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Research Article

Modeling Routing Overhead of Reactive Protocols at Link Layer and Network Layer in Wireless Multihop Networks

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To keep information recent between two nodes, two types of link sensing feed-back mechanisms are used: link layer (LL) and network layer (NL). In this paper, we model and evaluate these link sensing mechanisms in three widely used reactive routing protocols: ad hoc on-demand distance vector (AODV), dynamic source routing (DSR), and dynamic MANET on-demand (DYMO). Total cost paid by a routing protocol is the sum of cost paid in the form of energy consumed (in terms of packet reception/transmission) and time spent (in terms of processing route information). Routing operations are divided into two phases: route discovery (RD) and route maintenance (RM). These protocols majorly focus on broadcast cost optimization performed by expanding ring search (ERS) algorithm to control blind flooding. Hence, our model relates link sensing mechanisms in RD and RM for the selected routing protocols to compute consumed energy and processing time. The proposed framework is evaluated via NS-2, where the selected protocols are tested with different nodes' mobilities and densities.

1. Introduction

Recent research mainly focusses on wireless multihop networks (WMhNs) due to increased use of wireless devices all around. A mobile node, in WMhNs, acts as a transmitter and as a router (relay node) for nodes not in the direct transmission range of each other. Applications of these networks range from a small room to large areas like a battlefield or a natural disaster. Performance of WMhNs majorly depends on the routing protocols operating these networks.

On the basis of route calculation, routing protocols are divided into two major categories: reactive and proactive. Protocols from the former category calculate routes when data request arrives, thus, also called "on-demand" protocols. Examples of these protocols are ad hoc on-demand distance vector (AODV) [1, 2], dynamic source routing (DSR) [3, 4], dynamic MANET on-demand (DYMO) [5, 6], and so forth, whereas protocols belonging to the later category periodically perform routing table calculation independently from data request arrival. These protocols include destination-sequence distant vector (DSDV) [7], fish-eye state routing (FSR) [8, 9], optimized link state routing (OLSR) [10, 11], and so forth.

Reactive protocols are well suited for highly dynamic networks, whereas proactive ones are designed for large networks with low mobility. Reactive protocols exchange lot of control (routing) information to accurately route data within or outside the network. There are two main phases in which these protocols calculate routing information: route discovery (RD) and route maintenance (RM). After computation and establishment of a route for the requested destination during RD phase, RM phase starts if a link breaks. The first step is to perform periodic links' sensing

in active route (which are established during RD for data transmission). Links are sensed by the routing protocols either from link layer (LL) or from network layer (NL). After detecting a link breakage while sensing, the second step (RM phase) repairs the link. The control messages generated by routing protocols and the time which is spent during RD and RM, collectively generate routing overhead.

In this paper, we model routing overhead produced by three reactive protocols: AODV, DSR, and DYMO. We choose the selected three routing protocols because these are widely used in literature. Our main focus is to measure routing overhead for LL and NL feed-back mechanisms. To analyze the link sensing mechanisms of AODV, DSR, and DYMO, we conduct simulations in NS-2. The overhead is measured for nodes' different mobilities and densities.

2. Related Work and Motivation

2.1. Related Work. Routing protocols play an important role for performance optimization in wireless networks. Many protocols, including bioinspired routing [12, 13], security based routing [14, 15], and balanced load routing [16, 17], have been proposed for wireless networks. However, we focus on the modeling of overhead for reactive routing protocols at NL and LL. In [18], authors focus on quality routing link metrics for wireless multihop networks. Authors in [19] address performance evaluation of two on-demand routing protocols in WMhNs, DSR, and AODV. They simulate these protocols for 20 and 40 number of sources with speeds of 2 m/s and 6 m/s. Simulation results show that AODV protocol is more suitable as compared to DSR for wireless transmission with rapid change of network topology.

In [20], authors compare AODV and DYMO, using packet-level simulations for different speeds (1 m/s, 9 m/s, and 15 m/s) in NS-2. They select throughput, routing overhead, and average packet size of the routing packets as performance metrics. From simulation results, they conclude that AODV achieves higher throughput than DYMO. This is because the distance vector information of AODV consumes less bandwidth than source routing of DYMO.

The control overhead of ad hoc routing protocols is surveyed in [21]. The authors classify reactive and proactive protocols as "hello protocol" and "flooding protocol," respectively. They conclude through simulations that "hello protocols" generate more control overheads than "flooding protocols" in mobile scenarios. Hence, "hello protocols" are more suitable for static scenarios and "flooding protocols" for mobile scenarios.

The failure or unability of a routing protocol to identify all disjoint paths between a pair of nodes is called path diminution. In [22], this phenomenon is studied. The paper states that diminution of path becomes unavoidable whenever a protocol becomes aware of multiple disjoint paths while discovering a single route. In order to mitigate path diminution, the paper discusses various schemes. However, as per conclusion none of the discussed schemes guarantee to discover all disjoint paths between a pair of nodes.

Saleem et al. in [23] analytically model and compare the routing control overhead. The flooding mechanism of reactive protocols is compared with relay node technique of proactive protocols.

Packet drop and link failure significantly degrade network performance. As the root cause of these problems is congestion so [24] presents congestion and link failure aware data delivery mechanism. This work jointly considers control approaches, congestion detection, and buffering while increasing reliability of delivering data. Simulation results validate better performance of the proposed mechanism as compared to the selected existing ones in terms of end to end delay, throughput, and reliability.

Saleem et al. [25] propose a framework for flooding cost in routing protocols. They evaluate the framework using two key performance metrics: routing overhead and route optimality for DSDV, DSR, AODV-LL, and gossiping.

A reactive traffic-aware routing strategy for urban vehicular environments has been proposed in [26]. The beauty of this strategy is the avoidance of dead ends and unnecessary routes. In this work, dynamic paths are created on the basis of prior global knowledge of the traffic for each vehicle. Moreover, this prior global knowledge is used by decision making nodes while taking critical decisions.

As mobility and PHY/MAC layers implementation affect the routing protocols in ad hoc networks so [27] presents simulation based analysis of the two reactive routing protocols: DSR and AODV. The simulations are carried with modified IEEE 802.11a (PHY/MAC layers) along with modified mobility models (freeway, traffic sign, and stop sign). From OPNET based simulation results, they conclude that modified version of AODV performs better than DSR in terms of delay, throughput, and number of retransmission attempts.

2.2. Motivation. In our previous work [28], we model the routing overhead incurred by AODV, DSR, and DYMO in terms of energy and time costs for the generated control packets. We presented a framework for RD and RM of the protocols. These protocols mainly focus on the optimization performed by expanding ring search (ERS) algorithm to minimize the overhead generated due to blind flooding. The proposed framework is evaluated via NS-2 to compare performance of the chosen routing protocols.

A comparative evaluation of AODV and DYMO is also presented in [29]. Both the protocols are compared through simulations using LL feed-back mechanism.

Inspired from [28, 29], we enhance the framework of [29] for LL and NL link sensing mechanisms. Moreover, to validate the proposed framework, we simulate AODV, DSR, and DYMO with two link sensing mechanisms: LL and NL. Simulations are performed against varying network sizes and nodes' mobilities.

3. Modeling the Cost Paid by Reactive Protocols

Flooding is a process used by routing protocols to exchange routing information throughout the network. In this process, each node acts as router and each node broadcasts route information to all of its neighbors. This process is repeated until destination is reached. Blind flooding is a simple approach in which each node rebroadcasts the packet, whenever it receives packet for the first time.

In [25], an approximate per packet cost paid by a protocol for RD using blind flooding is presented as

$$C_p = \begin{cases} P_s d_{\text{avg}}, & \text{if } h = 1, \\ P_s d_{\text{avg}} + d_{\text{avg}} \sum_{i=1}^{h-1} (P_s)^{i+1} \prod_{j=1}^{i} d_f[j], & \text{if } h > 1, \end{cases} \quad (1)$$

where d_{avg} denotes the average degree or the average number of immediate one-hop neighbors of a node. A node is isolated, if it has $d = 0$. In (1), h is the number of hops in the network, $d_f[j]$ is the expected forward degree of a node at jth hop, and P_s is the broadcast probability [30].

ERS [31], adopted by AODV, DSR, and DYMO, is one of the optimization techniques that have been proposed to control the routing overhead. As ERS is adopted by the three reactive routing protocols so we focus on its working. This technique sets search diameters, based on time-to-live (TTL) value in RD phase, to limit broadcast overhead. In ERS, these search diameters are known as rings. In order to calculate the packet cost of a ring "R_i," h is replaced by TTL_VALUE of that ring. Let $C_E(R_i)$ be the cost of any ring R_i. The selected protocols set TTL_VALUE in route REQuest (RREQ) message. In ERS, RD can either be successful or not; successful RD is stopped after receiving route REPly (RREP) message, whereas unsuccessful RD results in dissemination up to maximum TTL_VALUE and rediscovery attempts. An R_i which generates RREP(s) is called R_{rrep} and ring up to maximum TTL limit is known as $R_{\text{max\_limit}}$ resulting in either successful or unsuccessful RD. Therefore, $C_E(R_i)$ is computed from our previous work in [28] as

$$C_E(R_i) = \begin{cases} P_r d_{\text{avg}}, & \text{if TTL}(R_i) = 1, \\ P_r d_{\text{avg}} + d_{\text{avg}} \sum_{\text{TTL}=1}^{\text{TTL}(R_i)-1} (P_r)^{\text{TTL}+1} \prod_{j=1}^{\text{TTL}} d_f[j], & \\ & \text{if TTL}(R_i) > 1. \end{cases} \quad (2)$$

In ERS, RD requires adjustments in TTL values to find destination. If source node fails to find destination, then TTL is incremented. In ERS, gradual growth of broadcast ring takes place to reduce the chances of flooding throughout the network which results in different rings for different broadcast levels. The cumulative routing cost for expanding rings, during RD process "$C_{E\text{-RD}}$," is computed as

$$C_{E\text{-RD}} = \begin{cases} \sum_{R_i=1}^{R_{\text{max\_limit}}} (C_E(R_i)) \times (\text{RREQ}), & \\ & \text{if no RREP received}, \\ C_{E\text{-}R_{\text{rrep}}} & \text{if TTL}(R_{\text{rrep}}) = 1, \\ \sum_{R_i=1}^{R_{\text{rrep}}} (C_{E\text{-}R_i})_{R_i}, & \text{otherwise}, \\ \{R_{\text{rrep}} = 1, 2, 3, \ldots, \text{max\_limit}\}. & \end{cases} \quad (3)$$

On encountering a dynamic topology due to varying number of nodes and mobility rates, a routing protocol "p" pays some cost in the form of per packets consumed energy "C_E^p" and in the form of per packet time spent "C_T^p". In [28], authors have computed this cost as

$$C_{\text{total}}^p = C_E^p \times C_T^p. \quad (4)$$

3.1. Cost of Energy Consumption. Each reactive protocol performs two routing operations: RD and RM. Therefore, we define the cost for energy consumption, during RD and RM processes, C_E^p, respectively

$$C_E^p = C_{E\text{-RD}}^p + C_{E\text{-RM}}^p. \quad (5)$$

C_E^p is different for each reactive protocol due to different routing strategies. For example, in DSR, multiple routes in route cache (RC) reduce the routing overhead with the help of gratuitous RREPs (grat. RREPs) and packet salvaging (PSing), whereas, in AODV, route length is shortened by grat. RREPs to reduce the cost of RD process and successful Local Link Repair (LLR) process diminishes route rediscoveries.

Receiver of the route REQuest (RREQ) generates a route REPly (RREP) to the originator, if it either is itself the destination or it contains an active route (AR) to the destination (also known as gratuitous RREPs (grat. RREPs)). Grat. RREPs are generated if the node generating the RREP is not the destination itself but is a substitute node along the path from originator to destination.

3.1.1. Energy Consumed during RD. AODV, DSR, and DYMO use ERS mechanism for RD via broadcasting the RREQ messages from the source node. Successful RD results in unicast of RREP message to the originator node. Depending upon the generating node, the RREP message is of two types: dest. RREP and grat. RREP. An RREP which is generated from destination node is known as dest. RREP which is used by all the three reactive protocols. A source node can receive RREP from the nodes that contain alternate (short) route to the desired destination. These replies are only supported in AODV and DSR and are known as grat. RREPs.

```
(1) if R = active_mode then
(2)     for all l ∈ AR do
(3)         start LSM
(4)         if upstream node detects Link Breakage (LB) then
(5)             start LLR
(6)             if successful repair through LLR then
(7)                 repairing node sends data to repaired route
(8)             else
(9)                 broadcast RERR message
(10)                receiver of RERR deletes faulty route from RT
(11)                S starts route re-discovery based on RREQ_RETRIES
(12)            end if
(13)        else
(14)            repeat
(15)        end if
(16)    end for
(17) else
(18)    no action is performed for link checking
(19) end if
```

Algorithm 1: Route Maintenance in AODV.

The cost paid for RREQ packets and for RREPs, produced during RD, is computed as

$$C_{E\text{-RD}} = \begin{cases} \sum_{R_i=1}^{R_{\text{max\_limit}}} \left(C_E\left(R_i\right)\right) \times (\text{RREQ}) \\ \qquad \text{if no RREP received} \\ C_E R_{\text{rrep}} \times (\text{RREQ}) \\ \qquad \text{if TTL}\left(R_{\text{rrep}}\right) = 1 + \sum_{n=1}^{n_{\text{rrep}}} (\text{RREP})_n \\ \sum_{R_i=1}^{R_{\text{rrep}}} \left(C_E\left(R_i\right)\right) \times (\text{RREQ}) + \sum_{n=1}^{n_{\text{rrep}}} (\text{RREP})_n \\ \qquad \text{otherwise,} \end{cases} \tag{6}$$

where n_{rrep} notation is used for number of nodes which unicast RREP to the sender. The ERS mechanism of AODV and DYMO is shown in Figure 1(a) with TTL_VALUES and waiting_time using LL feed-back mechanism, whereas Figure 1(b) shows NL feed-back mechanism.

The generation of RREP(s) in AODV and DSR (refer Figure 2) is also due to valid routes in routing table (RT) or RC. Therefore, R_i for DSR and AODV is less than DYMO due to the absence of grat. RREPs in DYMO. R_{rrep} can be $1, 2, 3, \ldots, \max\_\text{limit}$, depending upon the hop-distance from source to destination.

3.1.2. Energy Consumed during RM. After the establishment of a successful route, during RD process, the next process is to perform link state monitoring (LSM). During this process, links of active routes (ARs) are sensed, as we have mentioned earlier that this sensing can be performed at NL and LL.

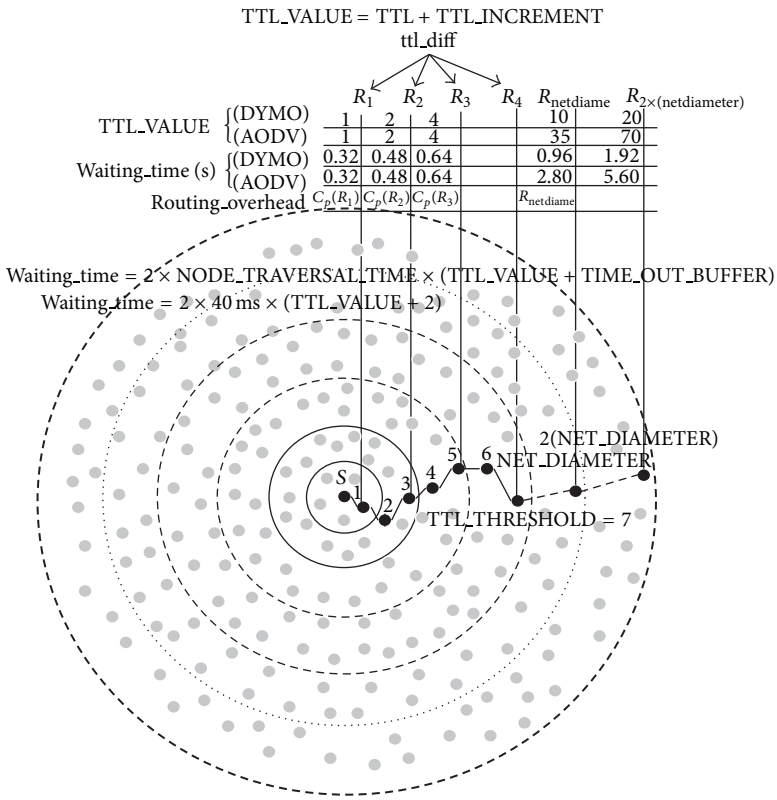
During RM process, different protocols pay different link monitoring costs and also use different supplementary maintenance strategies in case of link breakage. Therefore, this cost metric depends upon the respective routing protocols; $C_{E\text{-LLR}}^{\text{AODV}}$ for AODV and $C_{E\text{-PS}}^{\text{DSR}}$ for DSR, whereas DYMO does not use any supplementary mechanism. RM process for AODV, DSR, and DYMO is given in Algorithms 1, 2, and 3, respectively.

After the detection of route failure due to link breakage, there are three different scenarios for reactive protocols describing the route repair mechanism. The most simple mechanism describes that RD reinitiation process takes place under limited retries for route rediscovery process: RREQ_RETRIES = 3 in DYMO, RREQ_TRIES = 2 in AODV, and MaxMaintRexmt in DSR = 2 retransmissions.

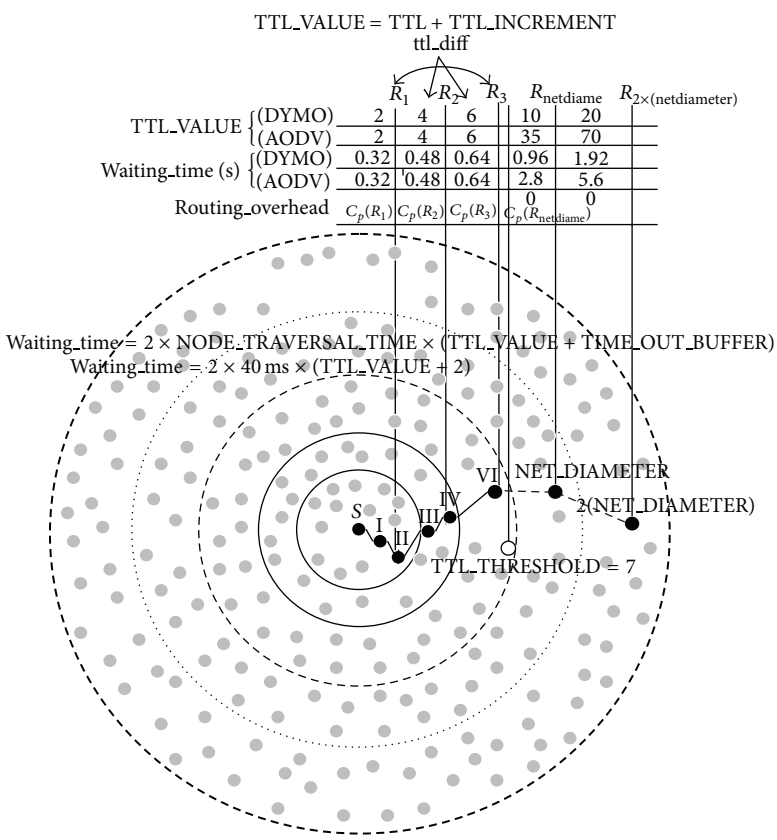
In AODV, after unsuccessful LLR and in DYMO ultimately after detecting link breakage, RERR messages are broadcasted by the node which detects any link breakage. If LLR becomes successful, then in a dense network, it saves the energy which is consumed for route rediscovery, otherwise reinitiating RD process after performing LLR strategy increases the energy consumption. DSR's PS technique reduces both the energy and time costs paid by the reactive protocols by diminishing the route rediscovery. In case of successful PS, RERR messages are broadcasted to neighbors for the deletion of useless routes, whereas absence of alternate route(s) in RC leads to failure of PS. In this situation, RERR messages are piggy-backed in the next RREQ messages during route rediscovery process. There are some approaches for detecting link breakages. In this paper, we focuss on two approaches for the detection of link breakage. In the first approach, link sensing is performed at link layer, which uses LL feed-back to check link's status. This checking is performed 100 times in every second. The principle behind notifying link breakage depends on failure of link level feed-back.

In Algorithms 1, 2, and 3, we use "l" for link, "S" for source node, and "R" for route.

If a node in AR receives eight consecutive failures, then it notifies broken link status. The second approach uses sending and receiving of beacon messages on NL (i.e.,

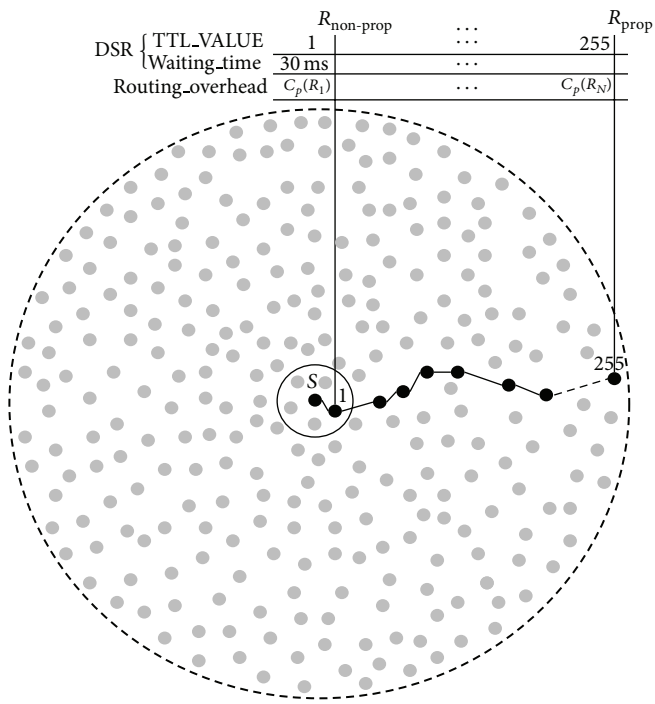


(a) AODV/DYMO RD using LL feed-back

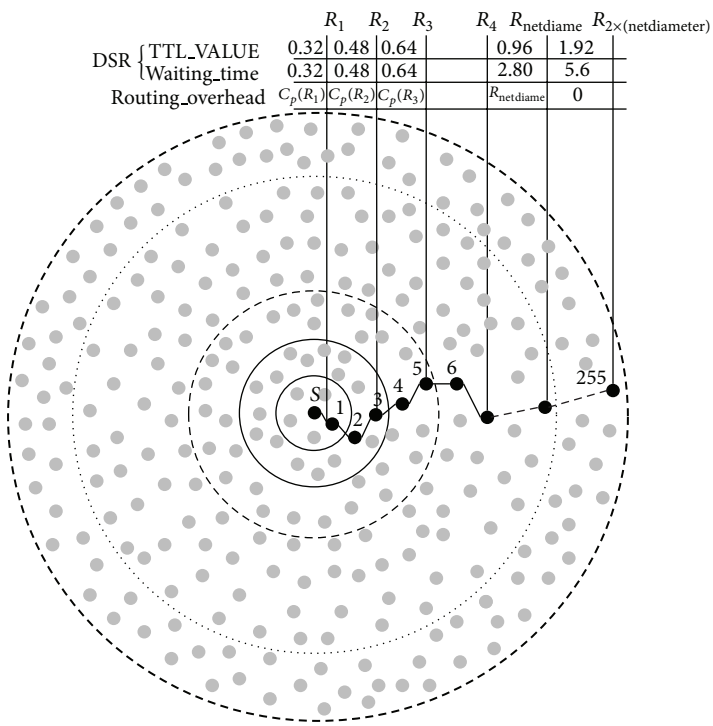


(b) AODV/DYMO RD using NL feed-back

Figure 1: AODV and DYMO: waiting_time and TTL_VALUE for RD.



(a) DSR without ERS



(b) DSR with ERS

Figure 2: DSR: waiting_time and TTL_VALUE for RD.

HELLO messages and ACKnowledgement ACK) to check connectivity of ARs. If ACK is not received, after a specific number of tries, then link is notified as broken. The example of this approach is the use of HELLO message in AODV. HELLO messages are sent after every HELLO_INTERVAL and if ACK is not received for ALLOWED_HELLO_LOSS value, then link is considered as broken.

Following equations give RM cost for the three protocols with NL and LL feed-back mechanisms. Cost of LLR in AODV is given by (8), where R_{LLR} denotes the ring that

```
for all l ∈ AR do
    start LSM
    if upstream node detects LB then
        remaining nodes of path search alternative route in RC
        if found alternative R then
            send data to this R
        else
            S starts route re-discovery
            S piggy-backs RERR with new RREQ
        end if
    else
        upstream nodes receive LL feed-back from downstream nodes
    end if
end for
```

Algorithm 2: Route Maintenance in DSR.

```
if R = active_mode then
    for all l ∈ AR do
        start LSM
        if upstream node detects LB then
            disseminate RERR message
            receiver of RERR deletes faulty route from RT
            S starts route re-discovery based on RREQ_TRIES
        else
            check links of AR
        end if
    end for
else
    do not perform any action
end if
```

Algorithm 3: Route Maintenance in DYMO.

limits LLR activity. TTL_VALUE for R_{LLR} is calculated with LOCAL_ADD_TTL(= 2) and MIN_REPAIR_TTL (i.e., the last known hop-count to the destination). The per packet cost of LLR in AODV, $C_{E\text{-LLR}}^{\text{AODV}}$, depends upon the TTL_VALUE of R_{LLR}. Consider

$$C_{E\text{-RM}}^{\text{AODV}} = \begin{cases} C_{E\text{-LSM}} + C_{E\text{-LLR}}^{\text{AODV}} + \sum_{z=0}^{n} (\text{RERR})_z \\ \quad \text{for NL feed-back} \\ C_{E\text{-LLR}}^{\text{AODV}} + \sum_{z=0}^{n} (\text{RERR})_z \\ \quad \text{for LL feed-back} \end{cases} \tag{7}$$

$$\begin{aligned} &C_{E\text{-LLR}}^{\text{AODV}}(R_{\text{LLR}}) \\ &\quad = P_r d_{\text{avg}} + d_{\text{avg}} \sum_{\text{TTL}=1}^{\text{TTL}(R_{\text{LLR}})-1} (P_r)^{\text{TTL}+1} \prod_{j=1}^{\text{TTL}} d_f[j]. \end{aligned} \tag{8}$$

In large networks, successful LLR process is more useful because the chances of route rediscovery are reduced, which consumes more bandwidth. $\text{TTL}(R_{\text{LLR}})$ is computed as

$$\begin{aligned} &\max(\text{MIN\_REPAIR\_TTL}, 0.5 \times \#\text{hops}) \\ &\quad + \text{LOCAL\_ADD\_TTL}, \end{aligned} \tag{9}$$

where #hops represents the number of hops to the sender of the currently undeliverable data packet. TTL_VALUE for LLR is calculated from TTL $\geq$ MIN_REPAIR_TTL + LOCAL_ADD_TTL expression. Consider

$$C_{E\text{-RM}}^{\text{DSR}} = \begin{cases} C_{E\text{-LSM}} + C_{E\text{-PS}}^{\text{DSR}} + \sum_{z=0}^{n} (\text{RERR})_z \\ \quad \text{for NL feed-back} \\ C_{E\text{-PS}}^{\text{DSR}} + \sum_{z=0}^{n} (\text{RERR})_z \\ \quad \text{for LL feed-back} \end{cases}$$

$$C_{E\text{-PS}}^{\text{DSR}} = \sum_{k=n_{\text{BLB}}}^{n_{\text{PS}}} (\text{RREQ})_k$$

$$C_{E\text{-RM}}^{\text{DYMO}} = \begin{cases} C_{E\text{-LSM}} + \sum_{z=0}^{n} (\text{RERR})_z \\ \qquad \text{for NL feed-back} \\ \sum_{z=0}^{n} (\text{RERR})_z \\ \qquad \text{for LL feed-back,} \end{cases} \tag{10}$$

where $C_{E\text{-LSM}}$ is the LSM cost on NL, and is given below

$$C_{E\text{-LSM}} = \frac{\tau_{\text{AR}}}{\tau_{\text{LSM}}} \times N_{\text{AR}}, \tag{11}$$

where n_{BLB} is the node before link breakage and n_{PS} is any node from source to n_{BLB}. In wireless environment, route failures are due to frequent link breakages. We denote LSM cost at NL by $C_{E\text{-LSM}}$ and depending upon the link duration in AR, τ_{AR}, τ_{LSM} is the periodic interval for link sensing and N_{AR} represent the number of hops in an active route.

Broadcast needs to send z number of RERRs depending upon different situations for different protocols. In DYMO, link breakage causes the broadcasting of RERR messages. In AODV, when the probability of successful LLR becomes zero then it leads to the dissemination of RERRs. On the other hand, DSR piggybacks RERR messages along with next RREQs in case of route rediscovery process, while these RERR messages are broadcasted in case of PS success.

3.2. Cost of Time Consumption. The cost of end-to-end path computation time "C_T^p" in reactive protocols depends upon $C_{T\text{-RD}}^p$ and $C_{T\text{-RM}}^p$. Consider

$$C_T^p = C_{T\text{-RD}}^p + C_{T\text{-RM}}^p \tag{12}$$

with details in the following subsections.

3.2.1. Time Consumed during RD for DSR. Let τ denote constant time initially used for (NonpropRequestTimeout) [3] and its value is 30 ms. $R_{\text{max\_limit}}$, the maximum ring size, depends on the buffer time as well as the maximum allowed broadcasting during propagating RREQ (DiscoveryHopLimit = 255) [3]. Binary exponential back-off (BEB) is associated with each propagating ring (BEB mechanism doubles previous TTL_Value (refer Figure 1(b)) and waiting_time to reduce routing overhead). The expression for time consumed during RD by DSR "C_T^p" is given below:

$$C_{T\text{-RD}}^{\text{DSR}} = \begin{cases} \tau, & \text{if } R_{\text{rrep}} = 1, \\ \sum_{R_i=1}^{R_{\text{max\_limit}}} 2^{R_i-1} \times \tau, & \text{if no RREP received,} \\ \sum_{R_i=1}^{R_{\text{rrep}}} 2^{R_i-1} \times \tau, & \text{otherwise.} \end{cases} \tag{13}$$

3.2.2. Time Consumed during RD for AODV and DYMO. In both AODV and DYMO, TTL_VALUE (in IP header) is set to TTL_START (= 1 in case of link layer feedback otherwise = 2); then it is incremented by TTL_INCREMENT(= 2) up to TTL_THRESHOLD(= 7) [2]. When TTL_THRESHOLD is reached, TTL_VALUE is set to NET_DIAMETER (for AODV = 35 [2] and for DYMO = 10 [4]). For dissemination in the entire network, both TTL_START and TTL_INCREMENT are set to NET_DIAMETER. Moreover, maximum RREQ retries are 3 for DYMO [4] and maximum retries are 2 for AODV. The RREQ_TIME is set to 2 × NET_TRAVERSAL_TIME (whereas, NET_TRAVERSAL_TIME = 2 × NODE_TRAVERSAL_TIME × NET_DIAMETER). See complete detail of TTL_VALUE and waiting_time in Figure 1. Consider

$$C_{T\text{-RD}}^{\text{AODV,DYMO}} = \begin{cases} \sum_{R_i=1}^{R_{\text{max\_limit}}} \tau_1 \left(\text{TTL}\left(R_i\right) + \tau_2\right) \\ \qquad \text{if no RREP received} \\ \sum_{R_i=1}^{R_{\text{rrep}}} \tau_1 \left(\text{TTL}\left(R_i\right) + \tau_2\right) \\ \qquad \text{otherwise,} \end{cases} \tag{14}$$

where τ_1 = 2 × NODE_TRAVERSAL_TIME and τ_2 = TIME_OUT_BUFFER. There are two possibilities for AODV and DYMO: first case, when RD process becomes successful in threshold rings "$R_{\text{thereshold}}$," whereas in second case RD process needs to disseminate the request throughout the network, $R_{\text{netdiameter}}$. For these two rings, we define TTL($R_{\text{thereshold}}$) and TTL($R_{\text{netdiameter}}$). The earlier one represents TTL_VALUE in a ring that generates RREP(s) inside $R_{\text{thereshold}}$ with THRESHOLD and the later one shows TTL_VALUE for the entire network: TTL($R_{\text{netdiameter}}$) with NET_DIMETER.

3.2.3. Time Consumed during RM for AODV. AODV starts LLR process after noticing a link failure. $C_{T\text{-LLR}}$ gives the time cost of LLR which depends upon TTL_VALUE of the ring, R_{LLR}. In case of LLR failure, AODV disseminates RERR messages. $\tau_{\text{recv-RERR}}$ represents the time spent to reach RERR message from the node which detects link failure to the originator node. $C_{T\text{-re-RD}}^{\text{AODV}}$ (= $C_{T\text{-RD}}^{\text{AODV}}$) cost is to be paid to start route rediscovery based on the value RREQ_RETRIES(= 2). This cost is given as

$$C_{T\text{-RM}}^{\text{AODV}} = \begin{cases} \sum_{R_i=1}^{R_{\text{LLR}}} \tau_1 \left(\text{TTL}\left(R_i\right) + \tau_2\right) \\ \qquad \text{if LLR is successful} \\ \sum_{R_i=1}^{R_{\text{LLR}}} \tau_1 \left(\text{TTL}\left(R_i\right) + \tau_2\right) + \tau_{\text{recv-RERR}} \\ \qquad \text{if LLR fails} \\ \sum_{R_i=1}^{R_{\text{LLR}}} \tau_1 \left(\text{TTL}\left(R_i\right) + \tau_2\right) + \tau_{\text{recv-RERR}} + C_{T\text{-re-RD}} \\ \qquad \text{otherwise.} \end{cases} \tag{15}$$

3.2.4. Time Consumed during RM for DSR. After detecting a link failure, time τ_{PS} is utilized to check alternative routes in RC of intermediate nodes (from a node which detects link failure to a node having alternate route for this broken link, n_{PS}). In case of failure of PSing or in the case of presence of alternative route in RCing of the originator node, the cost for consumed time during RM for DSR is given as

$$C_{T\text{-RM}}^{\text{DSR}} = \begin{cases} \sum_{k=n_{\text{BLB}}}^{n_{\text{PS}}} \tau_k(\text{PS}), & \text{if PS is successful,} \\ \sum_{k=n_{\text{BLB}}}^{n_{\text{orig}}} \tau_k(\text{PS}) + C_{T\text{-re-RD}}^{\text{DSR}}, & \text{otherwise,} \end{cases} \tag{16}$$

where $C_{T\text{-re-RD}}^{\text{DSR}} = C_{T\text{-RD}}^{\text{DSR}}$, n_{BLB} is the node just before link breakage, and n_{orig} is the node which originates RD process.

3.2.5. Time Consumed during RM for DYMO. An RERR message is broadcasted by the node which detects link breakage. After $\tau_{\text{recv-RERR}}$ is consumed by the source node for receiving RERR message, source node initiates RD; $C_{T\text{-re-RD}}^{(\text{DYMO})}$ is based on RREQ_RETRIES(= 3). This cost is computed as

$$C_{T\text{-RM}}^{\text{DYMO}} = \begin{cases} \tau_{\text{recv-RERR}}, & \text{if RREQ\_TRIES expires,} \\ \tau_{\text{recv-RERR}} + C_{T\text{-re-RD}}^{(\text{DYMO})}, & \text{otherwise.} \end{cases} \tag{17}$$

4. Analytical Simulation Results Corresponding to the Designed Framework

We evaluate performance of our modeled framework in NS-2. For simulation setup, we have chosen continuous bit rate (CBR) traffic sources with packet size of 512 bytes. Nodes are dispersed in 1000 m × 1000 m of network square space allowing mobile nodes to move inside the network area. Links are provided with bandwidth of 2 Mbps to transmit on. We consider three performance metrics: packet delivery rate (PDR), end-to-end delay (E2ED), and normalized routing load (NRL) for our analysis. We simulate 50 nodes with variable pauses from 0 s to 900 s at 30 m/s for mobility analysis, whereas nodes with different densities, from 10 to 100, are simulated with 15 m/s and a constant pause of 2 s using random way point (RWP) mobility model. The random way point model is chosen due to the following reasons: (i) simplicity in implementation, and (ii) it meets all the required design considerations.

4.1. PDR. AODV attains highest PDR among all the selected protocols because during RD, timely-based route checking in the routing table provides correct route information and grat. RREPs are generated to reduce routing delay by shortening the routes, as depicted in Figures 3(a), 3(c), 3(b), and 3(d). Moreover, LLR mechanism helps to deliver more data packets in high node densities. AODV-LL achieves 5.2% and 6% more cumulative PDR as compared to AODV-NL (refer to Figures 3(e) and 3(f)). This is due to quick notification through LL feed-back mechanism which results in instant repairing, whereas, in DSR, RC contains stale routes due to very high *TAP_CACHE_SIZE* of 1024 bytes and high period for storage of routes in the RC, RouteCacheTimeout of 300 s. As there is no explicit mechanism to delete stale routes except RERR messages, so incorrect RCing in high nodes' mobilities generates faulty information and thus causes packets to be dropped. DSR-NL drops more data packets as compared to DSR-LL, as shown in Figures 3(e) and 3(f), because quick link sensing on LL provides more convergence as compared to NL feedback. In moderate and no-mobilities, DSR's throughput is the highest as compared to AODV and DYMO because RCing during RD phase and PSing for RM phase makes end-to-end path calculation quick, as portrayed in Figure 3.

DYMO does not implement any ancillary mechanism as grat. RREPs in AODV and DSR: LLR of AODV and RCing as well as PSing of DSR (refer Figure 3). Same as that of AODV-LL and DSR-LL, LL mechanism in DYMO-LL achieves more PDR as compared to DYMO-NL. DYMO-LL achieve 5% and 4% more cumulative PDR in different nodes' mobilities and densities, respectively, which can be seen in Figures 3(e) and 3(f). AODV outperforms all the selected protocols when network is denser. LLR, the distinguished feature of AODV, makes this protocol more suitable for high node densities due to reduction of routing latency.

4.2. E2ED. In all the selected nodes' mobilities as well as densities, DYMO attains lowest routing latency due to simple ERS mechanism and lack of checking routes in RC or in RT as depicted in Figure 4. In high mobilities, quick repair is needed after detecting link breakage for maintaining broken link(s) (path(s) reestablishment). To avoid these route-rediscoveries, AODV starts LLR process to quickly upkeep the broken link for achieving low routing latency. AODV, among the reactive protocols, attains highest delay as shown in Figures 4(a), 4(c), and 4(e). Because LLR for link breakages in routes sometimes results in increased path lengths, DYMO produces the lowest E2ED among the reactive protocols because it only uses ERS for route finding that causes less delay due to absence of PSing, RCing, and grat. RREPs. At higher mobilities, DSR-NL suffers the most, that is, highest E2ED (refer Figure 4(a)). The reasons include RCing and PSing failure in high dynamicity which introduce routing latencies. As DSR does not implement LLR, so its E2ED is less than AODV; however, during moderate and high nodes' mobilities, RC search frequently fails and results in increased delay.

Absence of grat. RREPs and any supplementary mechanism keeps the lowest E2ED of DYMO in all the node densities, as depicted in Figure 4(b). PS and grat. RREPs keep the delay low in medium and high traffic scenarios for DSR (while first checking the RC instead of simple ERS based RD process), augments the delay when population increases. Thus more delay of DSR is shown in Figures 4(b), 4(d), and 4(f), as compared to DYMO. AODV experiences the highest E2ED in all the node densities due to LLR process.

AODV-NL possesses less delay as compared to AODV-LL and same as that of DSR. In AODV and DSR, auxiliary

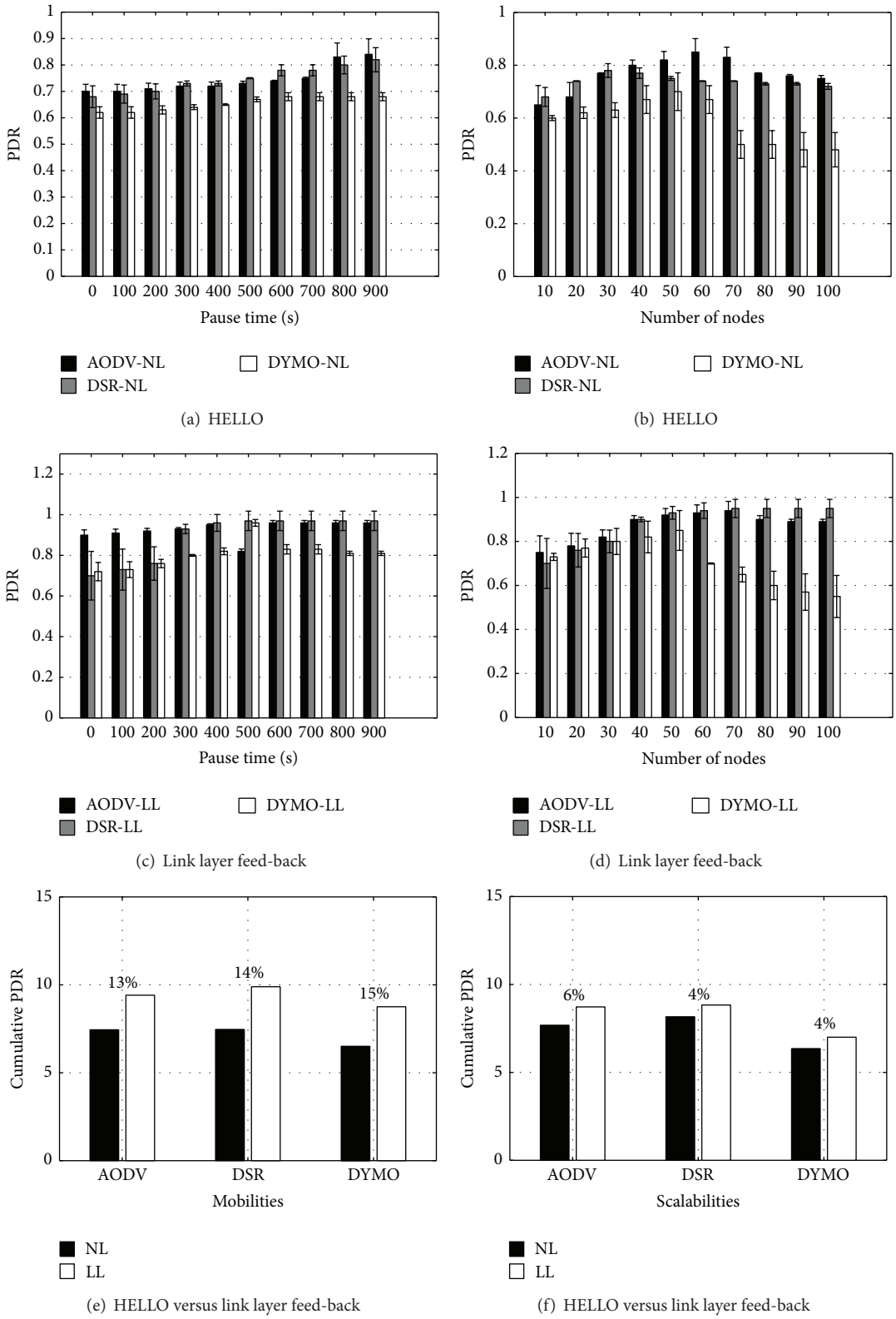


Figure 3: PDR achieved by the selected routing protocols.

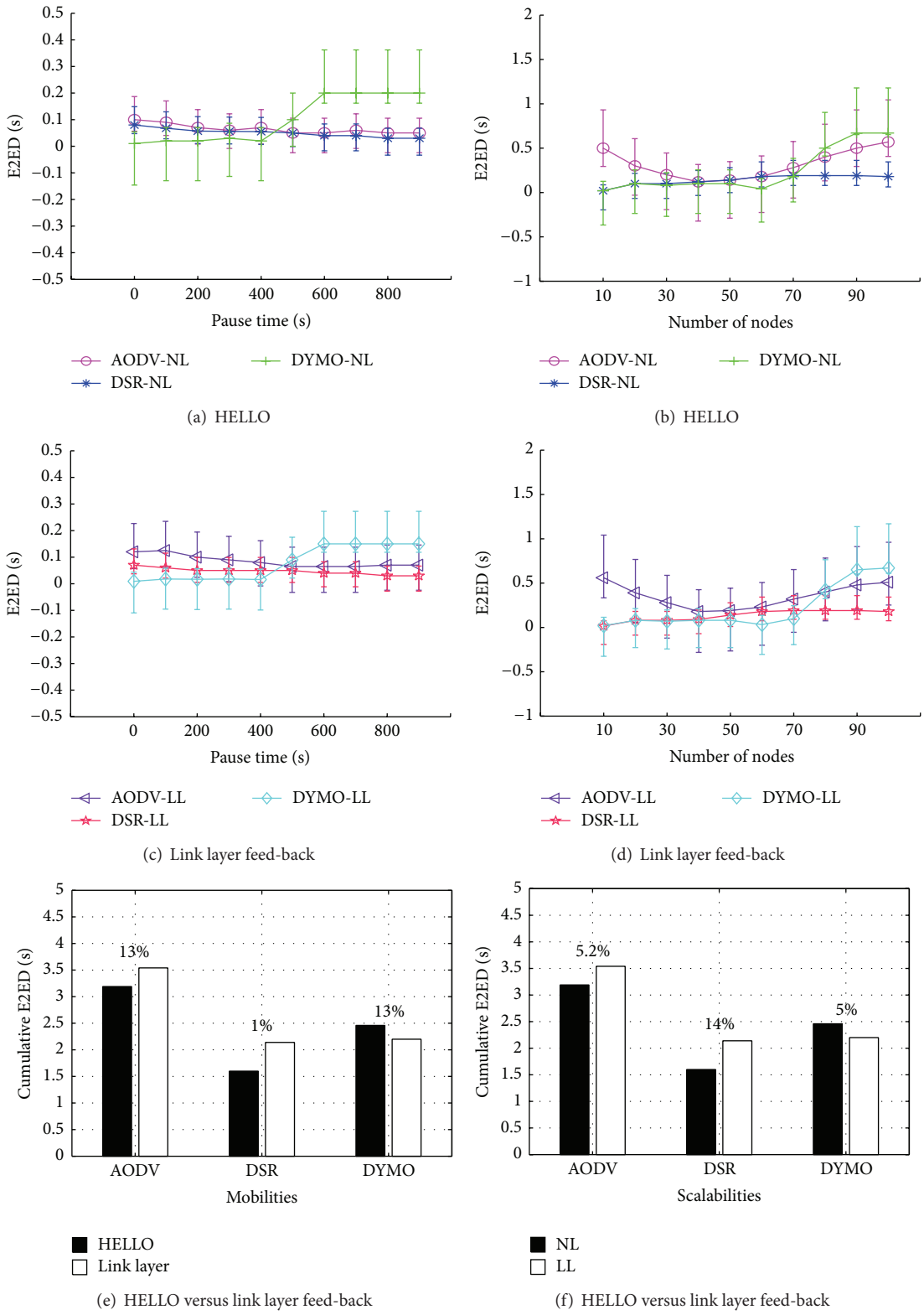


Figure 4: E2ED produced by the selected routing protocols.

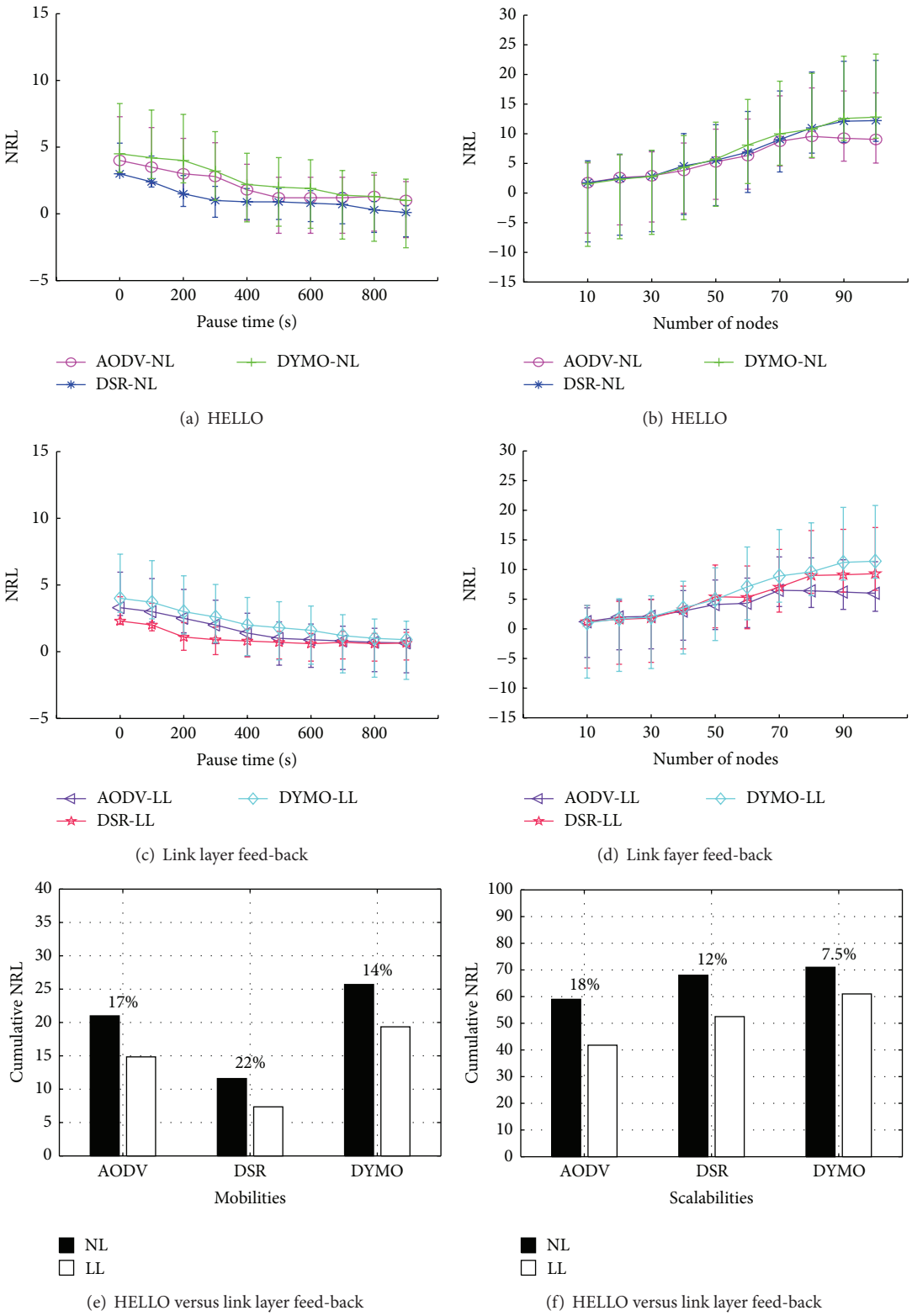


Figure 5: NRL produced by AODV, DSR, and DYMO protocols.

mechanisms during RM produce more routing latencies, because quick detection LB via LL feed-back mechanisms initiate these mechanisms (refer Figures 4(e) and 4(f)). As these mechanisms are absent in DYMO, thus, quick link failure detection in DYMO-LL results in less routing load as compared to DYMO-NL.

4.3. NRL. Due to absence of grat. RREPs, DYMO produces higher routing overhead among the selected reactive protocols, whereas in DSR route RCing and PSing due to promiscuous listening mode produce the lowest routing load in all the selected nodes' mobilities (refer Figure 5). Moreover, high rate of link breakages causes more route rediscoveries for path repairing. In DYMO, routing load increases with high nodes' mobilities because RERR messages are instantly broadcasted after detecting link breakage. Although, AODV uses grat. RREPs however due to the use of *HELLO* messages (to check the connectivity of the ARs in DYMO) and LLR, the DYMO causes more routing load than DSR, as shown in Figure 5(a).

One common noticeable behavior of the selected protocols is that, in high nodes' mobilities, routing overhead is higher as compared to moderate and low nodes' mobilities as shown in Figures 5(a), 5(c), and 5(e). Because, in response to link breakage, all the on-demand protocols disseminate RERR message to inform the route request generator about faulty links and thus prevent the use of invalid routes. As link breakage, in highly dynamic situations, is frequent, more RERR messages are generated resulting in high NRL.

In medium and high populations, routing load of DYMO is less than that of DSR and AODV (refer to Figures 5(b), 5(d), and 5(f)), whereas, in medium and high densities, AODV-NL attains the highest routing load. The *HELLO* messages (to check the connectivity of active routes), LLR and grat. RREPs increase the generation of routing packets. Each node that participates during RD (including intermediate nodes) of DSR, learns the routes to other nodes on the route due to source routing information in their RCs. During RD and RM phases, RCing and PSing processes are, respectively, used to get routes from RC of intermediate nodes. This approach is used to quickly access and to solve broken link issues by providing an alternative route. Thus, PSing and RCing mutually reduce the routing overhead in low node densities of 10, 20, and 30 nodes (refer to Figure 5(b)). However, in high densities, intermediate nodes, generating more grat. RREPs, augment routing overhead as shown in Figure 5(b). NL mechanism in all the three protocols augments routing packet cost as shown in Figure 5.

5. Conclusion

In wireless networks, routing protocols are responsible for efficient routing. In this paper, we select three reactive routing protocols: AODV, DSR, and DYMO. These protocols perform two phases for routing: RD and RM. During RM phase, LSM is more important to repair broken routes. We study two mechanisms of LSM: LL and NL feed-backs. A framework is also modelled for energy as well as time costs during RD and RM with LSM mechanism. For analytical comparison of these LSM mechanisms in the selected protocols, three performance metrics are chosen: PDR, E2ED, and NRL using NS-2. From analytical comparison, we deduce that LL mechanism is more suitable for LSM in reactive protocols as compared to NL feed-back mechanism.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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