[Practical Paper] A Routing Metric towards Reliable Communication in Mobile Ad-hoc Networks

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Abstract - MANETs (Mobile Ad-hoc Networks) have been studied as one of the future network technologies in which nodes construct a network autonomously via wireless communication. In MANETs, links are frequently cut due to node mobility or radio interference. To maintain the stability of users' communication, it is desirable to change communication paths to alternative ones before the paths become unavailable. To this end, several dynamic metrics are proposed so far for link-state routing protocols such as OLSR. They raise the metric of a link when its link quality decreases to avoid using low-quality links as communication paths. Those dynamic metrics, however, cause routing loops when the topology information at each node becomes inconsistent due to propagation delay of topology-change messages. Routing loops cause severe congestion so that it should be avoided. In this paper, we propose a new routing metric that is designed in order to ensure reliable communication against link cuts and routing loops. We evaluate the performance of the proposed routing metrics through simulation experiments. As a result, although we do not take the high-traffic-load effects into account, we confirmed that our metric works effectively in case of walking-speed mobility.

Keywords: Ad-hoc Networks, Dynamic Metrics, Communication Reliability

1 INTRODUCTION

Recently, wireless communications have been populated and wireless terminals such as smartphones are commonly used all over the world. Accordingly, as one of the next-generation communication technologies, wireless multi-hop networks such as MANET (Mobile Ad-hoc Networks) have been well studied. In MANET, because wireless links are not as stable as wired links, and also because node mobility frequently cut links, one of the key problems for practical use is how to improve the stability of communications. For this purpose, many studies have been conducted in the literature.

One of the major approaches to improve communication stability is to select links in forwarding paths as stable as possible using dynamic link metrics. In dynamic metric schemes, typically, lower metric values are assigned for higher quality links. By selecting a lower metric path as a forwarding path for each destination, we can significantly improve the throughput of networks. Various dynamic metrics have been proposed ever that consider several instability factors including communication speed, packet loss ratio, interference, mobility level, and so on [5]–[10].

Note that, in general, the objective of these proposals is to improve network throughput. However, in wireless multi-hop networks such as MANET, high network load causes congestion and even link cuts, which brings unexpectable behavior of traffic. Thus, to achieve reliable communication in MANET, we in this paper focus on route stability under dynamic metrics by excluding the effect of high load behavior.

In this paper, we concentrate on "link cut" due to node mobility, and "routing loops" due to transient inconsistency of network topology maintained at each node. By assuming that links are not cut by interference and physical obstacles, we can concentrate on these two factors (i.e., link cut and routing loops) as the cause of flow cuts of users. Note that even under this assumption, it is still difficult to realize reliable communication. Our trial in this paper is to examine whether dynamic metrics are effective to ensure reliability of communication against these two factors. Through investigating this point we try to get better understandings towards reliable communication over MANET.

More specifically, in this paper, we designed a new dynamic metric that is likely to work effectively against these two factors. In our metric design, we try to avoid link cuts due to node mobility, by controlling link metrics according to the distance between nodes using RSSI (Received Signal Strength Indication). Furthermore, to reduce routing loops, we apply methods called LMR[4] to our RSSI based metric. We evaluate our dynamic metric with several mobility scenarios to clarify the potential of dynamic metrics on communication reliability.

This paper is organized as follows: In Section 2, we shortly describe the related work of dynamic metrics in MANET. In Section 3, we describe the design of our dynamic metric for communication reliability. In Section 4, we evaluate our metrics through simulations, and finally in Section 5 we conclude the work.

2 RELATED WORK

2.1 Dynamic Metrics in MANET

Several dynamic metric schemes have been proposed in the literature. We first introduce the dynamic metrics for wireless mesh networks, in which nodes are stationary. One of the most widely known dynamic metrics is ETX (Expected Transmission Count)[5]. ETX of a link is computed as the successful transmission ratio of the link. Specifically, because a data transmission in wireless networks typically consists of a pair of "data" and "ack" frames, the ETX metric of a link

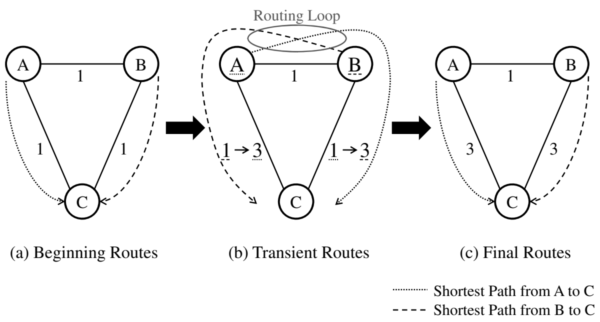


Figure 1: Example of Routing Loops

$l = (u, v)$ is defined as

$$\mathrm{ETX}(l) = \frac{1}{p \times q},$$

where p is the ratio of successful transmission of (u, v) and q is that of (v, u). In ETX scheme, nodes exchange periodical probe messages between their neighbors so that it is typically used in proactive routing schemes for MANET such as OLSR (Optimized Link-State Routing) [1].

As an extension of ETX, ETT (Expected Transmission Time) [6] was proposed, in which the average transmission time of a link is estimated by taking link speed into account. Because these two metrics (i.e., ETX and ETT) are computed based on the number of hello messages received in a certain time period, they have a drawback that they are not sensitive enough to handle mobility scenario. Although many other succeeding dynamic metrics for wireless mesh networks exist, (e.g., MIC (Metrics of Interference and Channel Switching) [7] takes interference among nodes into account), they all have the same problem of sensitivity when we apply them to mobility scenarios.

Several dynamic metrics for MANET with mobility are also proposed so far. In mobility scenarios, links connected to high-mobility nodes tend to be lost easily. Therefore, selecting links with low mobility nodes is essential for stable communication. Based on this idea, Yawut et al. proposed a node metric that estimates mobility levels of nodes [8]. However, to consider more specifically, relative speed between two nodes rather than speed of each node would be a more effective metric. Tickoo et al. computes relative speed between two nodes using RSSI (Received Signal Strength Indication) [9]. Furthermore, from the idea that the reliability of a path is determined by the lowest quality link of the path, Triviño-Cabrera et al. proposed a path metric to find the path with maximum least quality, which is computed based on RSSI [10]. They all, however, do not consider transient routing loops, which is also an important factor to consider reliability of communication.

2.2 The Routing Loop Problem

Routing loop is a problem that causes a severe instability of networks. The loops occur when a topology (including metrics) of a network changes. During the period of time until converging to the new routing tables, inconsistent routing tables computed from different topology create routing loops.

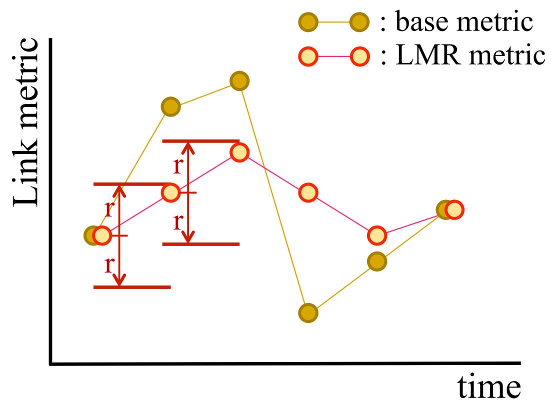


Figure 2: Reducing Routing Loops with LMR

See Fig. 1 for example. There are three nodes A, B, and C in the network. The metrics of links (A, B), (A, C) and (B, C) are all 1 at the beginning so that the shortest paths from A and B to C go directly to C (Fig. 1(a)). Assume that the metrics of (A, C) and (B, C) change to 3 simultaneously. It is natural that finally the shortest paths from A and B to C are the same as the beginning state (shown in Fig. 1(c)). In the transient state, however, routing loops are possibly created due to propagation delay, where A regards the metrics of (A, C) and (B, C) as 3 and 1, respectively, while B does those as 1 and 3, respectively. This state is shown in Fig. 1(b), where the dotted and broken underlines indicate the metrics that A and B know, respectively. Such routing loops frequently occur in ad hoc networks and cause severe congestion and communication disruption due to heavy packet loss.

As for the harmful effect of routing loops, Speakman et al. [14] reported that the loops cause severe congestion in MANET, and they proposed the technique to detect and suppress (i.e., drop) looping packets, which brought about 20% improvement in packet delivery ratio in a mobility scenario.

2.3 Dynamic Metric to Reduce Routing Loops

There are a few dynamic metrics in the literature that are aware of routing loops. The first loop-aware routing metric would be LLD [3], which constantly reduce link metrics little by little as time passes to prevent routing loops. LLD is based on the idea that the links with long living duration would be considered stable. Therefore, the link metric is designed depending on link duration. LLD, however, has a limitation that it cannot handle fluctuation of wireless link quality since the metrics monotonically decrease as time passes.

As another loop-aware method, LMR (Loop-free Metric Range) was proposed [4]. LMR can be applied to other dynamic metric scheme to reduce routing loops by limiting the amount of metric change per unit time. LMR defines a variable $r (> 1.0)$ called *metric stretch*, which limits in ratio the range of the next metric value to take. That is, $m_{old} \cdot r^{-1} < m_{new} < m_{old} \cdot r$ must be held, where m_{old} is the current metric of a link and m_{new} is the new (i.e., updated) metric. Note that, because LMR assumes a link-state routing scheme, link metrics are updated periodically when topology advertisement messages (TC messages in case of OLSR) are sent.

At each of the metric updates, if the new metric of the base dynamic metric scheme is out of the range, LMR uses the new metric with the nearest value in the range. The behavior of LMR described above is illustrated in Fig. 2. This figure shows the transition of the base metric, and the LMR metric that follows the base metric within the range of the metric stretch r.

As theoretical results of LMR [4], the value of r exists that guarantees loop-freeness under the assumption that no control packet are lost. Note that the value of r to guarantee loop-freeness depends on several values, i.e., the upper and lower bounds of link metric values m_{max} and m_{min} (we need to set these values to use LMR), and the network diameter w that is measured with hop count. Consequently, once m_{min}, m_{max} and w are given, the value of r to guarantee loop-freeness is determined.

Unfortunately, however, the value of r to guarantee loop-freeness is too small in general (e.g., the value is 1.002 when $m_{min} = 1, m_{max} = 5$ and $w = 10$ [4]), so we have to use larger values. To evaluate the loop reduction effect of LMR, we conducted a simulation experiment [4] using a network simulator Qualnet [13]. In the simulation, we prepared a 5×5 grid topology of stationary nodes and transmitted four UDP flows. As a result, the effect of LMR to reduce routing loops is clarified. Note that when r gets smaller, we can expect more effects on reducing loops whereas the effect of base dynamic metric scheme is limited because the dynamism of metric change is reduced. There is a trade-off between them so that we have to pay attention to the balance to work with optimal performance.

3 DESIGN OF ROUTING METRICS FOR RELIABLE COMMUNICATION

3.1 The Concept

We designed a dynamic metric that is aware of both link cuts due to node mobility and routing loops due to route inconsistency. To prevent disruption of users' communication caused by link cuts, we have to raise a link metric before the link is cut due to node mobility. That is, the routing metric must be sensitive to detect the symptom of link cuts. Note that, for this purpose, it is not suitable to use packet loss statistics like ETX because it requires long-term observation of probe packet transmissions to compute metrics, which means that this approach cannot trace the link quality sensitively.

In our metric design, we use RSSI (Received Signal Strength Indicator) values measured with hello messages transmitted by neighbor nodes to compute a sensitive routing metric. Specifically, we estimate the distance between two nodes using RSSI, and the link metric is computed according to the distance. Note that the distance estimation algorithm we use in this paper is quite primitive so that they might work surely only in simulations. However, we can use more practical distance estimation algorithms such as [11] when we apply our metrics in practice. Furthermore, because localization methods are also progressing day by day, if these methods achieve high accuracy localization, high accuracy distance estimation would also be possible.

On the other hand, to prevent routing loops, we apply LMR into our RSSI based routing metric. Note that LMR limits the effect of dynamic metrics instead of reducing routing loops. To take the balance of them, we have to select carefully the value of the metric stretch r.

3.2 Design of RSSI based Dynamic Metrics

The formula to compute the link metrics from the node distance should be carefully designed. In Fig. 3(a), we illustrate the case in which the distance between nodes A and C is approaching to the communication range. In this case, $A \to B \to C$ is the desirable communication path from A to C because the link (A, C) is about to be cut. Therefore, the condition $m(A, C) > m(A, B) + m(B, C)$ should hold, where $m(A, C)$ is the metric of link (A, C). On the other side, Figure 3(b) illustrates another case where the distance between A and C is far shorter than the communication range although the shape of node location is the same as Fig. 3(a). In this case, the desirable communication paths from A to C is $A \to C$, which reduces the hop count that packets travel. This means that the condition $m(A, C) > m(A, B) + m(B, C)$ is desirable in turn.

The above discussion means that the desirable paths depend on the distance among nodes, and the longer links should have higher metrics. To meet this constraint, we designed our link metric function as convex function. In this work, we use a simple polynomial convex function as a metric function.

The mechanism to compute our metrics consists of two parts; the process to estimate distances between nodes, and the process to compute the metric from the estimated distance.

The distance between nodes is estimated from the RSSI value observed with every hello messages of OLSR. That is, when a hello message is received, the metric of the directed link from the received node to the neighbor node is computed, and the metric value is updated. Note that RSSI decays in the inverse proportion to the square distance. Accordingly, we designed the formula to estimate the distance as follows:

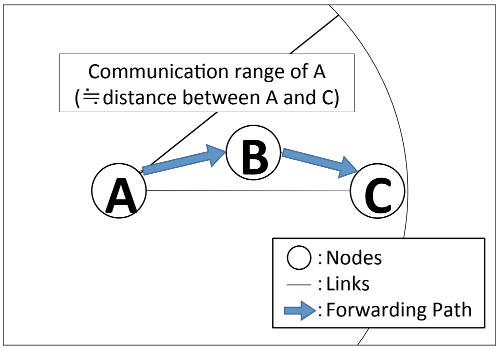
$$L = \sqrt{\frac{a}{R}},$$

where L denotes the distance between two nodes, R does the RSSI measurement, and a does the decay coefficient. Note that a should be determined properly. The metric values are propagated via hello messages and topology advertisement messages (i.e., TC messages in case of OLSR) all over the network, and they are used in the shortest paths computation.

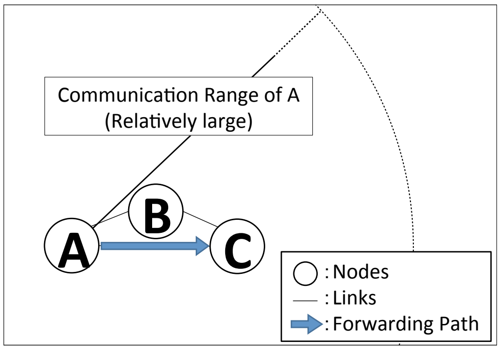
Our dynamic metrics are computed based on the estimated distance between nodes. As mentioned before, the metric function we use is a simple polynomial convex function. Let L_{max} be the maximum distance that allows communication between two nodes. M_{max} and M_{min} be the maximum and minimum metric values, respectively. Then, our metric function is expressed as follows:

$$M = (M_{max} - M_{min}) \times (\frac{L}{L_{max}})^n + M_{min}, \qquad (1)$$

where n is a parameter to determine the curve of the function. Figure 4 shows the curve of the metric function for several



(a) Case of A and C having long distance



(b) Case of A and B having relatively small distance

Figure 3: Desirable Paths with Node Distance

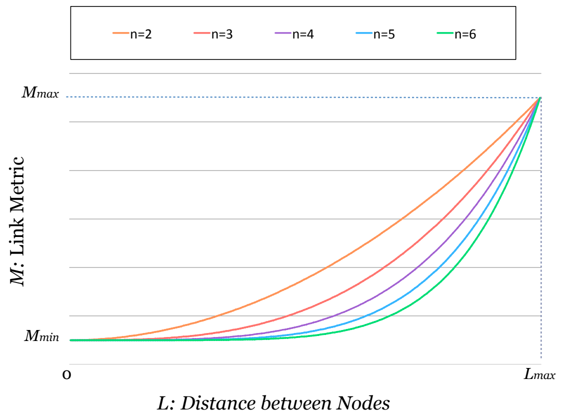


Figure 4: The Curve of the Proposed Metrics

value of n. The metric values take between M_{max} and M_{min} depending on the input distance that takes less than L_{max}.

3.3 Applying LMR

To reduce routing loops, we apply LMR to our RSSI based metrics described in Section 3.2. That is, by LMR, we limit the amount of metric change with a metric stretch r. Note that the amount of metric change in our RSSI based metric depends on the relative speed, the moving direction, and the distance between nodes. If the limitation of LMR on metric change is too strong, links are cut before their metrics have raised enough to use alternative paths. Conversely, if the limitation of LMR is too weak, routing loops appear that causes severe congestion. It is important to take the balance. We also note that dynamic metrics will not work when node speed is too fast. To find the node speed that our metric can catch up with is also important in the evaluation.

4 TRAFFIC SIMULATION

4.1 Scenario

We conducted a simulation using a network simulator Qualnet[13]. We implemented both our RSSI based routing metric and LMR by modifying OLSR module OLSRv2-NIIGATA, which is included in Qualnet version 5.0. We compared the performance of (i) the RSSI based metric and (ii) the RSSI based metric with LMR in the simulation.

We performed two simulation experiments. One is to investigate the relation between routing loops and link cuts, and another is to investigate the performance of our metric with various mobility parameters.

For the former simulation, we prepared 1000m$\times$1000m field to place 30 nodes in random location. Nodes move following Random Way Point model [12]. We tried two node speeds, i.e., 5km/h and 10km/h, and the pause time of nodes is 10 seconds. We generated 5 flows of 20kbps CBR (Constant Bit Rate) in 5 minutes, i.e., started at 1 minute and ended at 6 minutes from the beginning of the simulation. As the parameter that determine the curve of metric, we used $n = 4$. Note that OLSR have a mechanism called MPR to reduce control message load. To exclude the effect of MPR, we set TC_REDUNDANCY=2 so that all links are propagated into the network. As other OLSR parameters, we use default values. Note that when 1 minute past from the beginning of the simulation, all nodes share the information of all links.

For the latter simulation, we used the scenario similar to the former simulation. The difference is that we determined the default values for three parameters, and performed three simulations where one parameter varied while the other two parameter was fixed. The varied parameters were the number of nodes, node speed, and the parameter n in the metric function shown in equation (1). The default value of them were 30, 5km/h, and 4, respectively. In this simulation, we used our RSSI based metric without LMR because we intended to study the straightforward effect of mobility parameters against dynamic metrics. Also, the simulation time was 60 minutes.

4.2 Results: Routing Loops and Link Cuts

In Fig. 5, we show the packet reachability to the destinations with various values of r. Here, "power" means the case of RSSI metrics without LMR. In both 5km/h and 10km/h, the performance gets worse as the value of r goes lower. Totally the performance of lower mobility (5km/h) is better than higher mobility (10km/h).

In Fig. 6, we count the number of loop packets. We defined loop packets as the packets that reach the same node more

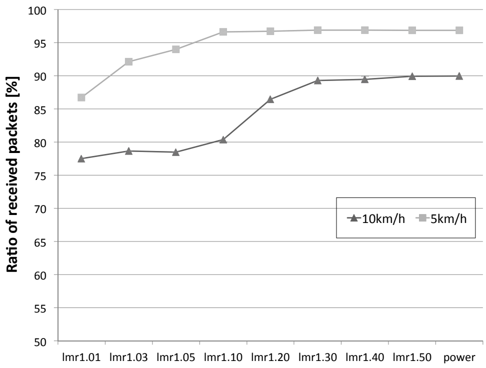


Figure 5: Packet reachability

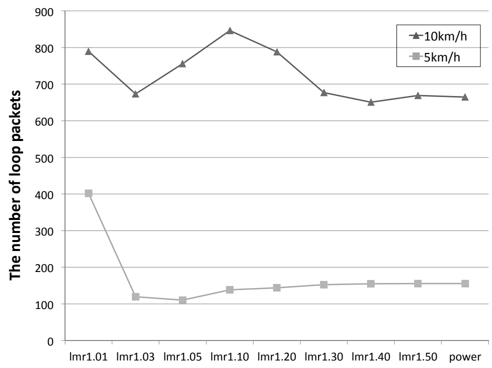


Figure 6: The number of loop packets

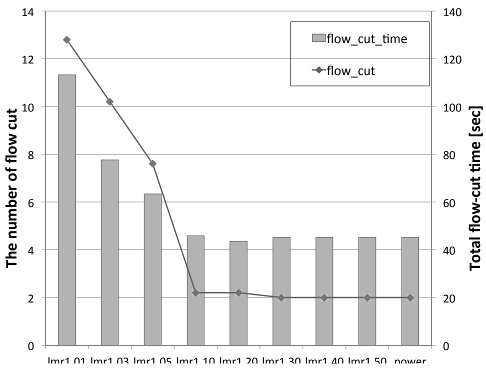


Figure 7: Flow cuts in 5km/h scenario

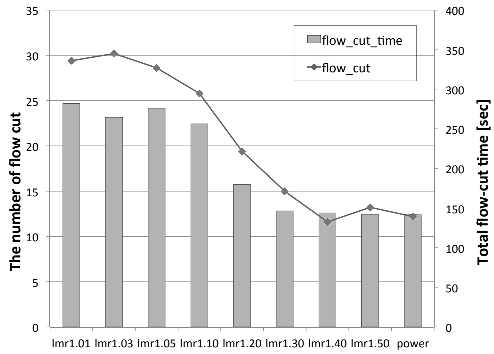


Figure 8: Flow cuts in 10km/h scenario

than once. First we found the number of loop packets is much larger in high mobility than low mobility. Note that there are many loop packets especially when $r = 1.01$ in lower mobility. This would be the effect of link cuts; when the limitation of LMR is too strong, links are cut before its metric is raised to the value enough to use alternative path. Consequently, if its new next-hop node is in the reverse direction of the destination, routing loops are created. Figure 6 shows this kind of loops, which caused of link cuts. Also, in the low mobility case, the number of loops gradually increases as r goes larger than 1.05. This implies that the effect of LMR to reduce loops appears when r gets lower. However, when r is lower than 1.03, the effect of link cut exceeds to this loop reduction effect. We conclude that the balance point is seen at $r = 1.05$ in lower mobility scenario.

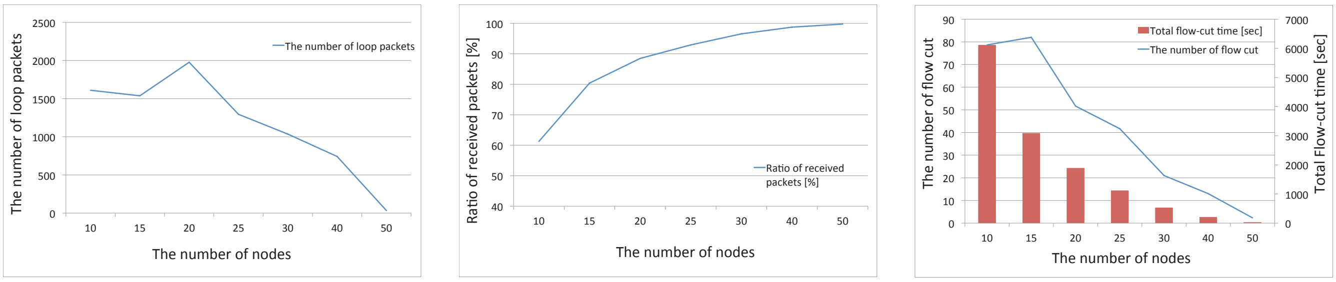
In contrast, such balance point is not seen in higher mobility scenario. This is because the bad effect of link cut is seen even in higher r, and simultaneously, the bad effect of loops is seen rather lower r. As a result, at the point around $r = 1.10$, the both effect is mixed so that their synergetic effects appear to be the highest loop counts. In fact, when we checked the event log of the simulation, the chain of those two factors, i.e., link cut cause loops then the loops cause another link cut and so on, are seen frequently.

In Fig. 7 and 8, we show the number of flow cuts and the total flow-cut time in both 5km/h and 10km/h scenario. We regard “flow cut” if CBR packets are not received in the period of more than 2 seconds at the destination node of each flow. The flow-cut time is the total sum of all link-cut duration of all of 5 CBR flows. Regardless of node speed, the performance goes worse when r goes smaller.

As we consider these four figures, we found several points to show. In Fig. 5, the difference of packet reachability between $r = 1.01$ and $r = 1.03$ in 5km/h scenario is about 5%, which is about 400 packets. In Fig. 6, the difference in loop packets is about 300 packets. It implies that 3/4 of the packet loss is caused by packet loops. In this part, the network performance deeply depends on packet loops.

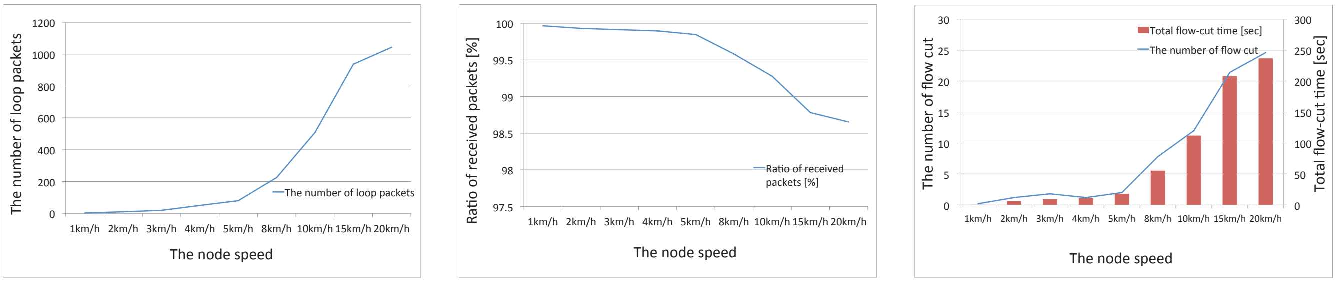
As another findings, see Fig. 6. we see the peak at $r = 1.10$ in 10km/h scenario. If we watch the right side slope of the peak and the packet reachability in Fig. 5 at the same r, we find that the packet reachability increases as loop reduces. This is also considered as the effect of loops. If we watch the left side slope, however, packet reachability does not change although loop packet reduces. This implies that packets are merely dropped instead of looping around $r = 1.05$. This is considered as the effect of link cut.

In summary, in this simulation experiment, we found that both of link cuts and routing loops effect on the performance of the network. Also, the relation between them is observed, i.e., link cuts create loop packets and vice-versa in the case of small value of r. We also found the balance point of those two in low mobility(5km/h) scenario, but in high mobility(10km/h) scenario we could not find the balance point because those two effects are mixed.



(a)Loop Packets (b) Packet Reachability (c) Flow Cuts

Figure 9: With Various Node Density



(a) Loop Packets (b) Packet Reachability (c) Flow Cuts

Figure 10: With Various Node Speed

4.3 Results: Effect of Scenario Parameters

To investigate the effect of scenario parameters on the performance of our dynamic metric, we show the results of three simulations. In Fig. 9 we show the results where the number of nodes (i.e., node density) varied. In Fig. 9(a), the peak of the number of loop packets appears at the node number of 20. When nodes become denser, loop packets decrease because the probability to find the next-hop node that is nearer the destination raises. If such next-hop nodes are always found, loops do not appear. In contrast, when nodes become thinner, loop packets decreases because the paths to the destination are easily lost. Therefore, in Fig. 9(b), packet reachability decreases as nodes goes thinner. Fig. 9(c) also shows this trend where the number and the time of flow cuts monotonically increases as nodes become thinner.

In Fig. 10 we show the results where node speed varied. These three figures show a simple trend that as node speed increases, the performance also decreases. Especially, note that the performance decreases rapidly when the node speed get faster than 5km/h. This means that our metric is possible to keep stability in the speed of walking. Note that, this is the result of default message interval of OLSR, i.e., hello interval is 2 seconds and TC interval is 5 seconds. If we use smaller interval, the proposed metric would work in higher mobility scenarios.

Finally, in Fig. 11, we show the results where the parameter n in the metric function varied. These three figures show that the performance is totally the same regardless of n.

5 CONCLUSIONS

In this paper we designed the a dynamic metric to solve the problem of communication (service) disruption caused by routing loops and link cuts due to mobility. Our metric is designed in combination with a RSSI based metric and a loop reduction method LMR to solve both of the factors.

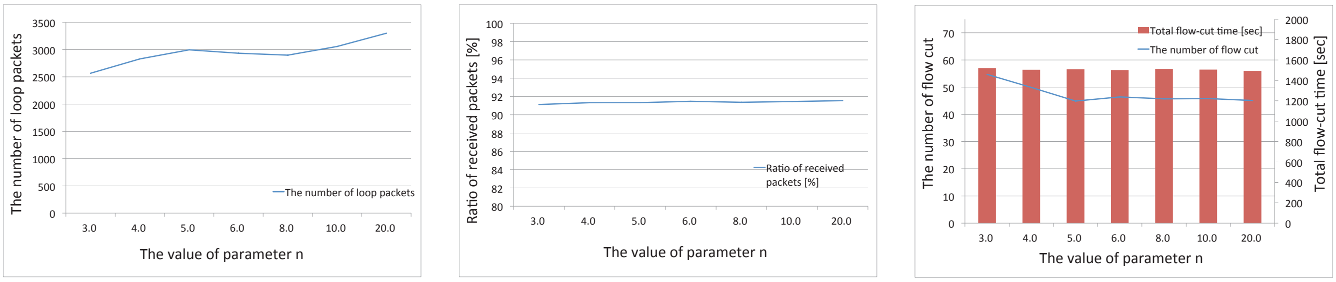
We conduct two simulation experiments to evaluate the performance of the proposed dynamic metrics in the scenario of which we exclude the effect of high traffic load. As a result, in 5km/h scenario, we found the balance point of the metric stretch r of LMR, which balances the two bad effects of routing loops and link cuts. Also, we found that the proposed dynamic metric can keep stable communication if the mobility is as fast as walking speed (i.e., 5km/h) and the node density is higher than a certain value.

Note that we can use reactive routing protocols such as AODV [2], which in general is regarded to be suitable for high mobility scenario. However, reactive routing protocols require re-construction of paths in case of link cuts so that users' communications are frequently disrupted. This study is an trial toward reliable communication in which users' communications are rarely disrupted using a proactive routing scheme.

As future work, we would like to develop the method to keep stability of the communication even in case of high-traffic-load scenarios.

ACKNOWLEDGMENT

This research is partly supported by Strategic Information and Communications R&D Promotion Programme (SCOPE), the Ministry of Internal Affairs and Communications, Japan.



(a) Loop Packets (b) Packet Reachability (c) Flow Cuts

Figure 11: With Various Parameter n

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(Received March 19, 2012)
(Revised June 14, 2012)

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