we add traffic generators at the node 14, 15, and 16. The three nodes generate packets according to a given network load in order to cause congestion in the routes.

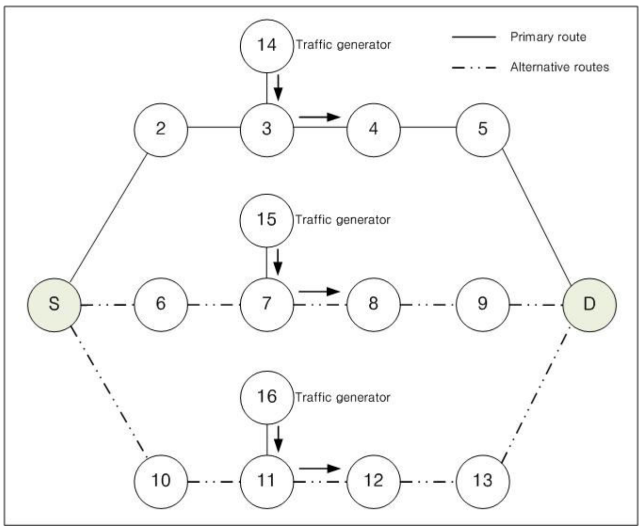

Fig. 5. Network Configuration in the Simulation.

6.2. Performance metrics

We consider the following metrics in our evaluation:

1) Throughput: The amount of data packets received at the destination for a second.
2) End-to-end delay: The average delay of data packets from a source to a destination.
3) Resilience to the dynamic of network: In the MANET, since the condition of wireless networks can be easily changed, the performance of routing protocols should be investigated with various packet loss rates and network loads.

6.3. Simulation, results and discussions

Figure 6 shows the throughput of AOMDV and A^2OMDV when the primary route suffers congestion by injected traffic that started at 50.0 s. The throughput of AOMDV drops under 100 kbytes/s due to the congestion. However, in

A^2OMDV, the source node senses the degradation of the primary route and switches to one of the alternative route. Though the selected route has lower throughput than the primary route, A^2OMDV can obtain the benefit of the switching in the condition of congestion. In addition, Fig. 7 depicts the end-to-end delay between the source and the destination. Likewise to the result of Fig. 6, A^2OMDV has about 20% improvement in the end-to-end delay because it can avoid the congested nodes.

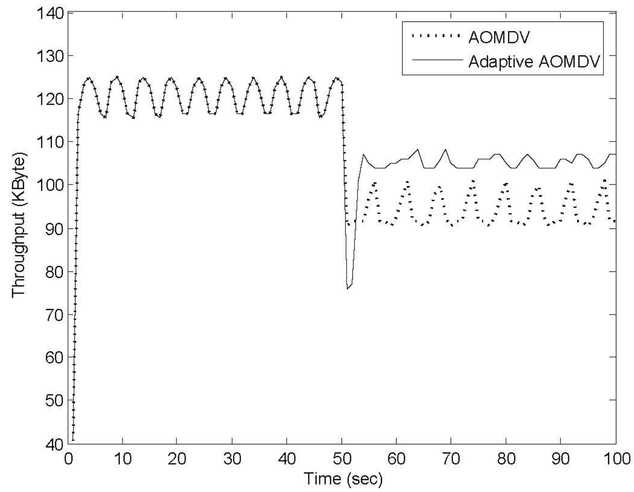

Fig. 6. Throughput in AOMDV and A^2OMDV.

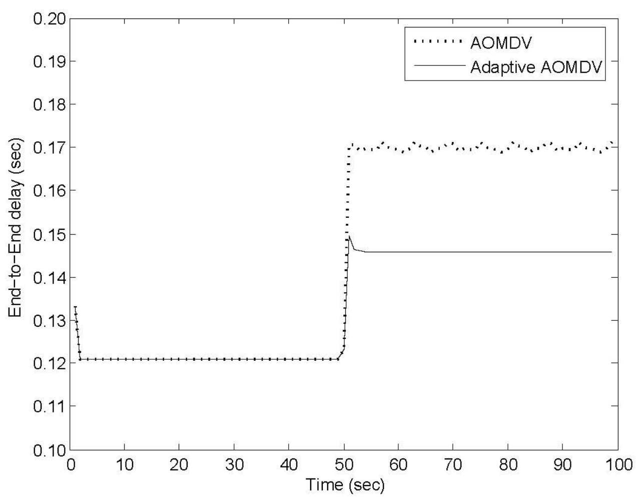

Fig. 7. End-to-End Delay in AOMDV and A^2OMDV.

Considering the characteristics of the wireless channel in the MANET, we evaluate the throughput of the proposed scheme with various packet loss rates. Figure 8 shows the decrease of the throughput when the packet loss rate is within the range of 0 and 0.03. Although the improvement of

A^2OMDV decreases as the packet loss rate increases, A^2OMDV keeps higher throughput than AOMDV regardless of the lossy channel. Therefore, it can be seen that A^2OMDV is more reliable even in the unstable channel condition.

In A^2OMDV, the frequency of the probe packet is in the relation of tradeoff between the response time to the dynamic of network and the control overhead. Thus, a suitable interval for the probe packet to various conditions of network should be investigated.

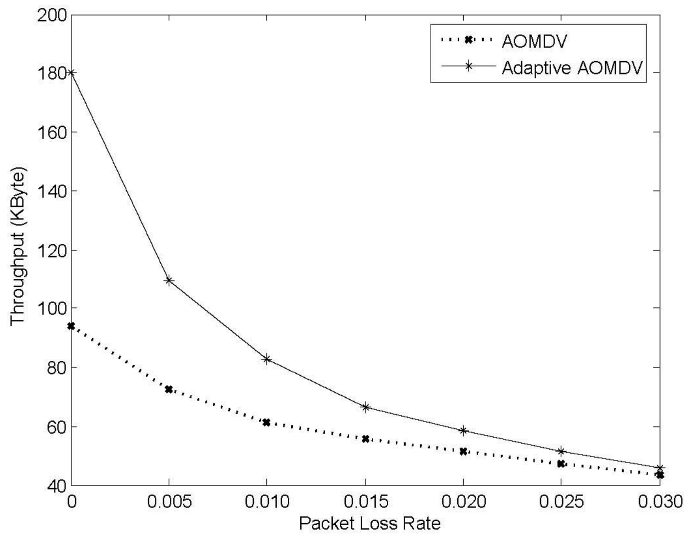

Fig. 8. Average Throughput with the Lossy Channel.

Figure 9 shows the average throughput with varied periods of network changes. In the simulation, to change the network condition, the traffic generators change their load at every period that has an exponential distribution whose μ varies from 10 to 70. That is, the best route is changed at the every period for network changes. In Fig. 9, each curve represents the throughput with different probing interval.

From the results of Fig. 9, we can observe that throughput increases only in case that the probing interval is smaller than the period of network changes. Additionally, note that the minimum throughput is obtained when the probing interval is slightly larger than the period. Hence, the suitable probing interval should be selected to a value that is smaller than the average period for the network dynamic and the gap between them has a certain margin. The estimation for the average period for the network dynamic and the margin will be studied as our future work.

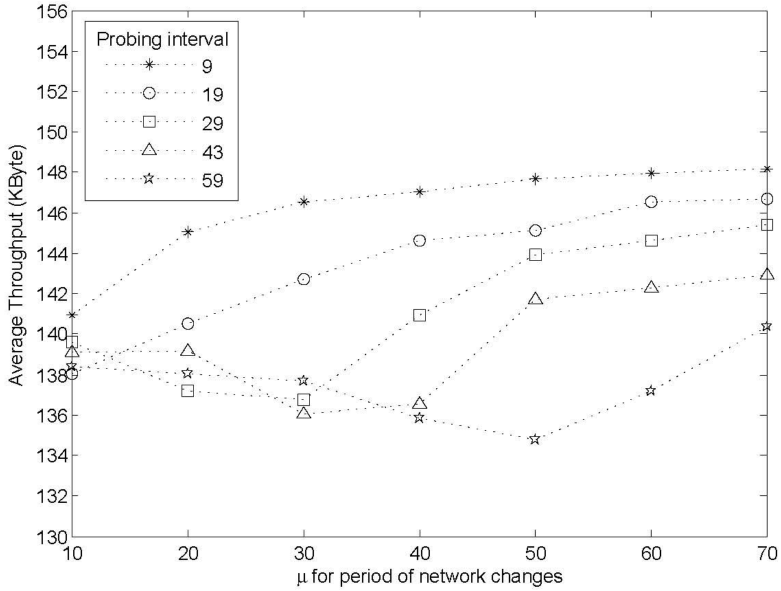

Fig. 9. Probing Interval and Period of Network Changes.

7. Conclusion

In this paper, we proposed A^{2}OMDV as an extension of AOMDV. The A^{2}OMDV resolves the limitations from the static route switching of AOMDV. In A^{2}OMDV, a source node can select the best route among its multiple paths by maintaining the status of them. Comparing to AOMDV, we expected that A^{2}OMDV shows better performance in terms of throughput and delay when the network is in the condition of heavy load and verified it through the analysis and the simulation. As our future work, we are extending A^{2}OMDV with additional studies about the penalty of the route switching and other decision metrics for prioritizing routes.

Acknowledgements

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