Link Stability and Route Lifetime in Ad-hoc Wireless Networks

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Abstract

Many routing algorithms, proposed for ad-hoc wireless networks, are based on source routing scheme. When a route is broken in source routing, route recovery and maintenance procedures are executed. However, these procedures consume many resources. To minimize route breaking, it's important to find a route that endures longer time. Shortest path route has short lifetime especially in highly dense ad-hoc wireless networks, and it's due to the edge effect discovered in this paper. Some routing protocols such as SSA [2] and ABR [3] are considering the link stability and try finding more stable route. In this paper, we will focus on the link stability and the lifetime of a route, and propose link stability comparison models for previously proposed routing algorithms. We will show properties of these models and compare them with local optimal algorithm that finds longest lifetime route at a given time. Finally, we will propose an enhanced link stability estimation model to find a route with longer lifetime.

Keywords – ad-hoc networks, routing, link-stability

1. Introduction

An ad-hoc wireless network is a network where no fixed infrastructure exists. Mobile devices randomly move and communicate over radio [1,2,3]. If two mobile devices are in radio transmission range, they can communicate to each other directly. Otherwise, other mobile devices should forward packets between them, and this requires packet routing algorithm.

Many routing algorithms were proposed for ad-hoc wireless networks, and most of them are based on source routing scheme [6]. In source routing scheme, a source node that wants to send packets to a destination node, searches and decides a route. Through the route, packets are forwarded to a destination node. A source routing scheme can be divided into route search, packet forwarding and route management procedures. When the route, found by a route search procedure, is broken, a route management procedure should recover the broken route. If this procedure fails, a route search procedure is initiated again.

Route search packets, generated in a route search procedure, decrease overall network performance and increase power consumption of mobile devices [1,2,6]. If a route search algorithm can find more stable route that endures longer time, we can reduce route search packets and route maintenance overheads. Above all, this may provide more stable communication in ad-hoc networks. In recent research, SSA [2] and ABR [3], they proposed routing algorithms to find more stable routes. Signal strength is used to estimate list stability in SSA and pilot signals are used in ABR.

This paper focuses on the lifetime of routes and the stability of links in ad-hoc wireless networks. We will show the edge effect that a shortest path route has shorter lifetime as node density is increased in ad-hoc networks, and propose a local optimal algorithm to show an upper limit of a route lifetime. Then, we will enhance a stability estimation model and compare it with previous estimation models used in SSA and ABR. For easy of handling the problem, we will use a centralized approach in simulation.

2. Related work

2.1. DSR (Dynamic Source Routing)

DSR [1] is known as well-performing and lightweight routing algorithm in ad-hoc networks. DSR is based on source routing and uses flooding mechanism to find a

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route to the destination. However, flooding generates too many packets and increase network overhead. In DSR, route cache is used to reduce route search overhead. Every node caches routes to other nodes and this reduced routing overhead.

Flooding mechanism used in DSR finds a shortest path theoretically. When flooded packets are forwarded at same speed and latency, it finds shortest path. However, each flooding packets are forwarded in different speed and latency due to different load and status of forwarding nodes.

2.2. SSA (Signal Stability-Based Adaptive Routing)

SSA [2] uses signal strength information to estimate link stability. A mobile node can measure signal strength from other nodes, and this information is used to estimate the link stability between them. If a node receives strong signal from a neighbor then these two nodes are closely located and the link between them can be considered as stable. In SSA, each node measures signal strength from other nodes and if the strength beyond certain thresh-hold the link between them is considered as strong link. SSA tries to find a route on these strong links. A route that is found through these strong links is known as a more stable route than an ordinary route. If it fails finding a route in first trial, it searches a route on all available links. A route found in this second try is similar as in DSR.

2.3. ABR (Associativity-Based Routing)

ABR [3] uses pilot signal to determine link stability. Every node sends pilot signal periodically. When a node receives this pilot signal from its neighbor nodes, it records pilot signal received. If it receives these pilot signals from a neighbor continuously and the number of continuous pilot signals beyond certain threshes hold, it considers the link between them as stable link. Route search in ABR is different from SSA. In ABR, it searches all possible routes to find a route that contains more strong links.

SSA and ABR show an importance of link stability and its effect to a route in ad-hoc wireless networks. However they focused on overall performance of networks. In this paper, we analyze previous algorithms and compare it with centralized optimal algorithm. And shows more optimized algorithm to find more stable route.

3. Route lifetime

Stable route is a route that endures longer time than other routes. In ad-hoc wireless networks, a route is composed of multiple wireless links between mobile nodes. If any one of these links is broken, the whole route is useless and we should recover broken link or find new route. In this paper, we do not concern about route recovery or maintenance. We will focus on a lifetime of routes, and parameters that affects the lifetime.

3.1. Edge effect

On researching a high-density ad-hoc wireless networks, we found that shortest route is very unstable. In high-density ad-hoc wireless networks, shortest route is composed of links that connect farthest neighbors. On this route, nodes are located on the edge of other node's radio transmission range. In this situation, a small movement of any node can easily break the route. We named it as the edge effect. **Figure 1** and **Figure 2** show the effect.

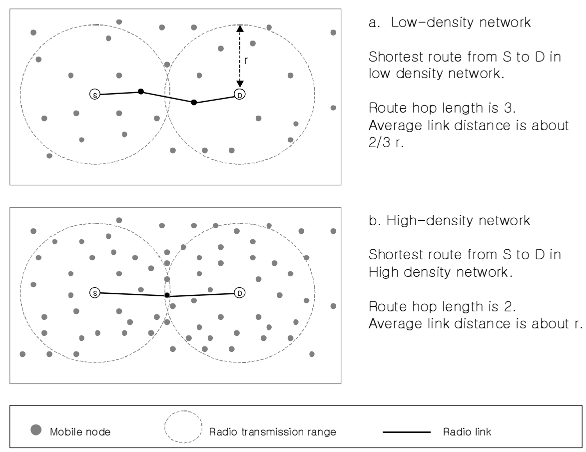


Figure 1. The edge effect

The edge effect appears as node density increases. Figure 1 (a) shows shortest route on low-density network and Figure 1 (b) shows shortest route on high-density network. In low-density network, average link distance is about 2/3 r as shown in Figure 1 (a). Where r is transmission range of nodes. These links are more stable than those in higher density network. In higher density network, the average link distance of route becomes longer and come closer to r. This makes each forwarding node is located at the edge of radio transmission range of neighbor forwarding nodes.

When the edge effect appears, the lifetime of route decreases. In Figure 2, the shortest route from a to e is a-b-c-d-e. On the route, node c is located at the edge of radio transmission range of node b and node d. A little movement of node c can break the route as shown in Figure 2 (b). This reduces the average lifetime of a route.

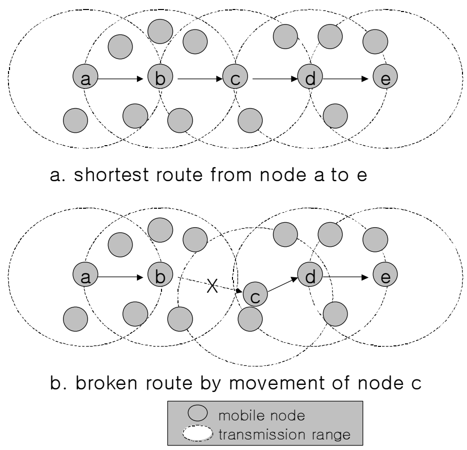
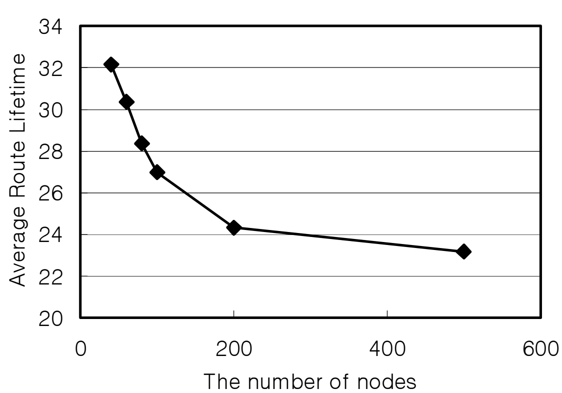


Figure 2. Easy breaking on shortest route

Graph 1 shows relationship between the node density and average route lifetime (ARL). In 1500m x 500m area, nodes can transmit packets to its neighbor and the transmission range is 250. Selected 20 source nodes find shortest path to randomly selected destination nodes. If the route is broken, the source node finds a new route to the selected destination node again. All nodes have mobility and we used random destination model to generate node mobility. As the node density is increased, the ARL is decreased. In a network with 500 nodes, most routes are straight line and fragile by little movement of any node on routes.



Graph 1. Average route lifetime of shortest route

3.2. Link stability and route lifetime

The number of links that compose the route and link stability of each links determines route stability, the lifetime of a route. When we define the probability of link failure as $P_{link\_fail}(i)$, the probability of route failure P_{route_fail} is defined as following.

$$P_{route\_fail} = 1-\Pi_{all\ i}(1- P_{link\_fail}(i))$$

This means that if we want to reduce route failure rate we must decrease link failure rate and the number of links that compose the route. However, in ad-hoc wireless networks, if we want to reduce the number of links on a route, we must select longer links. If we select too long link then the link failure rate of the link is increased. If we only consider link error rate and select short links, the route would be long. A long route may increase packet delay and packets error rates.

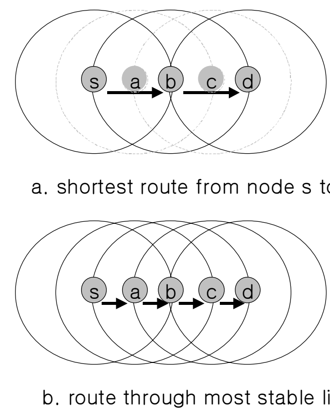


Figure 3. A route through stable links

Figure 3 (a) shows a route with long links. The route length is only two hop and we can send packets from the source node to the destination node with low delay. But just a little movement of a node may break the route and we should find a new route again. This eventually increases total transmission delay. Fig b shows a route with short links. The route length is longer than before but links are more stable. This route can make more packet transmission errors than before. However it can support longer time.

In SSA, a route composed of shorter links is preferred than a shortest route composed of longer links. In ABR, they used pilot signals instead of signal strength. A long link with weak signal strength can be considered as stable link in ABR, if two nodes, between them the link exists, are stable nodes without mobility. In consequence, we must determine the link stability to find stable route.

4. Link stability estimation

Link stability indicates how stable the link is and how long it can support communication between two nodes. We can estimate link stability using many parameters. Signal strength was used in SSA, and pilot signals were used in ABR. Relative speed between two nodes or remaining battery power of a node can be used also.

Link stability between mobile nodes is basically dependent on the distance between mobile nodes. Buffer zone effect, presented in SSA, shows the relationship between the distance and the link stability. However, if nodes have long pause time, the relationship between the distance and the link stability is broken. If two nodes with long pause time are located at the edge of radio transmission range, they can communicate during long pause time. Though, the bit error rate of the link is high, the link would not be broken. This makes the estimation of the link stability as a hard problem.

4.1. Signal strength based link stability estimation model (SBM)

SSA uses signal strength as link stability estimation. All nodes monitor signals from its neighbor nodes. If the strength of signal received from neighbor node beyond threshold, the link from the neighbor node is considered as strong stability link. Signal strength values can be obtained from radio device and strength regulator averages strength values [2]. In simulation, we assume free space radio propagation model and used a distance between two nodes, instead.

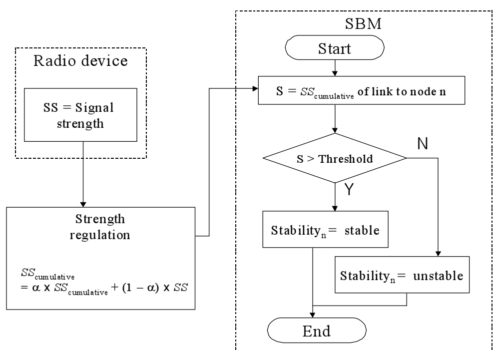


Figure 4. Block diagram of SBM

4.2. Pilot signal based link stability estimation model (PBM)

Pilot signal is used to estimate link stability between nodes in ABR. If a node receives continuous pilot signals from a neighbor node and the number of continuous signal exceeds a certain limit, it considers a link to the neighbor node as stable link. In this scheme, we must setup a pilot signal threshold. If a node can't receive pilot signal through a link in time limit, we consider the link as an unstable link. In simulation we did not consider about pilot packet generation overhead. Figure 5 shows a state diagram of PBM.

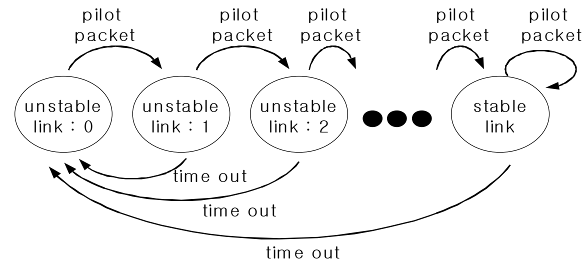


Figure 5. State diagram of PBM

4.3. Advanced signal strength based link stability estimation model (ASBM).

ASBM is proposed in this paper by enhancing SBM. SBM decide link stability only with signal strength. In ASBM, we added differentiated signal strength (DSS) as a parameter. DSS indicates the signal strength is going stronger or weaker. If it becomes stronger, it means that two nodes will be closer and the link between them would have longer lifetime. In SSA, only a link, the signal strength of that exceeds certain limit, are considered as a stable link. In ASBM, we consider both strong signal links and weak signal links that are coming closer as stable links.

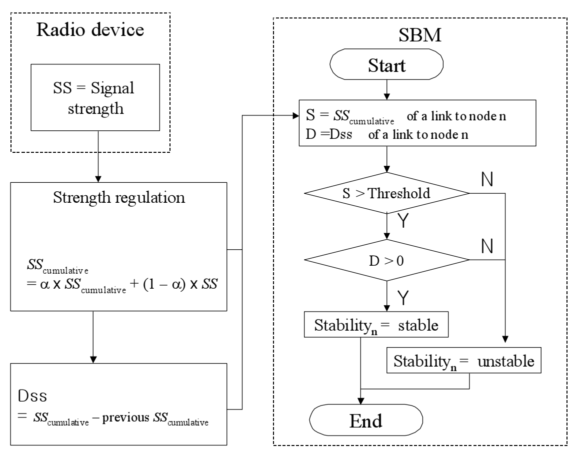


Figure 6. Block diagram of ASBM

4.4. Routing algorithm with link stability estimation

Link stability estimation models presented above are two-level estimation. The estimation results are stable or unstable. Because route lifetime is determined by the weakest link composing the route, to find a route with longer lifetime, we must find a route only with stable links. However, if we use only stable links, the route

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availability would be decreased. To avoid this phenomenon, we used two stage routing algorithm used in SSA. In first stage, a source node tries to search a shortest route to a destination only with stable links using centralized floyd-warshall. If this fails, it enters into second stage and searches a route with all available links. After finding a route, at every unit time, it monitors whether the route that was found before is valid or not. If the route is invalid, it searches a new route again. If no route is found in both stages, the node waits one unit time and tries finding a route again.

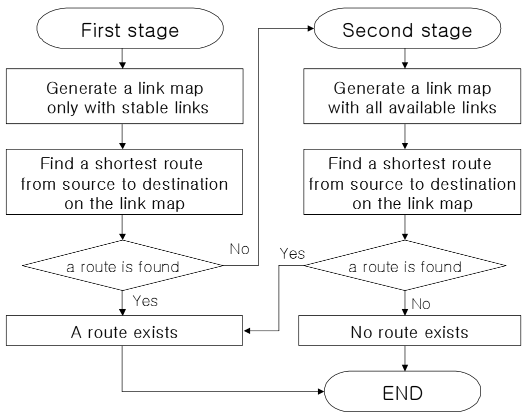


Figure 7. Two stage routing algorithm

4.5. Routing algorithm with perfect link stability knowledge

To compare with other routing algorithms, we made a local optimal routing algorithm that maximize route lifetime with perfect knowledge of link lifetime. Though, the node mobility is randomly generated, when it is stored as a file, the mobility is deterministic. And then, we can compute lifetime of all links, when it is created and destroyed. We generated a file that contains link creation and destroy time from a node mobility file. From this file, we can find a route that endures longest time from a given time. The resulting route is a local optimal route because the algorithm searches on links that exist at a given time.

The algorithm mentioned above can't be applied in real world, because we don't know movements of all nodes. It's just a data to compare with other algorithms.

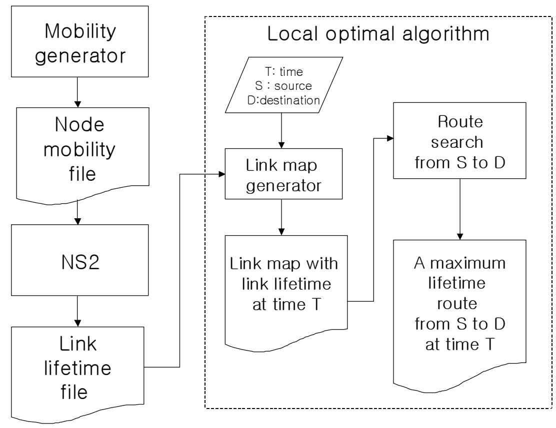


Figure 8. Local optimal algorithm to find most stable route

5. Simulation environments & results

5.1. Simulation environments

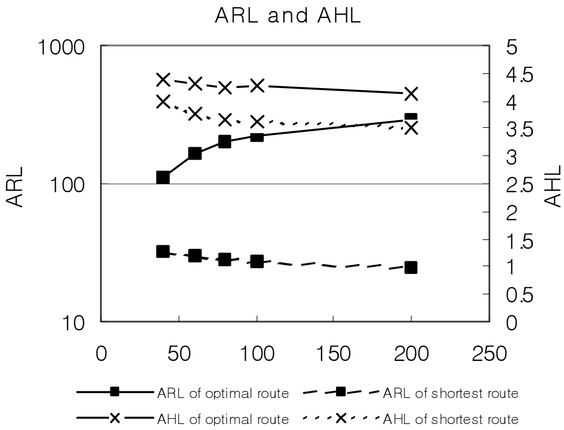
We used ns2 simulator on Pentium III Linux machine. Because, we focus on the link stability and route lifetime, no route overhead was considered in our simulation.

In 1500x500 unit area, mobile nodes exist. We used square area to increase average hop length of a route with relatively small nodes. Every mobile node is moving based on mobility data files that were generated by mobility generator module. The transmission range is fixed at 250 units. 20 nodes of them have destinations and try finding routes to their destination nodes. Maximum speed of node is set to 10 m/sec. All nodes do not stop moving, and the simulation time is 5000 sec. The number of nodes is varying from 40 to 200.

5.2. Node mobility model

Random destination model were used as node mobility model in our simulation. Every node randomly selects its destination to move and speed. Speed uniformly distributed from 0 to 10. We also setup maximum pause time and the number of fixed nodes when mobility file were generated. Every node stops moving for pause time after it reached its destination then select a new destination and starts moving. If a node was selected as a fixed node it does not move during simulation.

5.3. Shortest Route vs. Local Optimal Route



Graph 2. Shortest Route vs. Local Optimal Route

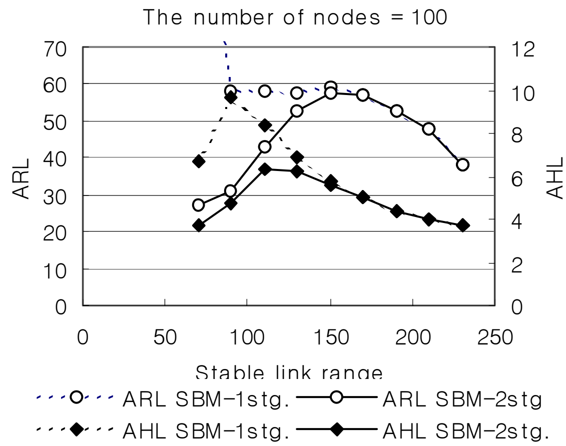
We compared shortest path routing algorithm and local optimal routing that knows future movement of all nodes. Graph 2 shows ARL (Average Route Lifetime) and AHL (Average Hop Length) of shortest routes and local optimal routes. As the number of nodes is increased, the ARL of local optimal routing is increased. However, the ARL of shortest routing is decreased. It's due to the edge effect concerned before. In highly dense environment, in this case the number of nodes is 200, the ARL of local optimal routing is 292 and the ARL of shortest routing is 24. The ARL of local optimal routing is 10 times longer than that of shortest routing. The difference of AHL, however, is less than 0.5 hop. The AHL of local optimal routing is little longer than that of shortest routing. This means that a little longer route can endure 10 times longer time in optimal case and shows the importance of route stability in ad-hoc networks.

5.4. SBM

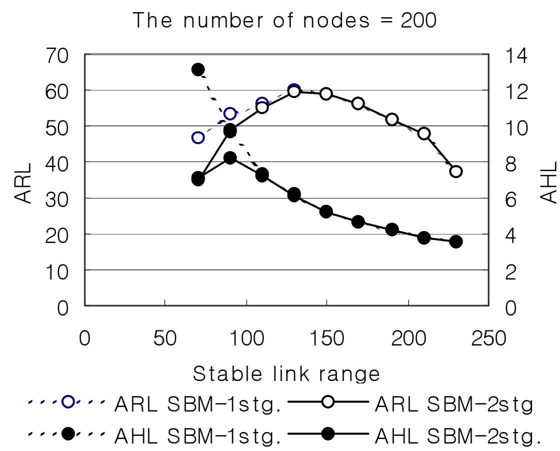
The ARL of SBM is dependent on the link stable range. To find best value for the link stable range, we simulated SBM varying stable range. Graph 3 and Graph 4 show the result. SMB-1stg. is a result from only 1st stage of our routing algorithm and SMB-2stg. is a full stage routing algorithm. The large gap between 1st and 2nd stage means that the 1st stage routing algorithm failed to find a route from source to destination. This means that no route exists from source to destination on stable links.

As the stable link range reduced from 250, ARL is increased. However if we reduce the stable link range below certain limit, failure rate of the 1st stage algorithm is increased and ARL is decreased.

In a network with 200 nodes, the ARL is longest when the stable link range is 120. If the stable link range is shorter than 120, the AHL increase rapidly and it decreases the ARL. In a sparser network with 100 nodes, the ARL is longest when the stable link range is 170. The best parameter for the stable link range is depends on the number of nodes in the network.



Graph 3. SBM with 100 nodes



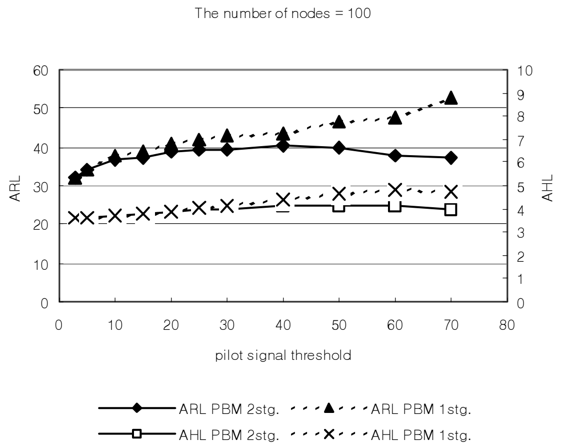
Graph 4. SBM with 200 nodes

5.5. PBM

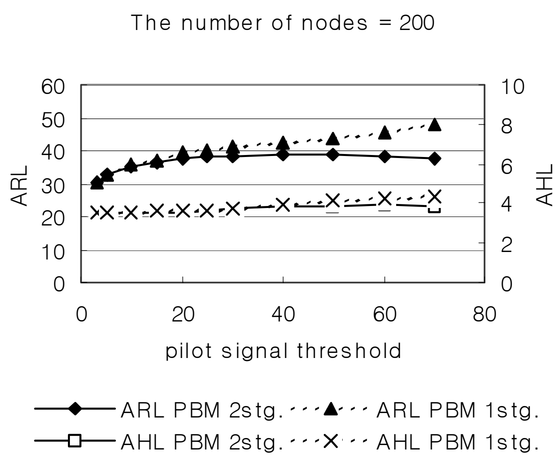
Graph 5 and Graph 6 show ARL and AHL of PBM with 100 nodes and 200 nodes. With 100 nodes, ARL increases as the pilot signal threshold is increased. Too high threshold reduces the number of stable links and the failure rate of 1st stage is increased.

The result with 200 nodes is similar with previous result with 100 nodes. The gap between 1st stage and 2nd stage is smaller then before. This means that more routes were found in 1st stage with high threshold than with 100 nodes.

In both graph, the AHL is about 4.



Graph 5. PBM with 100 nodes

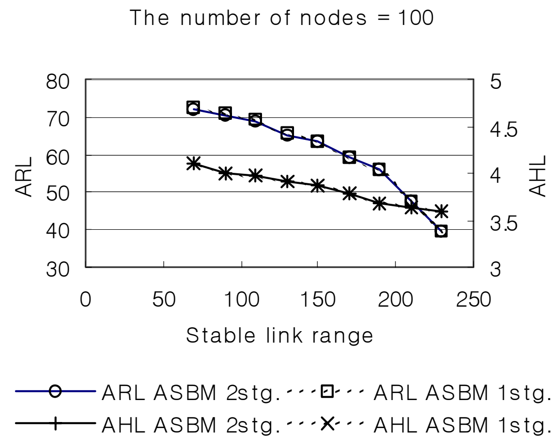


Graph 6. PBM with 200 nodes

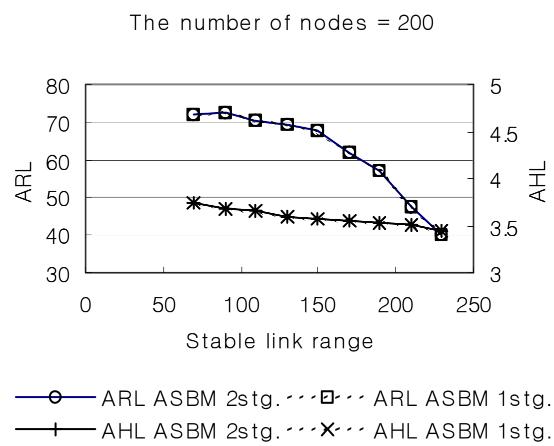
5.6. ASBM

Graph 7 and Graph 8 show good performance of ASBM. With 100 nodes, maximum value of ARL is 72 when the stable link range is 70. And the gap between 1st stage and 2nd stage is very small. This means that most of routes were found in 1st stage.

With small stable link range, the number of stable links is enough to make a route from the source to the destination.



Graph 7. ASBM with 100 nodes



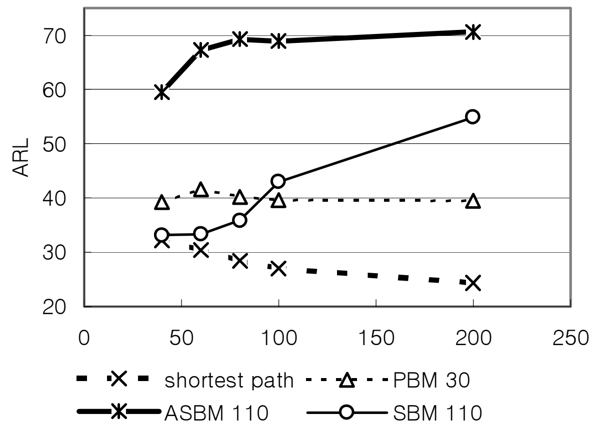
Graph 8. ASBM with 200 nodes

5.7. Comparison

We compared ARLs of three link stability estimation algorithms and shortest route algorithm. Graph 9 shows the result. PBM 10 is a result of PMB when the pilot signal threshold is 10. SBM 110 is a result of SBM when the stable link range is 110. Shortest path routing algorithm has shortest ARL of them, and ASBM has longest ARL.

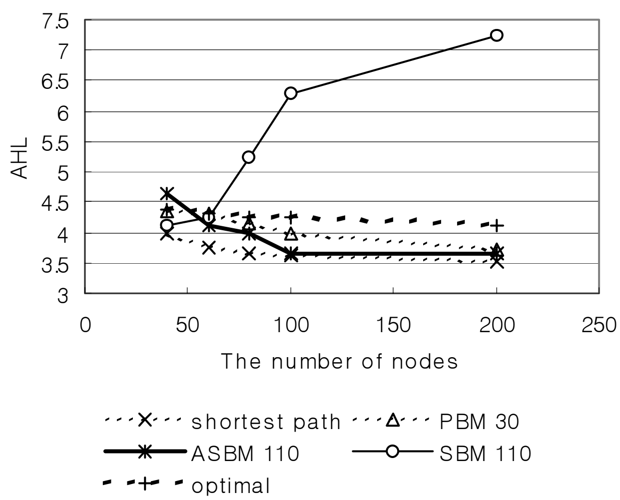
The ARL of shortest path routing algorithm is decreased, as the number of nodes is increase. However, other algorithms do not show ARL decrease, as the node density is increased. When the node density is increased, ARLs of SBM and ASM are increased and ARL of PBM changed little.

By adding a little modification to SBM, we made ASBM and it shows better performance than SBM. With 200 nodes, the ARL of ASBM is about three times longer than that of the shortest path. However, the ARL of the optimal algorithm is far beyond the ARL of ASBM.



Graph 9. ARL comparison

Graph 10 shows AHL of proposed models. AHL of shortest path is lower bound. AHL of optimal algorithm is just a little longer than that of shortest path. However, AHL of SBM-110 is two times longer than AHL of shortest path routing. Too long AHL of SBM increase packet delay and decreases overall performance of network. ASBM shows good AHL that is little longer than AHL of shortest path routing.



Graph 10. AHL comparison

6. Conclusion and Future Work

In a highly dense ad-hoc wireless network, shortest path routing algorithm finds unstable route. It's due to the edge effect proposed in this paper. And we showed that if we can find optimal route in that environment, the average route lifetime would be 10 times longer and it will reduces route maintenance and rerouting overheads.

In SSA and ABR, link stability estimation algorithms are used and they are based on signal strength and pilot signal. In this paper, we modeled these link stability estimation algorithms as SBM, PBM and showed the properties of them and enhanced SBM to ASBM. ASBM, a modified version of SBM, showed best performance of them and has about three times longer ARL than that of shortest path routing but has just little longer AHL than AHL of shortest path.

All these models have their own weakness. PBM requires pilot signal generation and monitoring of pilot signals of other nodes. SBM and ASBM require monitoring of signal strength of other nodes. Though these overhead, if we can find more stable route, overall performance of network would be increased.

As a future work, we will simulate these algorithms in various mobility models and enhance link stability estimation model to increase ARL. Most of all, the distributed version of algorithms should be designed and applied to real environment in near future.

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