An Enhanced AODV Route Repairing Mechanism in Wireless Ad-Hoc Sensor Network

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Abstract —Ad hoc On-demand Distance Vector (AODV) routing protocol has been widely applied in Wireless Ad-hoc Sensor Networks (WASN). Link breaks often occur in WASN due to the mobility of nodes or other reasons. Only after a link break detected, the route repair scheme in AODV will be initiated to keep the connectivity of network. In this paper, we propose an enhanced Preemptive Local Repairing Mechanism (PLRM) for AODV, which adopts the preemptive link break avoidance by monitoring link quality and other performance degradations. It allows for reducing control overhead and route length caused by the repairing process. Therefore, compared with other improved AODV route repairing schemes, PLRM shows the better performance by the simulations, in terms of packet delay, control overhead and packet delivery ratio in WASN.

Index Terms—AODV; routing protocol; local repair; wireless ad-hoc sensor network

I. Introduction

WASNs consist of inexpensive low-power sensor nodes, being applied in various fields, ranging from the environment monitoring, to emergency search and rescue operations and smart battlefields. Recently, due to their great application potential, a trend has emerged that introduces mobility to WASN, it not only reduces the maintenance costs of the system but also improves adaptability to dynamic environments. The static or mobile nodes self-organize themselves into a dynamical network with no fixed infrastructure [1]. However, the network topology changes can be frequently caused by link breaks due to the node mobility, limited energy and bandwidth or instability of the wireless environment. Therefore, one of the key challenges for routing protocols in WASNs is to deal with link failures, and to repair the routes [2].

AODV is one of the most popular reactive protocols used in WASNs due to its adaptability to network topology changes [3]. AODV can repair route by reestablishing a new route from the source node (Source Repair), or initiate repairing from the intermediate node where the link break is detected (Local Repair) [4]. However, it only recovers routes after route break detection and doesn't respond quickly enough to link failures. Thus, it may suffer from the risk of flooding the whole network for new route discovery, and the route repair process may introduce packet loss, high delay in packet delivery and high control overhead. All of these disadvantages further degrade the network performance. Considerable research efforts have been devoted to improving AODV performance by locally repairing broken links, anticipating link breaks by using preemptive mechanisms. However, some solutions are only focused on mobility prediction and require special hardware, other phenomena like external interference, congestion or energy depletion can also lead to link break. Some mechanisms may lead to longer routes. Some protocols predict link break by periodically broadcasting Hello messages within a one-hop radius, which will incur extra communication overheads energy consumption.

Motivated by the above challenges, in this paper, we focus on the problem of route repair in mobile WASN; an enhanced Preemptive Local Repairing Mechanism (PLRM) for AODV is present, which adopts the preemptive link break avoidance by monitoring link quality, residual energy and traffic load. It takes measures to reduce control overhead and packet delay in local repair process. In addition, it also allows for shortening route length by removing redundant nodes along the path. To achieve our objectives, PLRM takes advantage of overhearing functions of transceivers to collect information about neighbor nodes to perform route reestablishing immediately.

The subsequent sections of this paper are organized as follows. In Section II, we introduce some related work. Then, in Section III, the PLRM is present in detail. Section IV gives the results of simulations for the proposed mechanism. Finally, Section V concludes the paper and mentions the future work.

II. Related Work

In this section, we present the related work of route repair in WASN. Firstly, we review the route maintenance and repair mechanism used by AODV; secondly, we describe the main local repair and preemptive route recovery extensions for on demand routing protocols.

AODV is a representative of reactive routing protocols of ad hoc networks. A new route is established by the

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route discovery process only when a source node needs to communicate with an unconnected destination node. Once a node in an established route detects the link break, route repair mechanism will be initiated. AODV repairs routes with two methods. As for Source Repair, the node detecting the link break transmits a route error (RERR) message to upstream nodes towards the source. Once the source receives RERR, it starts a new route discovery process. If the repair process is successful, the source and destination of a broken route will remain disconnected from the moment of the transmission of RERR until the reception of a new route reply (RREP) by the source. The duration of this disconnection interval (or route change latency) may be extremely significant, especially in highly loaded, mobile, or large networks [5], [6]. Local repair can relieve this problem. It’s invisible for the source node. The intermediate repairing node broadcasts route request (RREQ) with a time-to-live (TTL) value set to the last known distance to the destination, plus an increment value and waits for the return of RREP. When the repairing node receives RREP, the route is successfully repaired. In this way, the route is recovered faster and the mechanism prevents the entire network from being flooded again. If the repairing node fails to receive RREP, it sends RERR to the source node, starting a new route discovery.

Xiao *et al.* proposed a novel AODV repair method that would repair the route within the next two-hop node (ILRAODV) [7]. Authors believed that the broken of link occurred mainly in a small range, so initiating the process of route repair in the next two-hop nodes could reduce the restoration delay and packet overhead. If the link was broken, it firstly initiated the repair process in the next two-hop nodes until found a new route, or repaired the route by AODV local repair scheme.

Feng *et al.* proposed a recursive route repair algorithm (SRAODV) [8]. When link breakage happened, the repairing node repaired the route locally at first. If unsuccessful, the cached data packet was transmitted back to the pioneer node, and then the pioneer node tried to repair the route locally; if still unsuccessful, the cached data packet was returned to the upstream node again, until the repair was successful or the data packet was returned back to the source node. The deficiency in the algorithm is obvious that it might bring much overhead in network.

While local repair may have relieved some problems, it also need to flood RREQ messages, which may lead to packet loss and communication delay once the link is broken, especially in heavy traffic condition. A number of researches have proposed improving the maintenance of routes for AODV using preemptive mechanisms.

One of the main categories of these preemptive route recovery protocols defines link quality as a function of the Received Signal Strength (RSS) [9], in order to anticipate link breaks. When an intermediate node receives a packet with RSS less than the predefine threshold, the node assumes the link is about to break, thus, it triggers route recovery preventing an incoming link break.

A major disadvantage of the protocol of Goff *et al.* is the great overhead encountered upon false warning messages. Hence the system is very vulnerable to false warning message or missing judgements of broken links [10].

The approach of Soliman and Al-Otaibi needs to maintain a Neighbor’s Activity Table (NAT) recording information located two-hop away [11]. The maintenance of such a NAT depends on nodes of an active route monitoring activities of the other active routes, which make their protocol sensitive to the number of conversations. In cases of fewer conversation-pairs, the NAT table may not be able to populate enough alternative links for future path detouring.

Srinath *et al.* present a preemptive route repair strategy called Router Handoff [12]. When predicting a link break, a node broadcasts a HANDOFF packet including information of the previous and next hop nodes of broken link. If the node that receives a HANDOFF packet has valid routes to both the previous and next hop nodes, it will send a reply to notify that there existed a valid route to the next hop. However, two tables about the RSS information of neighbors need to be maintained by broadcasting periodic HELLO messages, thus it imposes a considerable burden on the network.

Crisostomo *et al.* introduced a preemptive local route repair scheme as an extension for AODV [13], which uses GPS to obtain the position and speed of the nodes to compute the link expiration time (LET). When the LET of a link falls below a predefined threshold, a local repair is used to find an alternative path. This scheme requires GPS device equipped on each node and clock synchronization. Moreover, it's only aware of link degradation due to mobility.

In addition, these solutions can't predict network congestion, transmitting interference and node energy exhausted, which also cause link failures.

III. Preemptive Local Repairing Mechanism

In this paper, we propose an enhanced Preemptive Local Repairing Mechanism (PLRM) for AODV. Firstly, the link break prediction mechanism is present, and then we detail the fast local repair scheme which allows for reducing control overhead and route length. To achieve targets, in PLRM the nodes need to turn on their overhearing function to collect information about neighbor nodes.

A. The Prediction Mechanism of Link Break

Because the link break is not only caused by weak link quality, but also other reasons such as congestion and node energy exhausted, we perform the prediction mechanism of link break for PLRM by monitoring link quality, residual energy and traffic load. The link quality is generally modeled by the probability of successful frame transmission of that link, denoted as Link Delivery

Ratio (LDR) [14]. It can be estimated by radio hardware, without additional transmission of packets. The CC2520 radio provides an internal Link Quality Indicator (LQI) for each received frame [15]. The LQI is highly correlated with LDR.

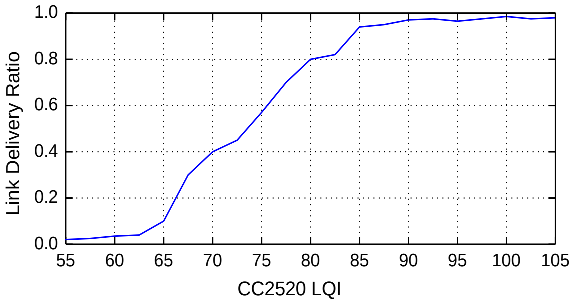


Fig. 1. Relationship between LQI and delivery ratio in CC2520 radio.

Fig. 1 shows the empirical relationship between LQI and LDR on CC2520. A linear model can be used to map LQI observations to LDR estimates, denoted as $ELDR(LQI)$. Residual energy rate is expressed by $RER = E_R / E_I$, where E_R is the residual energy and E_I is the initial energy of batteries. Queue length can be used to measure the traffic load. The nodes buffer the incoming packets in finite size queue and start dropping any new incoming packets when queue is full. Residual queue rate is defined as $QLR = QL_R / QL_M$, where QL_R is the residual free queue length, QL_M is maximum queue length.

We define $ELDR_{th}$, RER_{th}, QLR_{th} as validity threshold. In PLRM, when the relay nodes detect $ELDR < ELDR_{th}$, or $RER < RER_{th}$, or $QLR < QLR_{th}$, we consider the link break is about to occur.

B. Local Repairing Scheme of PLRM

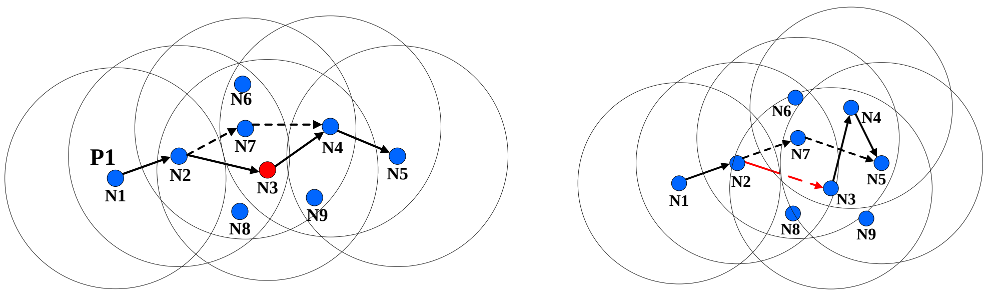
In PLRM, the Hop-Count (HC) value from the source node is piggybacked within the data packets, which is set to 0 on source node and increased by one on each hop along the route. The node with RER higher than RER_{th} needs to maintain a table named Neighbor Max-Min HC Table (NMMHT) as shown in Table I, by overhearing packets transmitting within its neighbor region.

TABLE I: NEIGHBOR MAX-MIN HC TABLE.

Field name	Description
SID	ID of source node
DID	ID of destination node
SN	Sequence number of packet
NID_{min}	ID of node with minimum hop count
HC_{min}	Minimum hop count
$ELDR_{min}$	ELDR to node with minimum hop count
NID_{max}	ID of node with maximum hop count
HC_{max}	Maximum hop count
$ELDR_{max}$	ELDR to node with maximum hop count
EXT	Expiration time

When a node overhears a packet, if the *ELDR* of the link is higher than $ELDR_{th}$, it checks if there is a valid record with the same <SID, DID> in NMMHT; if there isn't the one, the node insert the new record in the table, and the information of MAX-HC and MIN-HC nodes in table are both set to information of the node overheard. If there is a valid record with the same <SID, DID> in NMMHT, the node check the SN; if SN in packet is same with that in record, the node compares the HC values in packet and record, if HC in packet is less than the HC_{min}, or more than the HC_{max} in record, the relevant fields in record (HC_{xxx}, NID_{xxx}, $ELDR_{xxx}$, EXT) should be updated, or else the packet is discarded. If SN in packet is less than that in record, the packet is discarded. If SN in packet is bigger than that in record, the fields of this record should be updated as it's a new record.

An illustrative example is shown in Fig. 2 (a). When the node N7 overhears a forwarding process of packets in path P1, a record in NMMHT of N7 has been achieved as shown in Fig. 2 (c). The nodes of neighbors of N7 with minimum and maximum HC on P1 are N2 and N4 respectively. In Fig. 2 (b), the topology change occurs due to mobility, the node of neighbors of N7 with maximum HC on P1 changes to N5. Therefore, the record updates as shown in Fig. 2 (d).



(a) (b)

SID	DID	SN	NID_{min}	HC_{min}	$ELDR_{min}$	NID_{max}	HC_{max}	$ELDR_{max}$	EXT
N1	N5	sn	N2	1	eldr2	N4	3	eldr3	t1

(c)

SID	DID	SN	NID_{min}	HC_{min}	$ELDR_{min}$	NID_{max}	HC_{max}	$ELDR_{max}$	EXT
N1	N5	sn	N2	1	eldr2	N5	4	eldr5	t2

(d)

Fig. 2. An illustrative example of PLRM: (a) An example of local repairing; (b) The topology changing due to mobility; (c) A record in NMMHT of N7; (d) A record in NMMHT of N7 updated due to mobility.

TABLE II: NOTICE PACKET FORMAT.

Field Name	Description
SID	ID of source node
DID	ID of destination node
IDS	ID of sender
HC	hop count of the sender
FLAG	NOTICE Flag shows the inducement of link break denoted as: L (Link quality), Q (Queue length), E (Residual energy)

Once one node detects a link break is about to occur, it broadcasts the NOTICE packet to one-hop neighbors. The packet format is shown in Table II. The nodes receiving the NOTICE packet will perform preemptive local repair scheme according to NMMHT and the FLAG in NOTICE packet.

We give an illustrative example as shown in Fig. 2. In Fig. 2(a), when the node N7 receives a NOTICE packet from N3 with FLAG denoted as ‘E’ or ‘Q’, it shows that the inducement of link break on path P1 is residual energy or queue length. If $RER > RER_{th}$ and $QLR > QLR_{th}$ in N7, N7 checks its NMMHT; if there is a valid record with the same SID and DID as those in NOTICE packet; and if ($NID_{min} < ID_S$ and $NID_{max} > ID_S$); N7 is eligible to be a preemptive local repairing node. In Fig. 2(b), when the node N7 receives a NOTICE packet from N3 with FLAG denoted as ‘L’ due to mobility, it shows that the inducement of link break on path P1 is link quality. N7 checks its NMMHT as mentioned above; but if ($NID_{min} \leqslant ID_S$ and $NID_{max} > ID_S$) or ($NID_{min} < ID_S$ and $NID_{max} \geqslant ID_S$); N7 is eligible to be a preemptive local repairing node. The eligible preemptive local repairing nodes calculate the backoff time Tb of replying the node IDS when they receive the NOTICE packet for the first time. Tb is expressed as (1). T_{max} is the maximum backoff time.

$$T_b = \frac{(1 - ELDR_{\min} \times ELDR_{\max})}{HC_{\max} - HC_{\min}} \times T_{\max} \tag{1}$$

It means the eligible preemptive repairing nodes, which have the better link quality from upstream and downstream nodes, and bigger difference of the HC_{max} and HC_{min}, have shorter backoff time. A node doesn’t reply the NOTICE packet if it overhears a reply packet to the same sender of NOTICE packet before the backoff time elapses. As shown in Fig. 2(b), N7 has the shortest backoff time, and firstly replies to N3, other nodes overhearing the reply packet don’t reply. If N3 doesn’t receive any reply within T_{max}, it will perform the standard route repairing mechanism of AODV. Next, N7 updates its routing table, set N5 as the next hop node to destination and N2 as the previous hop node, and then notifies N2 and N5 to change its next hop and previous hop to N7 respectively. Thus, the new route denoted as dashed line replaces the old route on which the link is about to break. As we will show, this scheme can reduce the route length and the redundancy of reply packets transmitting.

IV. SIMULATION

To evaluate and analyze the performance of our proposed PLRM for AODV, we build our scheme into a custom MATLAB simulator. In our simulations, the WASN consists of 50 mobile nodes deployed uniformly at random in a rectangular area initially. In each simulation run, each node moves toward a randomly selected direction with a random speed ranges from 0 to 10m/s. Upon reaching some randomly determined location, the node pauses for a fixed pause time, and then moves again in the same way. Table III shows the main simulation parameters. In addition, we set $ELDR_{th} = 0.7$, $RER_{th} = 0.3$, $QLR_{th} = 0.3$. The simulation results are the average values in 10 independent runs.

TABLE III: SIMULATION PARAMETERS

Parameter	Value
Terrain	500m × 500m
Simulation time	600s
Node number	50
Mobile speed	0−10m/s
Mobility model	Random waypoint
MAC protocol	IEEE 802.15.4
Bit rate	250 Kbps
Radio range	150 m
Packet rate	0.5packets/s
Packet length	50 B

The performance of PLRM is compared with AODV, ILRAODV and SRAODV protocols. For comparative purposes, the periodic Hello messages are disabled in these protocols, and link layer feedback is used to detect link break. Three different metrics are used to evaluate the performance. Specifically, end-to-end delay is defined as the time duration from packet generation to its eventual delivery to the destination. Delivery ratio represents the ratio of the number of packets successfully arrived at destinations to the number of packets generated by sources. Normalized control overhead is the ratio of the control packets over all data packets that are delivered.

We firstly estimate how the node mobility affects the performance of these protocols. 10 concurrent connections from source to destination nodes are selected randomly in the simulation area. The performance metrics are evaluated with different pause time. The pause time of 0 means continuous movement of nodes; the pause time of 600 means the network topology is stationary.

Fig. 3 shows the delivery ratio varying with different pause time. The delivery ratios of all protocols are decreasing with the pause time. It's no surprise higher node mobility lead to lower delivery ratio. However, the PLRM has the highest delivery ratio under the same pause time due to the preemptive local repairing mechanism. In addition, generally, the longer the route length is, the higher the probability of a packet drop is. The PLRM can produce shorter route, which is in favor of improvement of the delivery ratio. For the same reasons, the advantage of delivery ratio of PLRM appears to be more obvious in more dynamic network.

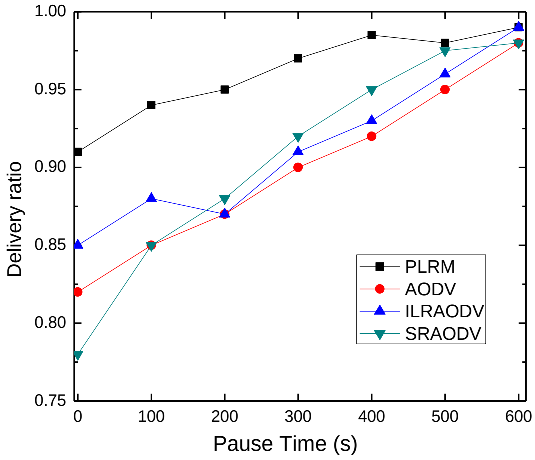


Fig. 3. Delivery ratio with different pause time.

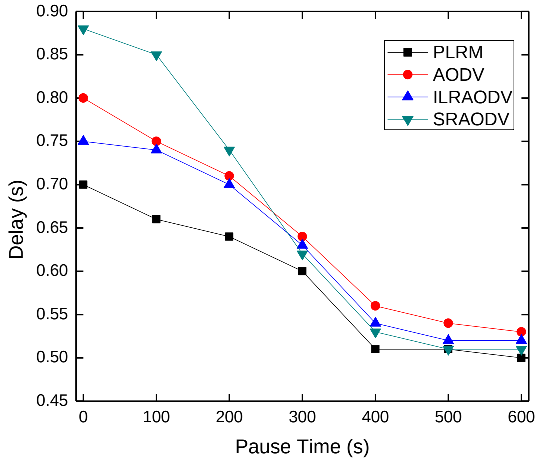


Fig. 4. End-to-end delay with different pause time.

In terms of end-to-end delay, the PLRM outperforms other protocols as shown in Fig. 4. The preemptive local repairing mechanism can avoid the buffering of any incoming packets to the broken link. Moreover, as has been stated, the PLRM may perform shorter route than other local repairing protocols, which also reduces the end-to-end delay. ILRAODV shows lower end-to-end delay than AODV and SRAODV under lower pause time; because when the link break occurs due to high mobility of nodes, the ILRAODV just repairs the link break within the next two-hop nodes, which reduces the probability of congestion and channel access contention due to flood RREQ messages to the whole network.

Fig. 5 shows the normalized control overhead varying with different pause time. With the mobility of nodes increasing, the chance of broken link increases, so the normalized control overhead increases in all protocol. The PLRM avoid flooding RREQ messages, therefore, it produce the least normalized control overhead. SRAODV introduces the most overhead in the network, because the recursive repairing algorithm may cause the local repairing process time and again in one route repairing process, especially under high mobility of nodes.

Next, we estimate the performance with different traffic load conditions under moderate node mobility, the pause time is set to 200s, and the number of concurrent connections varies from 5 to 25.

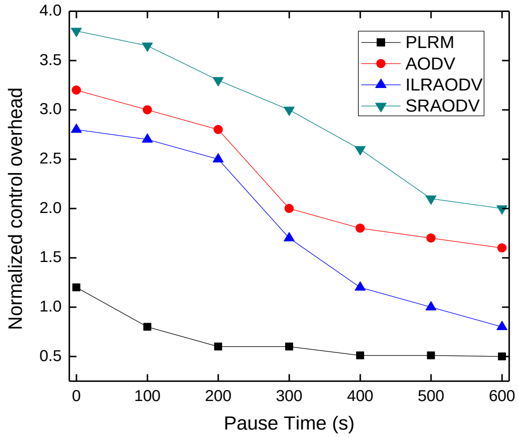


Fig. 5. Normalized control overhead with different pause time.

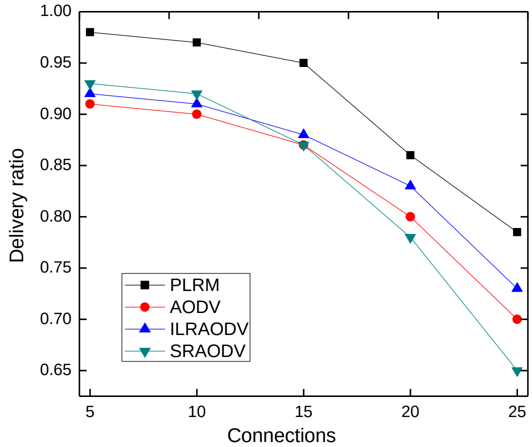


Fig. 6. Delivery ratio with different connections.

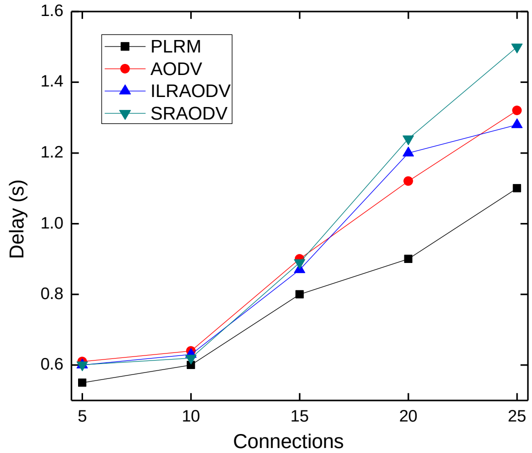


Fig. 7. End-to-end delay with different connections.

As shown in Fig. 6, Fig. 7 and Fig. 8, with the increase of the number of concurrent connections, concurrent packets from different sources may have higher probability in channel contention at the same relay nodes, which lead to lower delivery ratio, higher end-to-end delay and normalized control overhead, even congestion under heavy traffic load (25 connections). Because the prediction mechanism of link break of the PLRM allows for the link quality and traffic load at the same time, it outperforms other protocols under the same number of connections. Moreover, the local repair scheme of the PLRM considers reducing the route length and avoiding flooding RREQ messages, which is beneficial to improve the delivery ratio, reduce the end-to-end delay and control overhead.

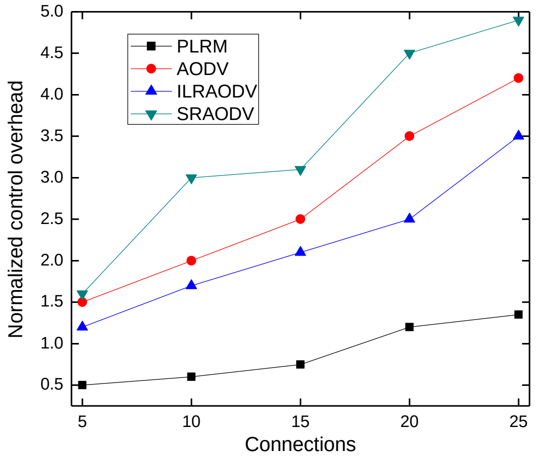


Fig. 8. Normalized control overhead with different connections.

V. Conclusions

In this paper, to suit the changing network topology of WASN, we propose an enhanced Preemptive Local Repairing Mechanism for AODV. The PLRM adopts the preemptive link break avoidance by monitoring link quality, residual energy and traffic load, and takes measures to reduce route length, control overhead and packet delay in local repair process. Although with increase of the number of concurrent connections, maintaining NMMHT needs more extra memory, the simulations show that the PLRM could indeed outperform original AODV, ILRAODV and SRAODV in term of delivery ratio, packet delay and control overhead within a high mobile network environment.

As future work, we will further evaluate the PLRM in various complex dynamic environments. Another aim is to focus on how to improve the success rate of local repairing scheme of PLRM.

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