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Neighbor-aware Adaptive Retry Limit for IEEE 802.11-based Mobile Ad Hoc Networks

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***Abstract*—In a mobile ad hoc network (MANET), it has been addressed that packet losses due to collision are often misinterpreted as routing failures, and cause unnecessary overhead for routing maintenance. There have been several attempts to avoid the unnecessary overhead through reducing collision losses. They are effective in a static topology where most losses are due to collision. In a dynamic topology, however, packets are lost due to actual routing failures (induced by mobility) as well as due to collision, and efforts for reducing collision are not enough. In this paper, we propose a new scheme for adjusting the limit of RTS retransmissions. In the proposed scheme, we treat packet losses differently as follows: (a) upon collisions, we increase the limit to reduce collision losses; and (b) upon routing failures, we decrease the limit to avoid unnecessary retransmissions. Through extensive simulations, it is shown that the proposed scheme effectively improves throughput in various scenarios and outperforms other comparable schemes.**

***Index Terms*—Mobile Ad Hoc Networks, IEEE 802.11, RTS retry limit.**

I. Introduction

A mobile ad hoc network (MANET) is a collection of mobile nodes forming a temporary network without any established infrastructure or centralized administration. During the last decades, a MANET is rapidly gaining popularity due to its numerous potential applications including military communications, disaster recovery and sensor networks.

One of the major obstacles to deploy a MANET in practice is low throughput. In [1]–[6], it has been addressed that a MANET based on IEEE 802.11 may suffer from heavy contention and following significant degradation of throughput. In [7], it has been also addressed that packet losses due to collision are often misinterpreted as link failures, called False Routing Failure (FRF). Then, the routing protocol attempts to find another path even though the current path is still valid. Setting up a new path is a high complexity process in both time and message, and eventually degrades throughput significantly.

There have been several attempts proposed to reduce collision and avoid FRF, and we may categorize them into two approaches, TCP-based approach and the cross layer approach between the MAC and the routing layers. In [5]–[7], it has been addressed that TCP's burst traffic is the main cause of frequent collisions followed by heavy contention. To avoid overloading a MANET, they have proposed to limit the congestion window in a TCP sender. It has been shown that appropriately limited window is effective to reduce collision and increase throughput in a MANET.

In [8], a cross layer approach between MAC and routing layers, called DAMPEN, has been proposed. To reduce FRF, in DAMPEN, the routing protocol responds only to bulk losses rather than to a single loss. In [9], an adaptive RTS/CTS retransmission scheme, called DSRL (Dynamic Short Retry Limit)[1], has been proposed to reduce collision loss in the MAC layer. This scheme adaptively changes the SRL based on the history of the previous packets. If frequent collision losses happen, it is considered that there is serious contention, and the SRL increases. It has been shown that both DAMPEN and DSRL can improve throughput in a static topology. The improvement of them is achieved based on alleviating the impact of losses by ignoring them in DAMPEN and by hiding them through increasing the SRL in DSRL. Those schemes may perform well in static topologies since most packet losses are due to collision. In mobile topologies, however, packets losses are induced not only by collision but also by actual routing failure due to mobility of nodes. Simply ignoring or hiding losses then leads to late respond to routing failure and reduce throughput consequently.

In this paper, we propose a new scheme for adaptive SRL. The proposed scheme attempts to distinguish collision and routing failure, and treats them differently. Upon collision, we increase the SRL to reduce collision losses. Upon routing failure, we decrease the SRL to avoid unnecessary retransmissions, which will eventually fail. Specifically, a heuristic method is employed to distinguish them without additional overhead. Each node overhears packets without regard to their destinations, and looks at their source addresses. Then, it applies a large SRL when it sends an RTS to a node whose packets are overheard recently since the node is likely to stay nearby. For a node whose packets have not been overheard recently, a small SRL is applied.

The main difference of this scheme from DSRL and DAMPEN is that the proposed scheme is designed based on the consideration of actual routing failures while others consider that most losses are due to collision. We perform

[1]Short Retry Limit (SRL) is the limit of RTS retransmissions for a data packet. If a node fails to transmit an RTS packet SRL times, then the corresponding data packet is discarded, and the routing maintenance process is triggered.

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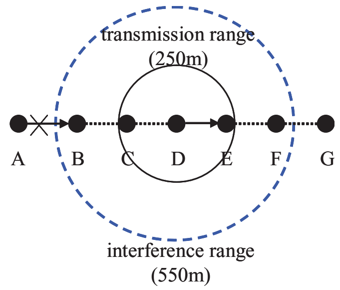
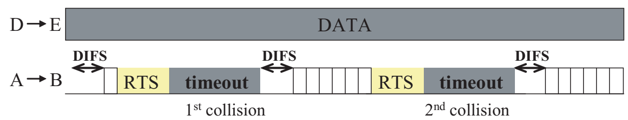


(a) Spatial reuse and contention



(b) RTS collisions due to the hidden terminal problem

Fig. 1. Interference of concurrent transmissions in a chain topology

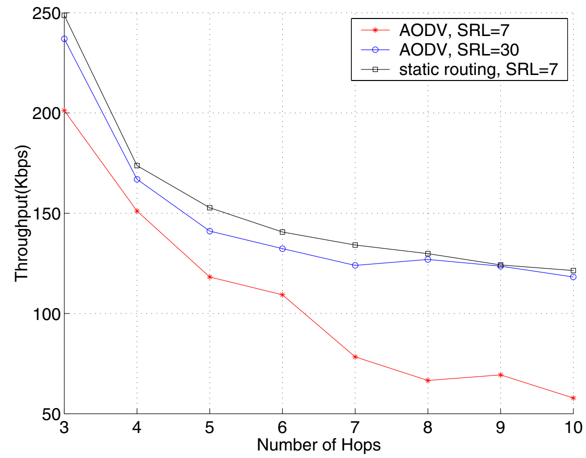
extensive *ns-2* [10] simulations, and show that the proposed scheme effectively improves throughput in mobile topologies as well as in static topologies, and outperforms other comparable schemes. It is also shown that the proposed scheme performs well with the TCP-based approaches.

The rest of the paper is organized as follows: The background and motivation of this paper are presented in Section II. In Section III, we present a detailed description of the proposed scheme. In Section IV, we evaluate the proposed scheme through extensive simulations with various scenarios. We conclude this paper in Section V.

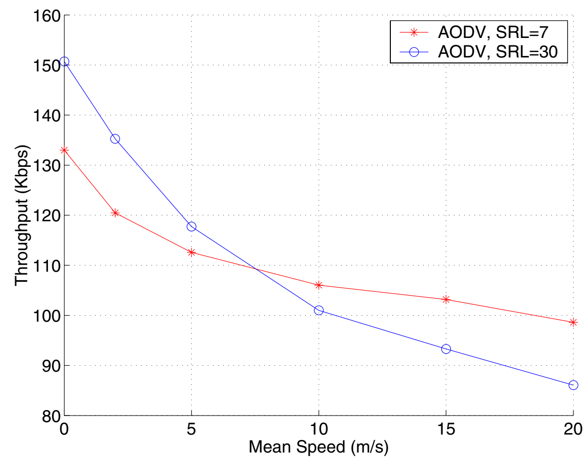
II. Background and Motivation

First, we describe how collisions occur in a MANET. The IEEE 802.11 DCF (Distributed Coordination Function) employs the RTS/CTS mechanism to avoid collisions by the hidden terminal problem. It is known that the RTS/CTS exchange is useful in heavily-contending environments, where many transmissions might fail due to collisions [11]. As illustrated in Fig. 1, however, collisions cannot be completely eliminated even with RTS/CTS due to the interference. If node A tries to transmit an RTS packet to node B while node D is sending a packet to either node C or node E, the RTS packet is corrupted by interference. Usually, the transmission time for a data packet is much longer than the transmission time of an RTS packet. Thus, once the first trial of an RTS packet is collided, then the subsequent trials tend to be collided as well. If a node fails to send an RTS packet a certain number of times, called Short Retry Limit (SRL), it discards the corresponding data packet, and considers that the destination node is no longer available. Then, it triggers the route maintenance procedure. In the current standard of IEEE 802.11, the SRL is set to seven statically.

The problem behind the static SRL arises from the fact that a node cannot distinguish collision losses and mobility-induced errors, and consequently, a MANET suffers from unnecessary overhead for routing maintenance. To examine the effect of



(a) In static chain topologies



(b) In mobile topologies

Fig. 2. TCP throughput in various topologies

routing instability due to the false routing failure, we compare TCP throughput in static chain topologies with a static and AODV [12] routing protocols. In the static routing protocol, each node forwards packets to its fixed next neighbor node, and the effect of routing instability is eliminated. For the AODV routing protocol, we perform two runs of simulation with SRL = 7 and 30, respectively, and observe the effect of SRL. We vary the number of hops from four to ten, and run two TCP flows. In Fig. 2(a), we present the aggregate throughput of the two flows. It is observed that the throughput in the static routing is much higher than that in AODV with SRL = 7. It is also shown that AODV with SRL = 30 achieves the similar throughput with the static routing. This result reveals that a large SRL can improve throughput in static topologies. In a topology with moving nodes, however, it may be dangerous to simply set the SRL large since a large SRL may force a node to attempt to send an RTS packet to a node which is not currently available.

To observe the interaction between SRL values and topology dynamics, we perform simulation in random topologies with different moving speed. In Fig. 2(b), we present the aggregate throughput of the 16 TCP flows. When the moving speed is low, the results confirm the previous simulation such that a large SRL is effective to increase throughput. As nodes move faster, however, it is observed that throughput with SRL = 30 decreases more quickly than throughput with SRL = 7.

III. The Proposed Scheme - Adaptive SRL

Based on the observations in the previous section, we propose a scheme for adaptive SRL to reduce the FRF. The main goal of this scheme is to stabilize routing path and eliminate unnecessary overhead for routing maintenance through differentiation of collision losses from mobility-induced losses. If collision losses can be distinguished from mobility-induced losses, we can avoid unnecessary routing maintenance overhead with increased SRL upon collision (refer to Fig. 2(a)) while reacting to topology changes more quickly with decreased SRL upon mobility-induced losses (refer to Fig. 2(b)).

The key challenge of this scheme is how to distinguish them. In both cases (collision loss and mobility-induced loss), a node observes the same result, no CTS within a certain amount of time interval, and it is hard to distinguish them without explicit helps from other nodes. In the proposed scheme, a heuristic method is employed to distinguish them without additional overhead. Each node overhears packets without regard to their destinations, and looks at their source addresses.[2] Then, it applies a large SRL when it sends an RTS to a node whose packets are overheard recently since the node is likely to stay nearby. For a node whose packets have not been overheard recently, a small SRL is applied to avoid unnecessary retransmissions. In Algorithm 1, we present the detail algorithm for the proposed scheme.

In the proposed scheme, each node maintains a table for SRLs of its neighbor nodes as shown in Fig. 3. For each neighbor node, the SRL and the timeout interval of the node are maintained. In the beginning, a node does not have a table for a SRL and uses a default SRL value (`MIN_SRL`) for data transmissions with neighbor nodes. Upon overhearing a packet

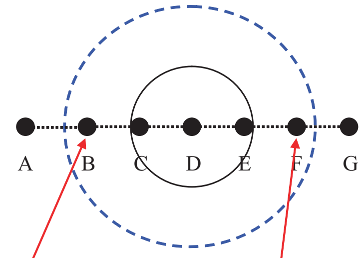
[2] In MANETs, many protocols rely on overhearing packets for their efficiency [13] [14].

Algorithm 1 An algorithm for adaptive SRL

: Upon detecting a packet from node i
1: `SRL`[i] = min{`SRL`[i] + k_1, `MAX_SRL`}
2: `timer`[i] = $\alpha\times$ (`now - last_arrival`[i])
3: `last_arrival`[i] = `now`

: Upon `timer`[j] expired
4: `SRL`[j] = max{`SRL`[j] − k_2, `MIN_SRL`}
5: `timer`[j] = `timer`[j] / β

6: `SRL`[i]: SRL of node i
7: `timer`[i]: timeout interval of node i
8: `now`: the current time
9: `last_arrival`[i]: time received the last packet



Node	SRL	Timer
A	9	50ms
C	13	60ms

<SRL table of node B>

Node	SRL	Timer
E	15	38ms
G	12	72ms

<SRL table of node F>

Fig. 3. Example of a SRL table maintained in each node

first from a neighbor node, the SRL of the neighbor node is added in the table and increased by k_1 up to `MAX_SRL`, and the timer for timeout is reset in Line 1–3. If there is no packet received from a node until the timer is expired, the SRL of the node is decreased by k_2 until reaching `MIN_SRL`. Upon reaching to `MIN_SRL`, the node's entry is deleted from the table. The timeout interval of a node is basically set to be proportional to the inter-packet space of the node such that a node sending packets less frequently has a longer timeout interval. It is reasonable to accommodate the sending rate. Otherwise, the SRL of a node with less traffic is constantly kept less. When timeout occurs for a node, the timeout interval of the node is reduced by $1/\beta$ to quickly decrease the SRL of nodes moved out.

IV. Performance Evaluation

In this section, we evaluate the performance of the proposed scheme through *ns-2* [10] simulation and compare it with other comparable schemes. In simulation, the DCF of the IEEE 802.11 standard [15] is used as the MAC layer protocol. The data rate of the wireless channel is 2 Mbps and a nominal radio transmission range for each node is about 250 meters while the interference range and carrier-sensing range are about 550 meters. We use TCP NewReno for senders, and unless otherwise stated, AODV [12] is employed as the routing protocol. For the proposed scheme, we configure the parameter set {`MIN_SRL`, `MAX_SRL`, k_1, k_2, α, β} as {7, 30, 1, 1, 2, 2}. Here note that `MIN_SRL` corresponds to the default value in the standard. To set `MAX_SRL` properly, we have performed simulations and observed that `MAX_SRL` greater than 30 shows the similar performance. Both k_1 and k_2 are simply set to one as in DSRL [9]. We have performed a number of simulations with different α and β, and have observed that α between two and four and β between one and four show the similar performance.

We evaluate the proposed scheme over different types of topologies such as chain, grid, and randomly-generated mobile topologies. In chain and grid topologies, each node is 200 meters away from its closest neighbors. For a mobile topology, we generate mobility scenarios based on the random way-point

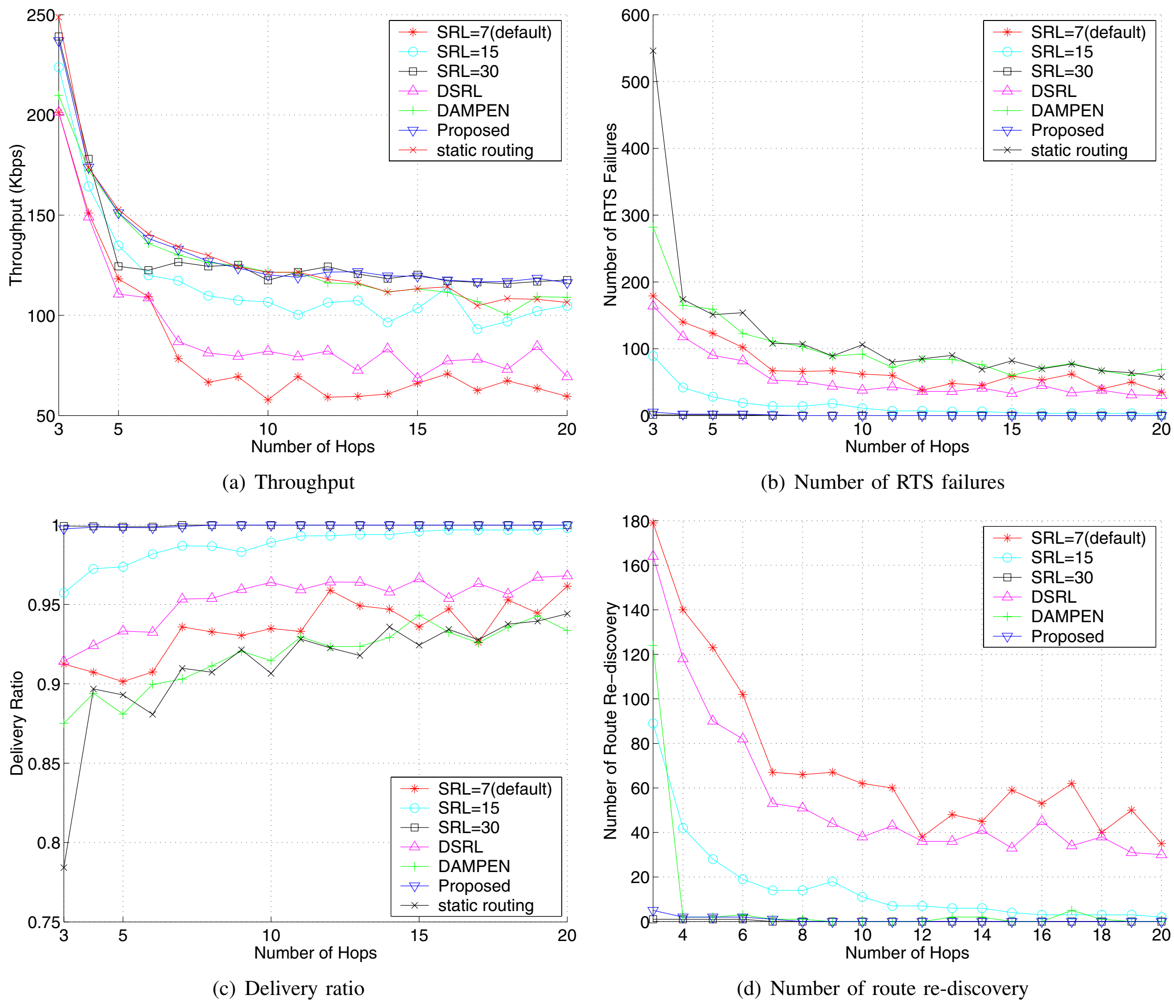


Fig. 4. Performance comparison of different schemes in a chain topology

mobility model [16]. We set minimum and maximum speeds to 0.9v and 1.1v, where 'v' is the mean speed.

A. Chain and Grid Topologies

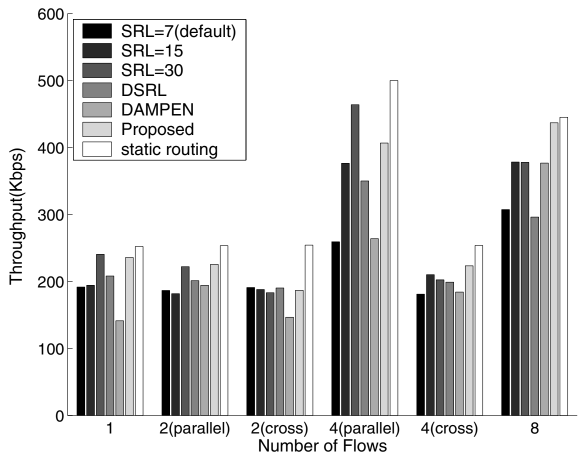
We first evaluate the proposed scheme in static topologies. Here we include the static routing as the performance bound since it shows the best performance in a static topology. We compare the proposed scheme with DAMPEN and DSRL. We also compare with the static SRL with different values. Results are presented in Fig. 4. Fig. 4 shows throughput in chain topologies with various numbers of hops from 3 to 20. As expected, it is observed that throughput with the static routing shows the best performance in overall. The proposed scheme, DAMPEN and the static SRL with 30 show the similar performance with the static routing. As the number of hops increases, DSRL achieves higher throughput than the static SRL with 7, but far less than the proposed scheme.

We also perform simulations in grid topologies with different numbers of flows, and present the results in Fig. 5. As we add more flows, contention level increases, and the similar results as in chain topologies are observed. It is also observed that the proposed scheme achieves higher throughput than DAMPEN, the static SRL with 30 even in static topologies.

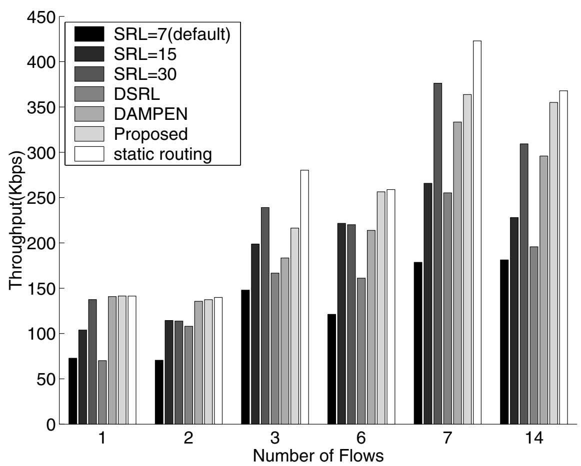
We also evaluate the proposed scheme with TCP window limit. Here the window limit is set to three as recommended in [5]. The simulation scenario is the same as the previous simulation with different numbers of flows, and we run two runs of simulation with 4 and 6 hop chain topologies, respectively. Results are presented in Fig. 6. It is observed that the proposed scheme with TCP window limit achieves additional performance improvement.

B. Mobile Topology

We now consider mobile topologies. We also evaluate the proposed scheme with different moving speed and compare it with other schemes. Here note that senders and receivers of TCP connections are pre-configured and fixed around the edge area of the network to observe the impact of multi-hop flows. We perform simulations using 20 scenarios with different seed numbers, and average the collected data. Here also note that the static routing is not applicable to mobile topologies and excluded in the following simulations.

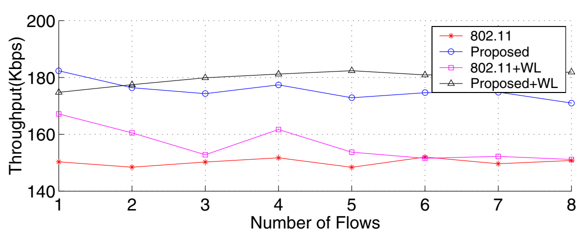


(a) 4x4 grid

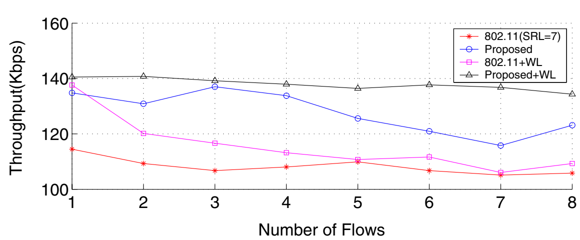


(b) 7x7 grid

Fig. 5. TCP Throughput comparison with different number of flows in grid topologies

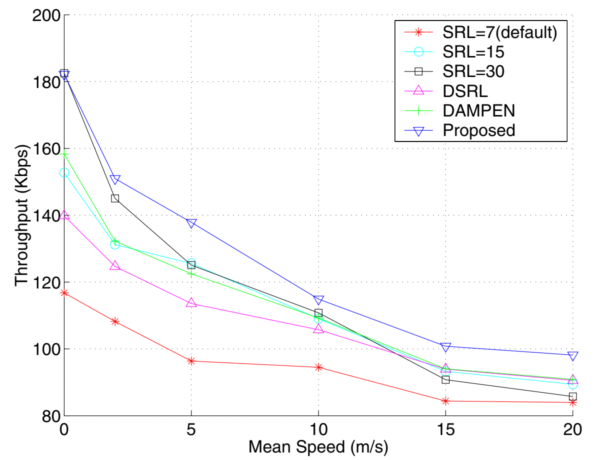


(a) 4-hop chain

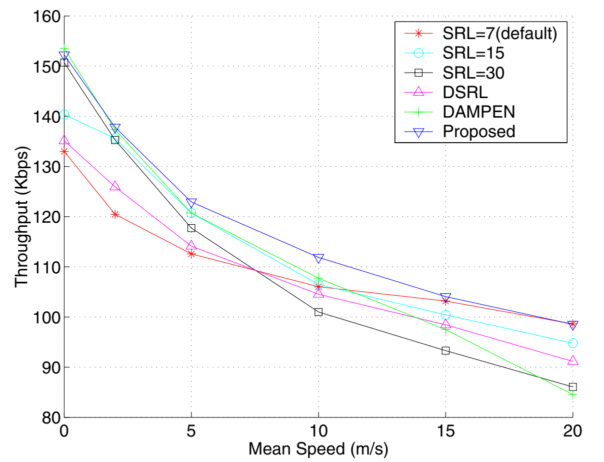


(b) 6-hop chain

Fig. 6. TCP throughput comparison with TCP window limit in chain topologies



(a) 8 TCP flows



(b) 16 TCP flows

Fig. 7. TCP throughput comparison with increasing node's speed in mobile topologies

Results are presented in Fig. 7. It is observed that the proposed scheme outperforms all the other schemes. As expected, it is also shown that a larger SRL shows the better performance in static and low mobility scenarios. As nodes move faster, it is observed that throughput with DSRL, DAMPEN and the static SRL with 30 decreases more quickly than throughput with the proposed scheme.

Throughout those results, it is obvious that the proposed scheme effectively manages the SRL even in mobile topologies as well as in static topologies. In TABLE I, we present average SRL values measured when packets are dropped due to collision and routing failure, respectively, in the proposed scheme. Those values indicate how many times a packet is retransmitted before being discarded. It is desirable to retransmit an RTS more times upon collision, and to drop the packet immediately upon routing failure, and it is observed that the number of retransmissions upon collision is almost twice of that upon routing failure. This means that the proposed scheme effectively distinguishes losses due to collision and routing failure, and explains how the proposed scheme achieves better

TABLE I
AVERAGE SRL WHEN PACKETS ARE DROPPED.

Actual Reason of packet losses	Mean Speed (m/s)					
	static	2	5	10	15	20
Collision	22.9	22.27	21.1	19.6	20.8	19.2
Routing failure	N/A	11.9	12.5	11.6	13.5	12.7

performance than others.

V. CONCLUSIONS

In this paper, we have proposed a new scheme for adjusting the limit of RTS retransmissions. Unlike other schemes, the proposed one attempts to distinguish the two types of packet losses, losses due to collision and routing failure. Through extensive simulations, it has been shown that the proposed scheme effectively improves throughput in mobile topologies as well as in static topologies and outperforms other comparable schemes.

In the future, we plan to conduct further research to enhance our scheme. It is important to determine an optimal value of SRL. This value could be varied in the different circumstance. We would like to formulate our scheme to obtain an optimal SRL. Also, we plan to investigate the cross-layer interaction for various mobility and channel error models.

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