Multihop Mobility Metrics based on Link Stability

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***Abstract*—This paper proposes and validates a new category of routing metrics which assist current multihop routing protocols in becoming more sensitive to node movement and, as a consequence, increase the protocol robustness. The proposed metrics are based on the notion of time-based link stability. The paper discusses the metrics formulation and provides their performance evaluation based on discrete event simulations.**

***Index Terms*—Multihop routing, node mobility, link stability.**

I. Introduction

The most recent paradigms in wireless architectures describe environments where nodes present dynamic behavior (e.g. *Mobile Ad-hoc Networks*, *MANETS*) or somewhat dynamic behavior (e.g., *User-provided Networks*, *UPNs* [6]). In these environments, nodes correspond to wireless devices which are carried or controlled by humans, and hence exhibit movement patterns which mimic the ones of humans - *social mobility patterns*. In such environments, data transmission is based on multihop routing, where the path selection follows shortest-path computation. This implies that the most popular multihop routing approaches normally rely on static link cost metrics, e.g. hop count, or on specific Quality of Service metrics [4][18].

However, the notion of movement is an aspect that multihop protocols leave aside, as a natural consequence of the fact that the know-how leading to such approaches derived from the know-how acquired in fixed networks. Therefore, when nodes move, current multihop protocols simply react to changes derived from the underlying layers , and hence, path re-computation is likely to occur. In other words, current multihop approaches lack sensitivity in what concerns node movement. To cope with movement, mobile networks usually consider specific control mechanisms - *mobility management approaches*. Therefore, depending on the operation of the routing protocol and algorithm followed, the performance of the network may be significantly affected by different reasons, since the protocol reacts to link breaks and performs route discovery differently [3]. As we have previously debated [7], it is important to consider routing metrics that are sensitive to node movement.

In this paper, we propose a new set of multihop routing metrics that are based on time based link stability. These metrics will assist current multihop routing protocols in becoming more sensitive to node movement and, as consequence, to better react to temporary link breaks. Experiments have been carried out in *Network Simulator 2(NS2)* using *Ad hoc On-Demand Distance Vector(AODV)* hop count metric as benchmark for our metrics.

The rest of the paper is organized as follows. Section II presents the related work. Section III discusses aspects related to metrics sensitive to mobility, and shows how movement of nodes is supported as of today in mobile networks. Section IV discusses our proposed metrics and performs the validation through simulation. The paper concludes in section VI.

II. Related Work

Node mobility impact on routing has been studied [3][9], and schemes to counter mobility effect on routing have been proposed [24][11]. Mobility metrics have been devised to capture the extent of node mobility in a topology [25][12][20]. Tsumochi *et al.* discussed different mobility metrics and classified them into three specific categories according to scope: node, link, neighborhood [20]. Qin and Kunz characterized the requirement to include mobility metrics as routing protocol independent [12], which is a goal shared by our work. Their work shows that an interesting parameter to consider when devising mobility metrics is the *number of link breaks*. For the specific case of link-state routing, Yagyu *et al.* have proposed, on *Optimized Link State Routing Protocol (OLSR)* [21], a solution that assists in providing an earlier detection of link changes based on node speed. A fast moving node adjusts its frequency of connectivity control messages. Albeit relevant, this work considers link-state approaches only, and speed is the determinant factor of movement. However, speed is not a parameter that can assist in tracking movement pattern characteristics, nor link stability. Moreover, the threshold dictates the performance of the solution: if not adequately chosen, then control messages will be unnecessarily sent.

Several proposals have been derived from the link based mobility category discussed by Tsumochi *et al*. [20], which mainly consider the notion of *link stability* based on signal strength. For instance, Sun *et al.* have proposed a mechanism [17] that results in stable routes by not recurring to nodes that are far away (low signal strength), and also by giving lower priority, when forming paths to nodes that are moving. However, as there is no relation to movement patterns [7], their approach will trigger unnecessary path re-computation. Work from Taj and Faez [18], Wenqing *et al*. [22] also falls on the category of link stability based on signal strength analysis.

Another category of work which has been started by Qin and Kunz [12] considers time as a parameter that is relevant to adopt as a way to measure link stability. In previous work [7], we have debated such line of thought, which is now validated in this paper.

III. Dealing with Mobility

Node movement and its impact on the network operation is often left to be taken care of by mobility management solutions (control plane). The most popular ones available operate on different layers, are IEEE 802.11[13]; *Session Initiation Protocol* (SIP) based mobility on application layer[16]; the *Mobile Internet Protocol* version 6(MIPv6) on network layer [14].

While these solutions assist in handing over data sessions, on the network layer the routing process will always experience link breaks independently of being temporary or permanent. In other words, current mobility management solutions assist in making applications agnostic to node movement up to some extent. However, the underlying layers experience such impact which will then have repercussion in the network performance.

Concerning routing, a potential way to overcome such impact is to investigate mobility metrics that assist routing in becoming more sensitive (more adaptive) to node movement patterns.

Prior work [7][12] has addressed potential mobility tracking parameters that can be used to derive adaptive routing metrics. Some of such mobility tracking parameters are *pause time*, *link duration* and *average number of link breaks.* From the mobility parameters that were reviewed (e.g. node degree, number of link breaks, link duration), link duration is a parameter that possesses some ability to capture properties that may assist in distinguishing between permanent and temporal link breaks. Hence, in this paper we focus on the link duration notion and propose a set of metrics that can assist multihop routing in becoming more adaptive to node movement and, as consequence, reduce the need for path re-computation.

Our intention is to define metrics that are not dependent on the protocol behavior. In this way, our aim is to provide current multihop routing protocols with metrics that sustain mobility without modifying the protocol.

IV. Link Duration as a Stability Metric

Link duration (LD) is a parameter that is tightly related to the movement of nodes; it is also, as of today, one of the parameters that is most popular in terms of tracking node mobility. By definition, *link duration is associated to the period of time where two nodes are within the transmission range of each other*. In other words, it is the time period that starts when two nodes move to the transmission range of each other, and that ends when the signal strength perceived by the receiver node goes under a specific threshold [12][23][19]. Some authors then provide a variation of this definition by working the threshold value[8].

In order to assist in developing a cost associated to link stability, we have considered two different metrics associated to the notion of link break and duration, and to the relation of these two elements.

The first embodiment of link stability for link l, $s1_l$, comprises the ratio between the time a link is down (link break duration), lb, and the link lifetime lf for the duration that elapses between two consecutive breaks, as expressed in equation 1:

$$s1_l = \frac{lb}{lb + lf} \qquad (1)$$

Such ratio gives a measure of stability in the sense that the more prone is a link to break, the lesser is its stability. It is a simple metric which should assist in prioritizing links over time, and in choosing the ones that have a lower $s1_l$. The ratio will avoid short-lived links, since the duration in which the link is in broken state (*lb*) will be large. As nodes move, new links are formed and others are broken, meaning that link stability can change with time. A good link metric is one that captures the change in link stability. A link break means that there is a change in link stability. In our metric, link cost depends on the time the link has been down: links that incur long breaks will not participate in routing in the presence of links that are stable. Link stability depends on the time the link has been down and up. Implicitly, the metric captures nodes that are in group mobility. It can differentiate links that are formed between two mobile groups whose propagation path differ. It can also capture stable nodes that are static.

In a second embodiment of link stability based on LD, we introduce an additional parameter: the *number of link breaks*, nb_l.We refer to this embodiment as $s2_l$, provided by equation 2.

$$s2_l = \frac{lb * nb_l}{lb + lf} \qquad (2)$$

$s2_l$ takes into consideration the time period that a link is active, and also the number of breaks incurred with respect to a specific time-window. In comparison to $s1_l$, $s2_l$ not only considers the percentage of time a link is active, but also the frequency of breaks during that period.

To provide a concrete example, let us consider two links i and j, with the same duration: $lf_i = lf_j = 10$ seconds and also with the same link break duration, $lb_i = lb_j = 2$ seconds. However, while in i such inactive time is derived from one single, longer break, for link j that has been the product of 2 link breaks.

If, in this scenario, we consider $s1_l$, then link i and j have the same ranking. While if we apply $s2_l$, then link i is chosen instead of link j. Figure 1 illustrates the example we have provided, by showing the frequency of breaks.

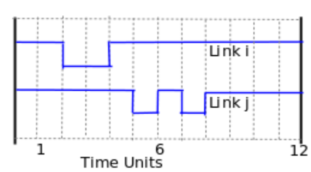


Figure 1: Example of the differences that may arise in link duration/robustness due to different frequencies of breaks.

V. Experimental Setup

A. Implementation Aspects

We have carried out experiments based on ns2.34 [1] using its native AODV module [4]. We have extended this module with our own metrics implementation [5], which is described in this section.

We have implemented a monitoring agent which periodically monitors each link and updates the parameters required to the computation of our metrics -average link duration lf ; number of link breaks nb; average link break duration lb. Such update is based on the exchanged AODV HELLO messages. Moreover, we then update status on each node based on the regular protocol operation, namely, by using Route Requests (RREQs) and Route Replys (RREPs). However, in order to ensure a better update of status and due to the breadth-first search of AODV, we have slightly modified the way AODV selects a path. Specifically, *Route Requests (RREQs)* are triggered to compute a path to an unknown destination, and a RREP is sent by the first node that has status concerning that destination. In our approach, we let the original RREQ travel to the destination, even if an intermediate node has already a path to the destination, to allow a quicker update of status and also to allow the destination to select a better path if one appears during a specific time interval.

This approach has implications in terms of signaling overhead and is not due to the metrics, but due to the way we have developed our metrics in ns2.34. From an operational perspective, we are currently investing in improving this part, by considering that the information required can be exchanged e.g. via HELLOs.

B. Scenario Setup

We have considered the parameters in ns2.34 to mimic *Wireless Fidelity(wi-fi)* 802.11b, being the parameters shown in Table I.

Table I: Summary of Simulation Parameters.

Parameter	Value
Simulation Time	1000 sec
Simulation Area	600 X 600 m^2
Transmission Range	250m
Propagation Model	TwoRayGround
Number of nodes	20
Traffic Type	CBR
Traffic rate	128kbps
Packet Size	512

We have considered several scenarios as provided in Table II. All of them comprise 20 nodes, which have been initially randomly placed in the area of the simulation. We have then considered two specific mobility models - Random Waypoint [10][2] and a follow-up of the Community Mobility Model (CMM) [15]). The major difference of this CMM variation in comparison to the original CMM is that this one also computes the stationary times of a node at selected targets.

We have also varied node speed considering two specific examples: low node speed, collected from the uniform interval [0.5, 5] meters per second (e.g. people walking); high node speeds, collected from the uniform interval [0.5, 20] meters per second. To analyze traffic impact, we have also considered two potential settings, by varying the number of flows: 2 flows representing low load on the network, and eight flows representing average load in the network. Each flow considers the parameters provided for traffic in Table 1.

The evaluation parameters that we consider are throughput on the network, packet loss, and routing overhead. .

Our benchmark is native AODV.

Table II: Simulation Scenarios.

Scenario	Speed Range	Mobility Model	Traffic Load
I	a)[0.5 - 5m/s] b)[0.5 - 20m/s]	RWP with attraction points	i) Two Flows ii) Eight Flows
II	a)[0.5 - 5m/s] b)[0.5 - 20m/s]	RWP without attraction points	i) Two Flows ii) Eight Flows
III	0 - 5m/s	Community based mobility model with pause time	i) Two Flows ii) Eight Flows

C. Results and Analysis

In this section, we discuss the performance of our metrics compared to hop count in the different scenarios (different traffic loads and different mobility patterns) as shown in Table II.

1) Scenario Ia) : On this experiment we consider Scenario I with nodes moving at low speeds in the interval [0.5, 5] meters per second. The nodes move according to the Random Waypoint model, where we have selected randomly 2 attraction points. The aim of this experiment is to understand the impact that speed may have on the performance of the metrics.

Figure 2 and 3 provide results for this scenario assuming low and high load, respectively on the network. From the figure 2, all the metrics performed the almost the same because the topology consisted of slow moving nodes with attraction points, meaning the nodes consisted of stable links with not so many link breaks. When the load was increased, the results obtained are as shown in figure 3.

In this scenario, the traffic load for the topology used in scenario I a) was increased to eight flows as shown in figure 3.

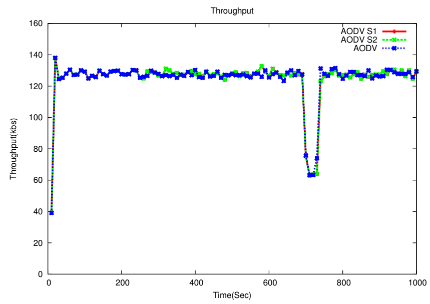
Observations derived from this scenario when the network is not loaded are not conclusive, other than the fact that we can observe one clear permanent break (around instant 700 seconds). Looking at the scenario when nodes move slowly but when there is more network load, then we can again observe a slightly better behavior for AODV S2 both in terms of achieved throughput, and packet loss. This is because the metric also considers a mobility parameter on number of link breaks.

However, in average, AODV S1 showed the best performance in terms of control overhead, especially in the first 600 seconds in the simulation.

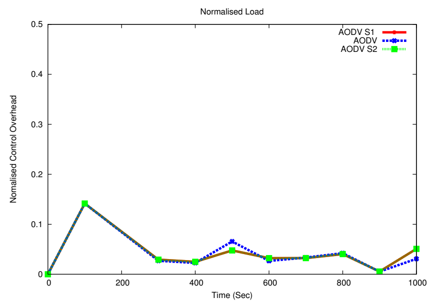
Comparing the performance of the metrics with differing traffic loads, evident is the increase in control overhead generated, more packet losses in high traffic and lower throughput loaded scenario. The more traffic transversing the topology, the higher the probability of a break on a route for a certain period and traffic congestion is also a factor that can lead to packet loss.

2) Scenario I b) : In this experiment we consider Scenario I with nodes moving with speeds in the interval [0.5, 20] meters per second. The nodes move according to the Random Waypoint model, where we have selected randomly two attraction points.

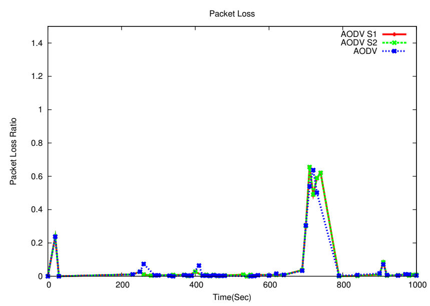
Results provided in Figures 4 show the performance of the metrics in scenario I for nodes moving at higher speeds, but



(a) Throughput.

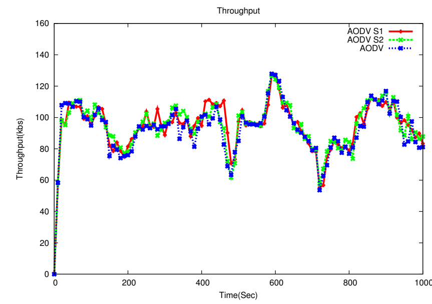


(b) Normalized Control Overhead.

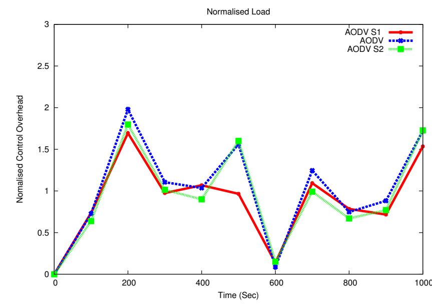


(c) Packet Loss Ratio.

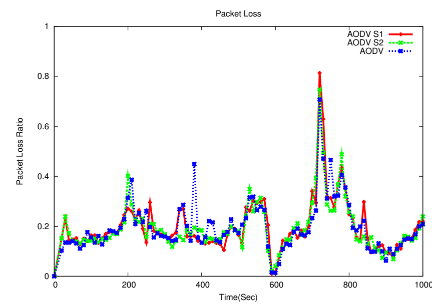
Figure 2: Scenario I perspective[speed range (0.5-5m/s) and 2 flows].



(a) Throughput.



(b) Normalized Control Overhead.



(c) Packet Loss Ratio.

Figure 3: Scenario I perspective[speed range (0.5-5m/s) and 8 flows].

with a lower traffic load in the network.

There is a noticeable lower throughput achieved when we consider AODV, at 200 seconds. This is because the nodes that were chosen on routes incurred link breaks. While both AODV S1 and AODV S2 managed to provide more stable paths. What is also noticeable is the higher control derived by applying AODV S1 and AODV S2 in the interval of 100 to 200 seconds. As explained in section 5.1, this is not due to the metrics and resulting path selection, but to our own implementation of such metrics in AODV: for each path discovery, one or two RREP(s) is/are sent to the source node. Globally, and even though differences seem small - result from the low load on the network - both AODV S1 and AODV S2 provide more stable paths. When comparing AODV S1 to AODV S2, AODV S2 provides slightly better performance in terms of throughput and packet loss

We repeat the experiment by increasing the network load, being the results provided in Figure 5.

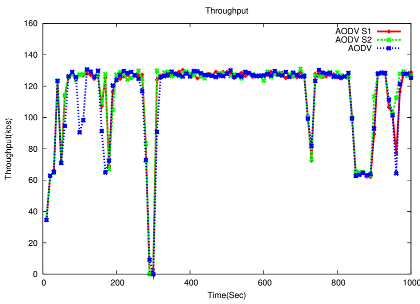
We again observe a slightly better behavior for AODV S2 in what concerns throughput. For control overhead, there is now an increase - in comparison to the previous experiment - for all of the approaches, but the one that is the more penalized is AODV S1.

During topology instability, AODV S2 seems to be the metric that captures the best stability, and that resulted in a lower control overhead, despite the way we have implemented our extensions.

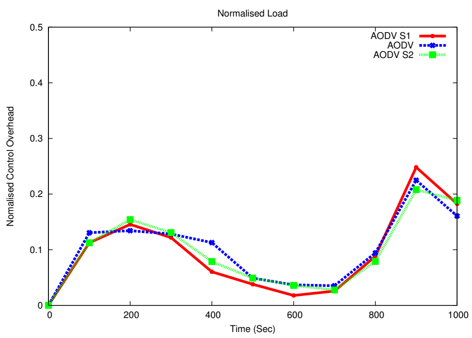
3) Scenario II a): In this section, we study the scenario II with slow moving nodes. Scenario II provides free mobility of nodes (i.e. without attraction points). The nodes in such a scenario will lead to shorter link duration when compared to mobility with attraction points. Network partitions may be frequent depending on the node density.

Figures 6 and 7 show the performance of the metrics with slow moving nodes with varied traffic loads.

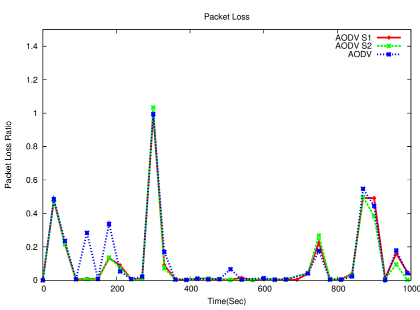
From figure 6, we see that a number of network partitions through monitoring the throughput. The performance of the metrics was generally the same-all affected by network partitions. The hop count metric incurred more packet loss than our metrics AODV-S2 gave the best throughput and packet loss



(a) Throughput.

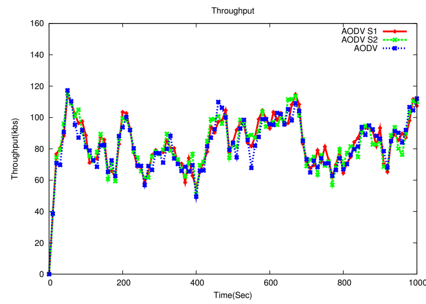


(b) Normalised Control Overhead.

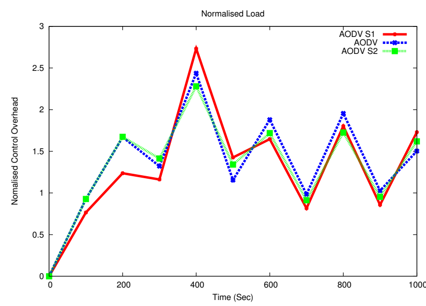


(c) Packet Loss Ratio.

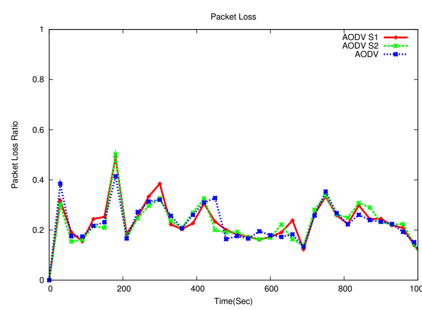
Figure 4: Scenario I perspective [speed range (0.5-20m/s) and 2 flows].



(a) Throughput.



(b) Normalized Control Overhead.



(c) Packet Loss Ratio.

Figure 5: Scenario I perspective[speed range (0.5-20m/s) and 8 flows].

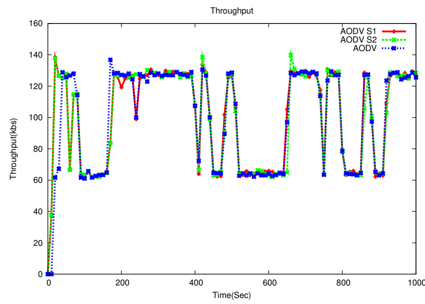
performance. For control overhead, the hop count metric only had the highest control messages monitored in the experiment for 20% of the simulation duration, meaning our metrics generated more control overhead than the benchmark metric. This can be attributed to the handling of route discovery control messages generated.

Traffic load in scenario II was increased while maintaining the node speed range of [0.5-5]. Figure 7 shows the performance of the metrics. The best performance was obtained from metric AODV-S2 in terms of throughput, packet loss and control overhead. The hop count metric accounted for 50% of the recordings with highest control overhead. AODV-S1 and hop count suffered a break in the period around 610 seconds in the simulation. Hop count recovered faster than our metric while AODV-S2 did not incur a break that affected the other two metrics.

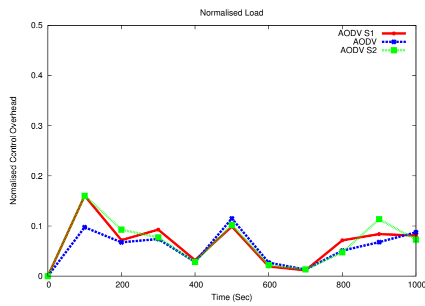
From figures 6 and 7, we can deduce that AODV-S2 was the best metric for this kind of topology.

4) Scenario II b): We now discuss our metrics´ performance when node speed is increased. When node speed is increased, with random mobility pattern, a higher number of link breaks is expected due to less spatial correlation among the nodes. On the other hand, for the same number of nodes and area the duration of the partitions may be reduced due to a fast node providing more opportunities to route(although this can be short-lived). Figures 8 and 9 show the performance of metrics with fast moving nodes and varied traffic loads.

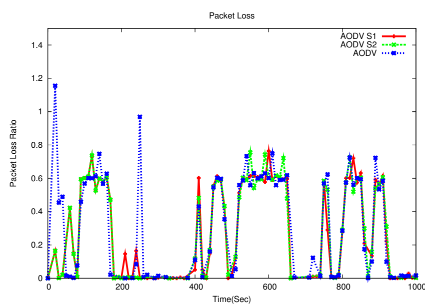
Figure 8 shows the performance of the metrics with low traffic load. AODV-S1 gave the best performance and the hop count metric the worst in this scenario. However, when traffic load was increased, with obtained results shown in figure 9, AODV-S2 had the best performance with AODV-S1 the worst performance among the metrics. As mentioned above, number of link breaks were expected high in this topology and an increase in traffic routes, exposes them to more path re-computations due to link breaks. AODV-S1 gave a good performance in low traffic loads by taking into consideration duration of link breaks and lifetimes and number of link



(a) Throughput.

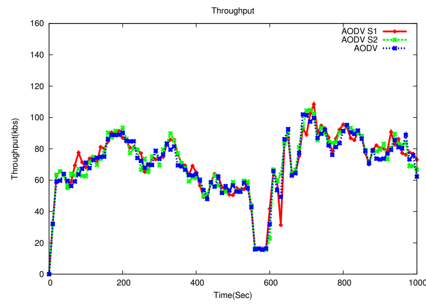


(b) Normalized Control Overhead.

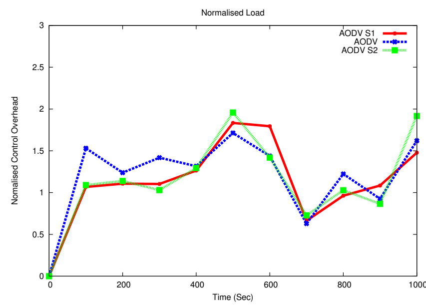


(c) Packet Loss Ratio.

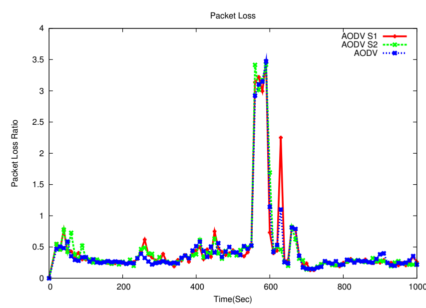
Figure 6: Scenario II perspective[speed range (0.5 - 5m/s) and 2 flows].



(a) Throughput.



(b) Normalized Control Overhead.



(c) Packet Loss Ratio.

Figure 7: Scenario II perspective[speed range (0.5 - 5m/s) and 8 flows].

breaks did not have an impact. However, when the traffic flows increased, more routes were breaking for AODV-S1 compared to AODV-S2 as the later takes into consideration breaks a link incurs.

5) Scenario III : To assess the impact of the mobility model on our analysis, we used a community mobility model with pause time to assess the performance of our metrics but only for slow moving nodes. We have varied traffic load as is the case in scenarios I and II. Figures 10 and 11 show the performance of the metrics under different traffic load.

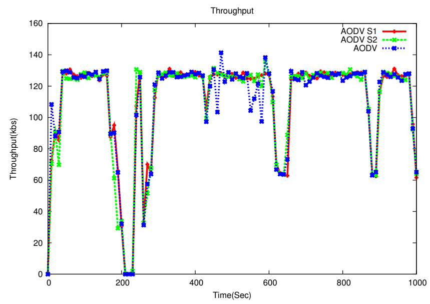
Figure 10 shows the performance of the metrics under low traffic load. In the first 100 seconds in the simulation, hop count gave the best performance by finding a route faster than our metrics, and that accounted for better performance in terms of throughput, packet loss and control overhead for the first 100s in the simulation. This is to say that there instances where hop count metrics is the best. However, for the rest of the simulations our metrics gave better performance while the difference in performance between them was minimal

Figure 11 shows the performance of the metric the traffic load was increased. From the results, non of the metrics gave a predominant good performance, while AODV-S1 was clearly the worst.

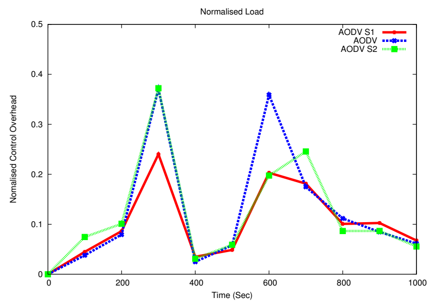
VI. Conclusions and Next Steps

This paper proposes and validates a new set of routing metrics based on the notion of link duration, with the purpose to understand how to provide routing protocols with more robustness to node movement, without jeopardizing the regular multihop routing protocol. We have discussed the fundaments for such metrics, proposing two possible embodiments, and have provided a simple validation of the metrics with the ns2.34 simulator.

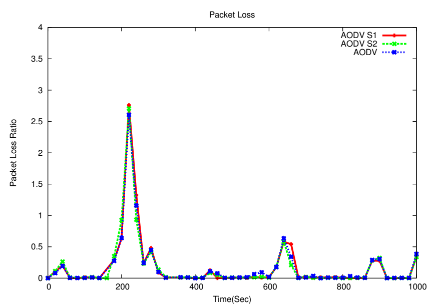
Based on the results obtained, we can conclude that our metrics, and in particular the metric based on equation 2 (AODV-S2) seems to assist AODV with more robustness in path selection. We have also understood that the way we have implemented our metrics requires tuning, as the overhead has increased due to the operational simplifications we did. Therefore, an adequate specification for AODV is currently



(a) Throughput.

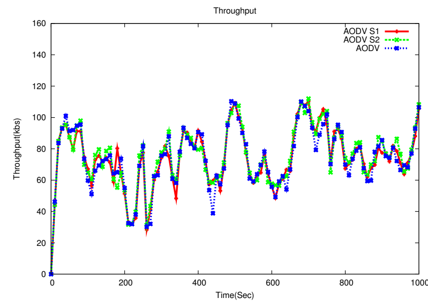


(b) Normalized Control Overhead.

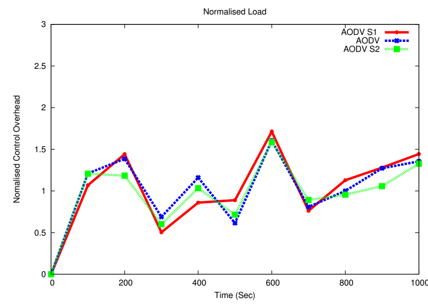


(c) Packet Loss Ratio.

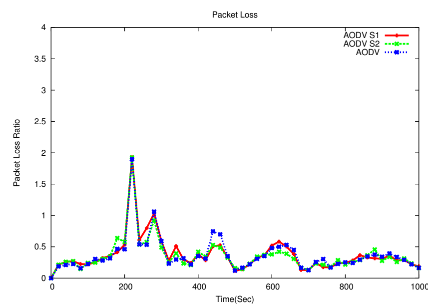
Figure 8: Scenario II perspective[speed range (0.5 - 20m/s) and 2 flows].



(a) Throughput.



(b) Normalized Control Overhead.



(c) Packet Loss Ratio.

Figure 9: Scenario II perspective[speed range (0.5-20m/s) and 8 flows].

being tackled as a next step. Moreover, and in order to understand if the metrics are indeed beneficial for any routing protocol, we will evaluate them based on link-state protocols such as OLSR.

Acknowlegment

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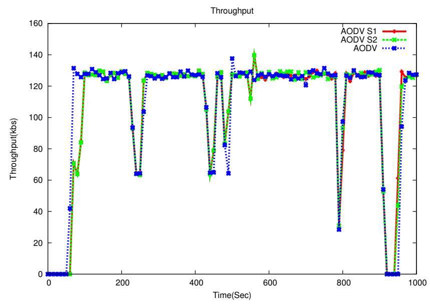
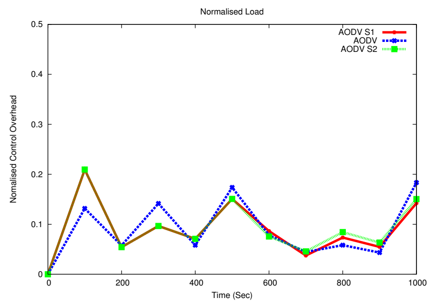
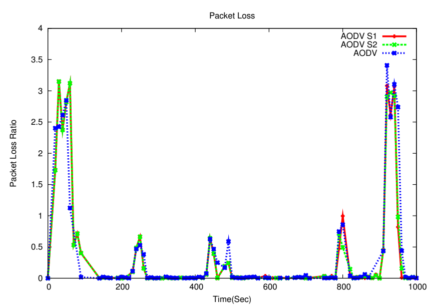


(a) Throughput.

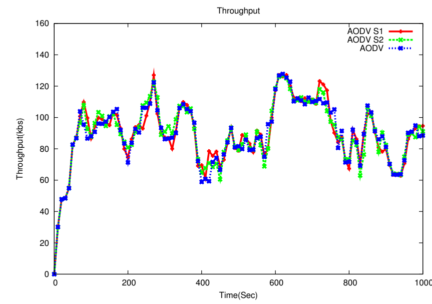


(b) Normalized Control Overhead.

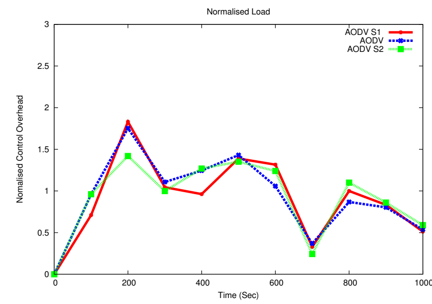


(c) Packet Loss Ratio.

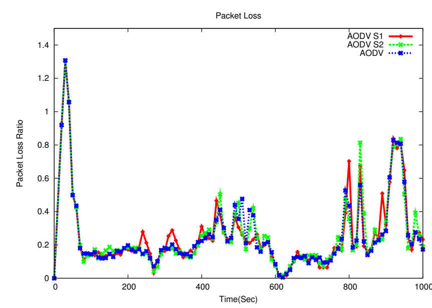
Figure 10: Scenario III perspective[speed range (0-5m/s) and 2 flows].



(a) Throughput.



(b) Normalized Control Overhead.



(c) Packet Loss Ratio.

Figure 11: Scenario III perspective[speed range (0 - 5m/s) and 8 flows].

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