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# Link stability based multicast routing scheme in MANET

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A B S T R A C T

The group-oriented services are one of the primary application classes that are addressed by Mobile Ad hoc Networks (MANETs) in recent years. To support such services, multicast routing is used. Thus, there is a need to design stable and reliable multicast routing protocols for MANETs to ensure better packet delivery ratio, lower delays and reduced overheads. In this paper, we propose a mesh based multicast routing scheme that finds stable multicast path from source to receivers. The multicast mesh is constructed by using route request and route reply packets with the help of multicast routing information cache and link stability database maintained at every node. The stable paths are found based on selection of stable forwarding nodes that have high stability of link connectivity. The link stability is computed by using the parameters such as received power, distance between neighboring nodes and the link quality that is assessed using bit errors in a packet. The proposed scheme is simulated over a large number of MANET nodes with wide range of mobility and the performance is evaluated. Performance of the proposed scheme is compared with two well known mesh-based multicast routing protocols, i.e., on-demand multicast routing protocol (ODMRP) and enhanced on-demand multicast routing protocol (EODMRP). It is observed that the proposed scheme produces better packet delivery ratio, reduced packet delay and reduced overheads (such as control, memory, computation, and message overheads).



## 1. Introduction

The characteristic of mobile ad hoc networks (MANETs) is that they do not have fixed network infra-structure, i.e., every node in a MANET acts as both host and router. The nodes are mobile and have limited resources, transmission power and battery life. They have capability to self organize themselves to create a network. MANETs require fundamental changes to conventional routing protocols for both unicast and multicast communication inspite of its unique features. With rapid requirement of group communication services, multicast routing in MANETs has attracted more attention recently [1–6]. In multicast routing, a path is set up connecting all group members and packets are multicast to every receiver from a source in single transmission so that bandwidth is conserved. Group communication applications include audio/video conferencing as well as one-to-many data dissemination in critical situations such as disaster recovery or battlefield scenarios. Also, MANET applications are felt in mobile/wireless environments, where the mobility and topological changes produce high overheads and affect the throughput performance in terms of packet delivery ratio.

Since group-oriented communication is one of the key application classes in MANET environments, a number of MANET multicast routing protocols have been proposed.

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These protocols are classified according to two different criteria. The first criterion maintains routing state and classifies routing mechanisms into two types: proactive and reactive. Proactive protocols maintain routing state, while the reactive protocols reduce the impact of frequent topology changes by acquiring routes on demand. The second criterion classifies protocols according to the global data structure that is used to forward multicast packets. Existing protocols are either tree or mesh-based. Tree-based schemes establish a single path between any two nodes in the multicast group. These schemes require minimum number of copies per packet to be sent along the branches of the tree. Hence, they are bandwidth efficient. However, as mobility increases, link failures trigger the reconfiguration of entire tree. When there are many sources, network either has to maintain a shared tree, losing path optimality or maintain multiple trees resulting in storage and control overheads. Examples of tree-based schemes include [7–9]: ad hoc multicast routing protocol (AMRoute), ad hoc multicast routing utilizing increasing ID-numbers protocol (AMRIS), and multicast ad hoc on-demand distance vector routing protocol (MAODV).

Mesh-based schemes establish a mesh of paths that connect the sources and destinations. They are more resilient to link failures as well as to mobility. The major disadvantage is that mesh-based schemes introduce higher redundancy of packets since multiple copies of the same packet are disseminated through the mesh, resulting in reduced packet delivery and increased control overhead under high node mobility conditions. Some examples of mesh-based protocols include (a) on-demand multicast routing protocol (ODMRP [10]), (b) forwarding group multicast protocol (FGMP [11]), (c) core assisted mesh protocol (CAMP [12]), (d) neighbor supporting ad hoc multicast routing protocol (NSMP [13]), (e) location-based multicast protocol [14], and (f) dynamic core-based multicast protocol (DCMP [15]).

In ODMRP, a source periodically floods an advertising packet in the network. Receiver responds to the packet by using backward learning. The nodes on the path from the receiver to the source form a mesh of forwarding nodes for the multicast group and thus ODMRP is one of the well established mesh-based protocols. The major advantage of ODMRP is that it produces high packet delivery ratio and throughput even under highly mobile network conditions because it reduces the overhead due to re-establishment of routes under a route failure condition as there is a mesh structure to provide back up path. The disadvantage of ODMRP is that the control overhead also grows higher and higher with network size. Similar process takes place when there is a link or node failures and mobility of nodes, since ODMRP does not support mobility. However, mobility is augmented as re-establishment of routes in ODMRP [16,17,24,25].

Some of the proposals to overcome above listed disadvantages of ODMRP are: Enhanced ODMRP with Motion Adaptive Refresh (EODMRP) [26], Enhanced ODMRP Using Conditioned Broadcasting Algorithm [27], A Dynamic Counter-Based Forwarding Scheme for ODMRP (CODMRP) [28] and Resilient On Demand Multicast Routing Protocol (RODMRP) [29].

### 1.1. Related works

In this section, we discuss some of the related works on stable link based multicast routing protocols. The work given in [16] solves the problem of limiting control and data overhead for mesh-based multicast routing. It defines the mean link duration metric to adapt and reduce refreshing control packets and also suggests a new reactive multicast mesh construction algorithm with overhearing technique that forms a fish bone structure. Each mesh member chooses its forwarding node independently and entirely in a distributed fashion, based on its own perceived network conditions to provide a trade off between reducing data overhead and achieving multicast reliability. The work given in [4] proposes query packets containing source id, sequence number, next sequence number, hop count and the time interval needed to send next query packet. Query packet is sent by multiple sources and are processed by intermediate nodes and receivers.

In [18], a stable and delay constrained QoS routing protocol (SDCR) for MANET is proposed that makes routing decisions according to link state and dynamic delay detection. The end-to-end path stability is found using stable link mobility model, in which the protocol finds paths with higher link stability that are constrained by maximum delay, in the route discovery phase. A feasible path with longer lifetime is selected for data transfer. In the route maintenance phase, SDCR effectively keeps monitoring network topology changes by delay prediction mechanism and performs rerouting before the current path becomes unavailable and thus there is a significant improvement in routing performance that guarantees the requested QoS.

In [19], the received signal strength is continuously assessed based upon Newton interpolation polynomial, which selects middle values out of several sample values. The link lifetime is estimated with a mobility model, which proves independence of link lifetime on the relative movement direction and velocity of nodes. The sampling policy is derived with reference points calculated from Newton interpolation polynomial. Using this mechanism, the source nodes sets up route hop-by-hop to calculate the maximum link lifetime and proposes On-Demand Routing Protocol based on Link Duration Estimating (ODLE).

The work given in [20], proposes a routing algorithm called link failure prediction QoS routing (LFPQR) that predicts the future state of a node to decide whether the node is a good selection as a router or not, i.e., the downstream node decides whether the upstream node is a good candidate for selection as a router. The future prediction depends on the mobility and power level of a node. The protocol selects more stable paths and hence QoS requirements are satisfied.

In [21], Zhen et al. provide a partial multipath routing algorithm with the parallel packet redundancy mechanism in MANET, in which the link lifetime estimation predicts the lifetime of the links in the route establishment procedure without the aid of additional positioning equipments and extra control messages. The starting and ending nodes are set as relay nodes, which are responsible for sending the copies of some packets of the primary path to the secondary path and recording the sequence number of the forwarded packets. Parallel packet redundancy method has been employed to transmit packets along multipaths simultaneously, the relay nodes send out the redundant packets along secondary path after the redundancy threshold, which can compensate the packet loss and enhance the end-to-end path reliability.

EraMobile (Epidemic-based Reliable and Adaptive Multicast for Mobile ad hoc networks) is presented in [22] that supports group applications requiring high reliability. The protocol aims to deliver multicast data reliably with minimal network overhead under adverse network conditions such as dynamic and unpredictable topology changes due to mobility. Multicast routing is created without the help of traditional approaches such as maintenance of tree or mesh-like structures and global or partial view of the network and information about neighboring nodes/group members. It substantially lowers overhead by eliminating redundant data transmissions and it adapt to varying node densities delivering data reliably in both sparse networks (where network connectivity is prone to interruptions) and dense networks (where congestion is likely).

Ssua et al. in [23] present an efficient geographic multicast protocol using fermat points (GMFP). It improves the overall routing distance for multicasting. Authors show that GMFP outperforms the conventional Position-Based Multicast protocol in terms of the total routing distance, the packet transmission delay, the packet delivery ratio, and the node energy consumption. The performance improvements provided by GMFP are apparent as the scale of the network topology increases.

In [24], an on-demand multicast routing protocol named as source routing based multicast protocol (SRMP) is presented. This protocol constructs a mesh of paths to connect group members, providing robustness against mobility. It also provides stable paths based on link availability according to future prediction of links state, and higher battery life paths tending to power conserving. SRMP does not use periodic network flooding of control packets but instead, it constructs a stable mesh-based upon an estimate of future link availability and thus enhances battery life and minimizes the possibility of link failures and finally reduces the overhead needed to reconstruct the paths compared to ODMRP and ADMR protocols.

The work given in [30] by EffatParvar et al. proposes a cluster-based on-demand multicast routing protocol (SC-ODMRP) as an extension to the flat multicast routing protocols in large scale ad hoc networks using clustering concept on ODMRP to improve network performance in terms of end-to-end delay and control packets. The paper also proposes a link stability approach to design a stable multicast algorithm. This approach increases data delivery and decreases overhead. In [31], a cluster based stable multicast routing protocol (CBSRP) in ad hoc networks is proposed. The protocol uses flooding algorithm under extended range of some network conditions like higher mobility and enhanced traffic conditions. It constructs a new metric of node stability and selects a stable path with the help of entropy metric to reduce the number of route reconstruction. It selects nodes having higher weight factor to provide stability and thus the nodes act as cluster heads. Though the stable node selection increases the stability of nodes. However, after selection of cluster heads, the proactive maintenance of cluster heads is a major overhead and the overhead increases with number of nodes.

Enhanced ODMRP with Motion Adaptive Refresh (E-ODMRP) given in [26] presents an enhancement of ODMRP with refresh rate dynamically adapted to the environment. An additional enhancement is "unified" local recovery and receiver joining. On joining or upon detection of a broken route, a node performs an expanding ring search to graft to the forwarding mesh. Enhanced ODMRP (E-ODMRP) reduces overhead by up to 90% yet keeping similar packet delivery ratio compared to the original ODMRP. A conditioned broadcasting algorithm for on-demand multicast routing protocol is proposed in [27], which computes the rebroadcast probability of packets through neighbor node density with their relative distance and thus reduce the overhead. A Node that has the ability of achieving more coverage area and with low node density has a higher value of rebroadcast probability. ODMRP fueled with this algorithm is more efficient than original protocol in terms of packet delivery ratio, control byte overhead and end-to-end delay.

A Dynamic Counter-Based Forwarding Scheme for ODMRP (CODMRP) [28] attempts to improve packet delivery efficiency by minimizing the data redundancy as long as the packet delivery ratio of the protocol is comparable to a state of the ODMRP in the same conditions. In counter-based scheme, a counter maintained at receiver, records the number of times a same packet received is maintained by each host for each broadcast packet. When counter reaches a predefined threshold, the scheme inhibits the host from rebroadcasting this packet because the benefit (of additional coverage area) could be low. CODMRP combines the fixed counter-based approach with the distance-based approach. It dynamically adjusts the value of the counter threshold at the forward node according to the distance between itself and the packet sender. In addition, CODMRP provides a control over the redundancy in the mesh and does not need the support of positioning system (GPS) and neighbor information.

A thesis in [29] proposes a ODMRP based wireless multicast protocol (RODMRP) that offers more reliable forwarding paths in face of node failures and network failures. A subset of the nodes that are not on the forwarding paths rebroadcast the received packets to nodes in their neighborhoods to overcome perceived node failures. This rebroadcasting creates redundant forwarding paths to circumvent failed areas in the network. Each node makes this forwarding decision probabilistically.

In our previous work [32], a mesh-based multicast routing scheme is discussed which establishes a multicast mesh on-demand. The work is not supported with validation of the scheme and performance analysis and also lacked proper formulation of components of the scheme. This paper provides an extension to the work by providing detailed functioning of the scheme, examples and simulation based performance analysis.

As per the literature survey, it is observed that multicast protocols try to achieve better performance in terms of packet delivery ratio, reliability, less control overheads and packet delays. However, performance can be further improved by considering stable links during mobility conditions where stability is based upon the frequency of change in link quality. Without the stable links, the paths established are vulnerable due to large mobility patterns of nodes. Thus, there is a need to develop efficient link stability based multicast routing schemes that provides much better packet delivery ratio, delays and different types of overheads compared to existing multicast routing protocols. This paper attempts to provide such a solution.

### 1.2. Proposed work

In this paper, we propose a link stability based multicast routing scheme that establishes a route from a source to multicast destinations in MANET. A multicast mesh is created with stable links when a source node needs to send data to receiver nodes. The scheme consists of the following phases. (1) Mesh creation through the route request (RR) and route reply (RP) packets. (2) Finding stable routes between source and destination pair of nodes by selecting stable forwarding nodes (SFNs) using link stability metric. (3) Mesh maintenance to handle link failures.

Our contribution in this paper are as follows. (1) Defining RR and RP packets to create a mesh by using transmission power and antenna gains, (2) Defining a model of link quality using statistical measure of bit errors, (3) Creating and maintaining of routing information through every hop using RR and RP packets based on link stability, (4) Selecting SFN for multicast paths based on link stability which is computed using the parameters such as received power, distance between the nodes and link quality, (5) Selecting various SFN's in a mesh during link failures rather than immediately attempting for route discovery, and (6) Comparing the performance of the proposed scheme with ODMRP and EODMRP. ODMRP and EODMRP are chosen for comparison since these protocols are well established and robust mesh-based protocols.

### 1.3. Organization of the paper

The rest of the paper is organized as follows. Section 2 presents the proposed link stability based multicast routing scheme in MANET, in which the details of creating multicast mesh is discussed with the help of route request, route reply packets, multicast routing information cache and link stability database. Section 3 presents simulation environment comprising network model, channel model, mobility model and traffic model along with parameters used for simulation. Section 4 discusses simulation results and comparison with ODMRP and EODMRP. Finally, conclusions are given in Section 5.

## 2. Link stability based multicast routing

This section presents the functioning of proposed link stability based multicast routing scheme in MANET (LSMRM). Here, we discuss the process of creating a mesh of multicast routes with the help of RR and RP packets, routing information maintained in multicast routing information cache (MRIC) and link stability database (LSD). MRIC is maintained at every node. After creating a multicast mesh, stable route between source-destination pair is established using SFNs (which are a part of multicast mesh) that have stable link connectivity. LSD is maintained at every node, which stores the updated information used for finding stable multicast routes in a mesh.

### 2.1. Route request, route reply and route error packets

To create a multicast mesh and stable routes in a mesh from source to destination, various control packets such as RR, RP and route error (RE) packets are used. In this section, we describe some of the fields of these control packets required for multicast mesh creation, stable path establishment and handling link failure situations. Various fields of RR packet are as follows.

- *Source address:* It is the address of the node originating the packet.
- *Multicast group address:* It is the address of the multicast group.
- *Sequence number:* The sequence number assigned to every packet delivered by the source that uniquely identify the packet.
- *Route request flag (RR flag):* This flag is set for the duration of forward travel of RR packet from source to destination.
- *Previous node address:* It is the address of the previous node that RR packet has visited during its forward movement. In the route request phase, a node receiving RR packet stores this address with multicast address in its MRIC as next hop node to send the packets to the RR packet source. This field is updated after every movement to the next node until it reaches the receiver with multicast address.
- *Power:* This is the power of a node that transmits packet to its neighbor.
- *Antenna gain:* This is the gain of an antenna at the forwarder of RR packet to its neighbor.

RP packet format for multicast mesh creation is almost similar to RR packet with few changes in RR packet. The changes in RR packet to convert it into RP packet are as follows: RR flag value will be made 0 (indicating that it is a RP packet), previous node address is removed, and source address is replaced by receiver address. RP packet moves on path traversed by RR packet by using MRIC and also updates MRIC towards receiver/multicast address by adding one more next hop (node address from where RP packet has come) to multicast address. In general, next hop at every node to reach a source is set by using RR packets whereas RP packets set next hop at every node to reach receivers from the source.

RE packet is generated when a node is unable to send the packets. Some of the fields of this packet are source address, destination address, sequence number, and route error flag (RE flag). Whenever a node identifies link failures, it generates RE packet with route error flag set and sends the packet to either source or receiver. If link failure occurs in forward journey of a RR packet from source to multicast receiver, RE packet is sent to the source and if link failure occurs for reverse journey of the RP packet from receiver to the source, RE packet is sent to the multicast receiver.

### 2.2. Link quality

Link quality is a major component that decides the link stability to construct multicast routes. It is derived by the ratio of bits in error to the total number of bits received (i.e., bit error ratio (BER)). Theoretically, we take any BER measurement over an infinitely long time to precisely estimate its true value since small measured intervals of BER does not provide accurate estimation [33,34]. We can determine how many transmitted bits are sufficient for the desired estimate quality. This can be obtained by using the concept of statistical confidence levels. In statistical terms, the BER confidence level (CL) can be defined as the probability that the true BER (*TrueBER*) would be less than a specified BER (*BERS*). Mathematically, CL can be expressed by Eq. (1) [35]

$$CL = PROB[TrueBER \leqslant BERS]. \tag{1}$$

For particular measured error, if $S$ is the average of standard deviations of many bit error trials and $a$ is the accuracy of received bits, then *TrueBER* between nodes $i$ and $j$ (denoted as $BER_{ij}$) within a CL is given by Eq. (2) [33]

$$BER_{ij} = \frac{S^2}{a^2}. \tag{2}$$

As link quality $q_{ij}$ between two neighboring nodes $i$ and $j$ is inversely proportional to BER, a better approximation of link quality with proportionality constant $K$ is given by Eq. (3)

$$q_{ij} = K \times \frac{1}{BER_{ij}}. \tag{3}$$

Link quality $q_{ij}$ depends on parameters such as the interference effect of the wireless channel, Additive White Gaussian Noise (AWGN) and signal transmission range.

### 2.3. Routing information cache

Each node in the network maintains its own Multicast Routing Information Cache (MRIC) that aids in forwarding packets to group members. A node adds information to its MRIC (that have stability factor $\geqslant Th_{SFN}$, an SFN threshold) as it learns of new routes for various multicast groups in MANET; for example, a node may update new routes when it receives RR and RP packets, and likewise. A node removes information from its MRIC as it learns of existing routes in the ad hoc network that become unavailable due to link and node failures. For every visited packet (RR or RP) at a node, MRIC is updated with some of the following fields required for establishing multicast mesh and stable paths (see Fig. 1).

- *Group address and destination address:* Group address is the address of multicast group. Destination address is the address of the node where packet has to be forwarded with multicast address. This helps to accommodate the routes created by RR packets and RP packets.
- *Next hop addresses:* These are the addresses of next hop interfaces for forwarding to a multicast group.
- *Forwarding flag (FW flag):* This field stores two bit flag that indicates the status of node in three modes; *mode* 00 – node is multicast group node, *mode* 01 – node is a forwarding node and *mode* 10 – node is a forwarding node and is on the stable path.
- *Sequence number:* This is the number given by the node who has a route to multicast receivers. It helps in differentiating the time order in which route is created. A node updates routes if the received sequence number in RR/RP packet is higher than the existing sequence number. It is set to infinity if a next hop link fails.
- *Next hop stability:* This defines stability factor of a link connecting next hop (taken from link stability database, discussed in Section 2.4). FW flag for a forwarding node will be set to 10 if the node has high stability factor compared to other next hops. In Fig. 1, stable next hop used for forwarding to multicast address/destination address 228.10.10.0/92.19.10.10 is 128.80.0.110.

If stability factor of certain neighbor node is less than the required stability factor, then such entry will not be made in MRIC in order to reduce the memory storage overhead.

### 2.4. Link stability database (LSD)

Each node maintains LSD that stores link and node related information for establishing and maintaining multicast mesh and stable path from source to multicast destinations. LSD structure (shown in Fig. 2) maintains the following parameters: node ID, antenna related information ($G_t$, $G_r$, $L$ and $\lambda$), power level, distance ($d_{ij}$), bit error rate ($BER_{ij}$) and stability factor ($S_{ij}$).

- *Node ID:* It stores the neighbor node ID.
- *Power level:* Whenever a packet (either RR or RP packet) is received from its neighbor, this field stores the ratio ($Pw_{ij}$) of measured value of the power received ($P_r$) at the node to the power transmitted ($P_t$) by neighbor node.
- *Distance:* This field stores the distance between the neighboring nodes. The distance is computed by using the free space propagation model [36,37] given in Eq. (4)

  $$P_r(d) = \frac{P_t G_t G_r \lambda}{(4\pi) d^2 L}, \tag{4}$$

  where $G_t$ and $G_r$ are the antenna gains of the transmitter and the receiver, respectively. $L$ is the system loss, $\lambda$ is the wavelength and $d$ is the distance between two MANET nodes.
- *Link quality:* This field stores the value of the link quality of neighboring nodes estimated by Eq. (3). This value gets updated for every packet received at a node over a certain period.
- *Stability factor:* It is the value computed for a link to a neighbor based on the power level, distance and link quality. Stability factor $S_{ij}$ of a link between nodes $i$ and $j$ is defined by Eq. (5)

| GROUP ID /DST. ADDR | NEXTHOP ADDR. | FW FLAG | STABILITY FACTOR | SEQ. NO. |
|---|---|---|---|---|
| 228.10.10.0/ 92.19.10.10 | 128.80.10.1 | 01 | 0.7 | 100 |
| | 128.80.0.80 | 01 | 0.9 | 105 |
| | 128.80.0.110 | 10 | 1.0 | 234 |
| ....... | .... | .... | ....... | ........ |

**Fig. 1.** Multicast routing information cache.

| Node ID | Gt | Gr | L | λ | Power Level | $d_{ij}$ | $BER_{ij}$ | $S_{ij}$ |
|---|---|---|---|---|---|---|---|---|
| 128.80.10.1 | 1 | 1 | 1 | 0.135 | 400mW | 168 | $10^{-4}$ | 0.6 |
| 64.45.28.24 | 1 | 1 | 1 | 0.103 | 300mW | 232 | $10^{-3}$ | 0.5 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... |

**Fig. 2.** Link stability database (LSD).

$$S_{ij} = \frac{Pw_{ij} \times q_{ij}}{d_{ij}}, \tag{5}$$

where $Pw_{ij}$ and $d_{ij}$ are the signal strength and the distance between nodes $i$ and $j$, respectively. $q$ is link quality. Substituting the value of $q_{ij}$ from Eq. (3), with a $BER_{ij}$ between nodes $i$ and $j$, we get $S_{ij}$ as given in Eq. (6)

$$S_{ij} = \frac{Pw_{ij} \times K \times \frac{1}{BER_{ij}}}{d_{ij}}. \tag{6}$$

## 2.5. Multicast mesh creation

Multicast mesh creation involves two phases; a request phase and a reply phase. Request phase invokes route discovery process to find routes to the multicast group. Different routes to the multicast group are setup during the reply phase. There are two types of nodes defined based on whether they are multicast group members or non-group members. Group members include all multicast sources, receivers and that of non-group members include intermediate nodes that help to create multicast routes from source to receivers. Non-group members help in forwarding the data packets. Both group members and non-group members help in recovery of failed links due to mobility of nodes and other interferences in route maintenance phase.

LSMRM identifies some of the intermediate nodes from the forwarding group as SFN's that forms stable multicast path based on link stability. Any non-group member may join the group by registering itself as a group member. Registration is made by sending RR packet to its neighbors and getting the RP packet from any one of the group members or forwarding nodes in its neighborhood. Once a non-group member receives RP packet from neighbor group member node, it becomes a group member. In the following section, we discuss the process of request phase, reply phase that helps in creating multicast mesh.

### 2.5.1. Request phase

A source finds the multicast routes to its receivers by using RR packets. The sequence of operations that occur are as follows. (1) Source prepares a RR packet by putting the following information: its address, multicast destination address, set RR = 1, sequence number, previous node address as its address, transmission power and antenna gain. (2) Broadcast RR packet to neighbors. (3) A node receiving RR packet will discard it if it is already received (by using sequence number and source address). (4) If RR packet is not a duplicate, update the MRIC and LSD: checks MRIC for availability of route for multicast address/source address, if available and the sequence number of RR packet is higher than the MRIC sequence number then update the next hop for multicast address/source address as previous node address with new sequence number. (5) Rebroadcast the RR packet to its neighbors. (6) Perform steps 3–5 until receiver is reached. (7) If receiver is not reached within certain hops, send RE packet to source.

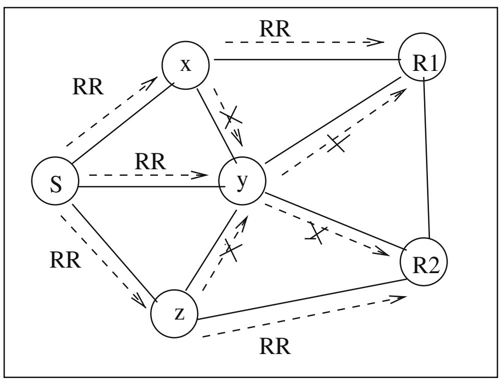


**Fig. 3.** Route request paths from $S$ to $R1$ and $R2$.

Fig. 3 illustrates the basic operation of route request phase.

- Source $S$ broadcasts RR packet to discover the route for two multicast receivers $R1$ and $R2$.
- Nodes $x$, $y$ and $z$ receive RR packet from $S$. These nodes update the paths to $S$ in its MRIC by using next hop as $S$. Also updates the LSD and stability factor of next hop in MRIC.
- Node $x$ broadcasts RR packet to $R1$ and $y$. Node $z$ broadcasts to $y$ and $R2$. Node $y$ broadcasts to $x$, $R2$, $R1$ and $z$.
- Node $y$ finds that these packets are duplicates of the same RR packet already received. Thus they will be discarded by node $y$, which is indicated by cross mark in the figure. Similarly nodes $x$ and $z$ discard duplicate RR packets received from $y$.
- $R2$ and $R1$ discards duplicates from nodes $z$ and $x$, respectively.
- $R2$ and $R1$ updates MRIC and LSD.
- Now, $R2$ and $R1$ have path to the source $S$, $R1$–$x$–$S$, $R1$–$y$–$S$, $R2$–$z$–$S$, and $R2$–$y$–$S$.

### 2.5.2. Reply phase

Multicast receiver initiates the reply phase. In reply phase, RP packet is generated at a multicast receiver after receiving a RR packet. The following operations are performed in the reply phase. (1) Receiver prepares RP packet by putting the following information in the packet: its address as receiver address, source address as destination address, makes RR=0, increments sequence number, changes previous node address as next hop address, transmission power and antenna gain. (2) Send RP packet to its neighbors corresponding to groupid/source address in MRIC (as prepared during forward movement of RR packets). (3) The node receiving RP packet compares sequence number and next hop address corresponding to groupid/destination address (receiver address) with the respective values in MRIC, if available. (4) If sequence number of the arrived RP packet is greater than the sequence number in MRIC, then change the next hop in MRIC as the address from where RP packet has arrived; If the route is not available in MRIC then add the route for groupid/destination address (receiver address) with next hop as the node from where RP packet has arrived. (5) Update LSD and stability factor in MRIC. (6) If next hop address in RP packet matches with node address then set FW flag as 01 indicating it as one of the forwarding nodes. (7) Update the previous node address in RP packet to corresponding next hop address for groupid/source address by using MRIC (which is already set during forward movement of RR packet). (8) Send RP packet to its neighbors corresponding to groupid/source address in MRIC (as prepared during forward movement of RR packets). (9) Perform steps 3 to 8 until source is reached. (10) If source is not reached within certain hops or could not find any next hop as set by RR packet in MRIC, send RE packet to receiver.

Let us illustrate the reply phase using Figs. 4 and 5 by using same example as given in Fig. 3 for request phase. RP packets are sent on the reverse paths from $R1$ and $R2$ to mark path from $S$ to receivers and update respective MRIC of the nodes on the path. Reply phase sequence of operation is given as follows.

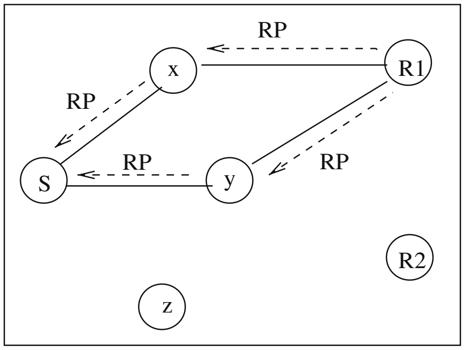


**Fig. 4.** Reply paths from $R1$ to $S$.

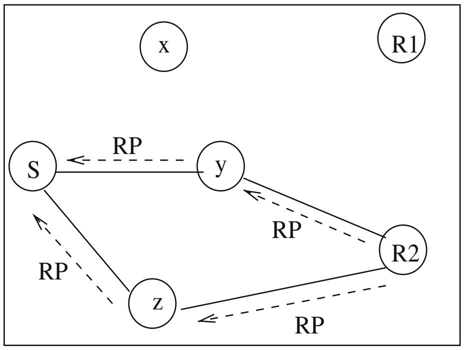


**Fig. 5.** Reply paths from $R2$ to $S$.

- $R1$ broadcasts RP packet to source $S$ through $x$ and $y$.
- Nodes $x$ and $y$ receives RP packet from $R1$. These nodes update the paths to $R1$ in its MRIC with next hop as $R1$. Also nodes update the LSD and stability factor of next hop in MRIC.
- Node $x$ compares next hop address in MRIC with the next hop address of RP packet and if match is found, node $x$ updates MRIC for FW flag = 01. This procedure is repeated at node $y$, and it also sets FW flag = 01.
- Now, $S$ has paths to $R1$: $S$–$x$–$R1$ and $S$–$y$–$R1$.
- Similarly $S$ has paths to $R2$: $S$–$z$–$R2$ and $S$–$y$–$R2$.

Finally, the created mesh between source $S$ and multicast receivers $R1$ and $R2$ with $x$ and $y$ as forwarding nodes is shown in Fig. 6.

## 2.6. Stable path finding in a mesh

Stable forwarding node (SFN) selection among all forwarding nodes in the mesh is an important process in LSMRM since it helps in establishing stable path from receivers to source or vice versa among many alternate paths already found. A forwarding node checks for higher value of stability factor $S_{ij}$ in its MRIC for next hops corresponding to groupid/destination address. A forwarding node selects one of the next hops as SFN using Eq. (6), and selected SFN FW flag will be set to 10 in its MRIC as in Eq. (7)

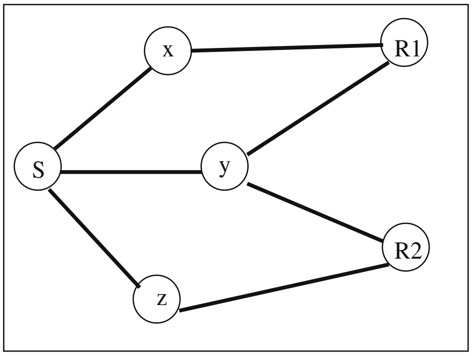


**Fig. 6.** Mesh created between source and receivers $R1$ and $R2$.

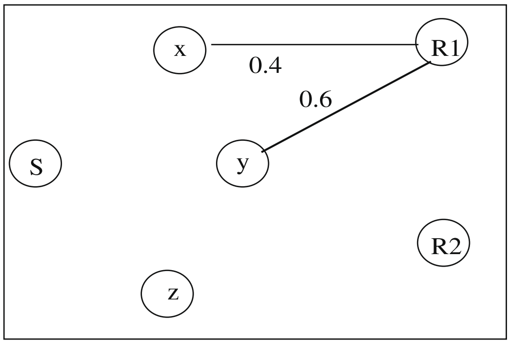


**Fig. 7.** SFN selection from $R1$.

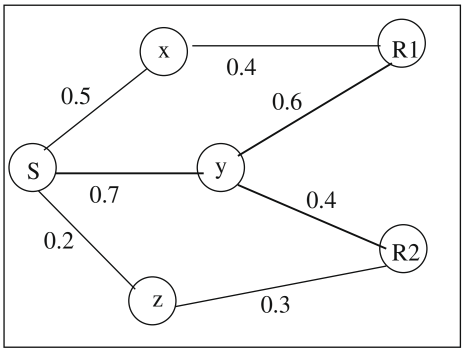


**Fig. 8.** SFN selection from $R2$.

$$SFN = \max\{NEXTHOP_i(S)\}. \tag{7}$$

For example, in Fig. 7, the SFN selected at R1 is node $y$ since it has higher value of $S = 0.6$ than the other node x, whose $S = 0.4$. As $y$ belongs to the forwarding node, it updates FW flag = 10 in its MRIC indicating that this node is an SFN.

A complete example of SFN selection from $S$ to $R1$ and $R2$ based on stability factor is given in Fig. 8 considering the mesh given in Fig. 6.

### 2.7. Mesh maintenance

LSMRM detects two types of link failures: (1) link failure between SFN nodes and (2) link failure between a multicast source/receiver and a SFN. In the case of link failure between two SFN's, the node detecting failure condition will try to find the next stable link in the mesh and route the packet through such a link. In case, if all the forwarding node's link fail, RE packet is sent to the source to rediscover the routes. The route through the failed link in MRIC will be removed and the FW flag for the chosen next hop will be updated accordingly. When links fail between a SFN node and a multicast node, the multicast node detecting failure deletes the multicast node routing information from its MRIC corresponding to failed SFN. Multicast node updates next hop SFN based on high stability factor. In case, all the forwarding nodes' links connected to multicast node fail, then the node rediscovers the mesh and stable route using RR and RP packets.

## 3. Simulation model

Proposed LSMRM has been simulated in various network scenarios to assess the performance and effectiveness of the approach. Simulation environment for the proposed work consists of four models: (1) Network model (2) Channel model (3) Mobility model, and (4) Traffic model. These models are discussed below.

- **Network model:** An ad hoc network is generated in an area of *lxb* square meters. It consists of $n$ number of mobile nodes that are placed randomly within a given area. The coverage area around each node has a bandwidth, $BW_{one\text{-}hop}$ that is shared among its neighbors. MRIC stores only stability factors of SFN with respect to each of its neighbors that have stability factors $\geqslant Th_{SFN}$ (SFN threshold). It is assumed that, the operating range of transmitted power $P_t$ for every node varies with different applications. Other important parameters of the model are transmitting and receiving antenna gain $G_t$ and $G_r$ that is set to an appropriate value.
- **Channel model:** It assumes the free space propagation model defined with following parameters: wavelength $\lambda$ of the transmitted signal, system loss $L$, frequency of transmission $f$ and distance between the transmitter and receiver $d$. Radio propagation range $r$ for each node changes dynamically, depending upon transmitted power of a node. Each wireless link is associated with white noise (additive white Gaussian noise, AWGN) that causes BER confidence level, in which bit errors, *TrueBER* are assessed with respect to specified BER *BERS*. This helps in finding link quality $q$. To access the channel, ad hoc nodes use CSMA/CA MAC layer protocol to avoid possible collisions and subsequent packet drops. Received signal strength is measured in terms of signal-to-noise ratio (SNR). A packet will be accepted, if it is received with SNR higher than the fixed receiver threshold $Rx_{Th}$. Packet propagation delays (per hop) are generated proportional to distance between the nodes, i.e., we consider $m$ s/m.
- **Mobility model:** We use a random way-point (RWP) mobility model based upon three parameters; speed of movement, direction for mobility and time of mobility. In RWP, Each node picks a random destination uniformly within an underlying physical space, and travels

with a speed $v$ whose value is uniformly chosen in the interval 0 to *Vmax*. *Vmax* is some parameter that can be set to reflect the degree of mobility. Upon reaching the destination, the node pauses for a time period *Z*, and the process repeats itself afterwards. Eight directions are considered for movement of nodes: east, west, north, south, north-east, north-west, south-east and south-west. A node starts with a random direction to pick its neighbor in that direction and this process continues till it reaches the boundary, and after reaching the boundary it bounces back.

- **Traffic model:** Traffic model used is constant bit rate model that transmits a certain number of fixed size packets, $Tr_{pkts}$. Various multicast group sizes *GpSize* are defined to assess the performance of packet delivery ratio, control overhead and packet delay with group sizes. The packets are transmitted with bandwidth *bt* bps.

### 3.1. Simulation parameters

The following parameters are used for simulation. $l = 1000$ m, $b = 1000$ m, $n$ = 50–250 with an increment steps of 50, $BW_{one\text{-}hop} = 20$ Mbps, $Th_{SFN} = 0.5P_t = 100$–1000 mW with an increment step of 100 mW, $G_t = G_r = 1$, $\lambda = 0.100$–$0.135$ m, $L = 1$, $f = 200$ MHz, $d = 20$–$800$ m, $r$ = 200–350 m. $TrueBER = 10^{-2}$–$10^{-6}$ with $BERS = 10^{-2}$ and $q$ = 0.2–0.6. Receiver Threshold $Rx_{Th} = 50$ mW. Propagation delay per hop $m = 0.001$ s/ m, speed of a node $v = [0, Vmax]$ = [0 m/s, 20 m/s], pause time $Z = 0.2$ ms. $Tr_{pkts}$ = multiples of 1000, *GpSize* = 5–50 and $bt = 2$ mbps.

### 3.2. Performance measures

The following performance measures are considered in simulation. Our objective is to increase the packet delivery ratio (PDR) and reduce various overheads (i.e., control, memory, computation, and message overheads) and packet delays. Increased PDR and reduced packet delay improves network throughput and reduced overheads reduce bandwidth consumed and efficient usage of various resources for route discovery and maintenance.

- *Packet delivery ratio (PDR):* It is defined as the sum of number of packets received at all the multicast receivers to the product of number of packets sent at source and number of multicast receivers.
- *Control overhead:* It is the total number of control packets needed to establish a stable route from source to the multicast receivers.
- *Memory overhead:* It is the average number of bytes stored in MRIC and LSD of all SFN's with respect to their neighbors at any given time. Memory overhead is given by Eq. (8)

$$Memory\ overhead = \frac{\sum_{a=1}^{A}\left[\sum_{b=1}^{B}(MRICbytes + LSDbytes)_b\right]_a}{A}, \quad (8)$$

where $A$ is the number of SFN's in a network at any time, $B$ is the number of neighbors of each SFN. *MRICbytes* and *LSDbytes* are the number of bytes to be stored in MRIC and LSD of an SFN with reference to $b$th neighbor (for which $S_{ij} \geqslant Th_{SFN}$), respectively.

- *Computation overhead:* It is the average number of computations needed by all the involved SFNs to calculate stability factor $S_{ij}$ at any given time. It is given by Eq. (9)

$$Computation\_overhead = \frac{\sum_{c=1}^{C}\left[\sum_{d=1}^{D}(Comp)_d\right]_c}{C}, \quad (9)$$

where $C$ is the number of SFN's in the network at any given time, $D$ is the number of neighbors to each SFN, *Comp* is the number of computations needed to find stability factor at selected SFN with reference to $d$th neighbor.

- *Message overhead:* It is the average number of messages exchanged between every SFN and its neighbors at any time. It is given by Eq. (10)

$$Message\_overhead = \frac{\sum_{e=1}^{E}\left[\sum_{f=1}^{F}(Msg)_f\right]_e}{E}, \quad (10)$$

where $E$ is the number of SFN's in the network at any time, $F$ is the number of neighbors to each SFN, *Msg* is the number of messages that are exchanged between every SFN and its $f$th neighbor.

- *Packet delay:* It is defined as the average time taken to transmit predefined number of packets from source to multicast destinations for various group sizes.

## 4. Results

In this section, we discuss the results obtained with proposed LSMRM. Six categories of results are analyzed: (1) Analysis of PDR, (2) Analysis of control overhead, (3) Analysis of memory overhead, (4) Analysis of computation overhead, (5) Analysis of message overhead and (6) Analysis of packet delays. Analysis is done in comparison with ODMRP and EODMRP.

### 4.1. Analysis of PDR

Three cases of PDR analysis are performed: (1) Effect of transmitting power at a node on PDR for varying number of nodes of certain group size, (2) Effect of multicast group size on PDR for varying number of nodes, and (3) Effect of group size over PDR for varying speed of nodes for a fixed group size. Figs. 9–14 depict the analysis of PDR.

Fig. 9 shows that there is an increase in PDR as power at transmitting node increases (for 1 source, 5 receivers for transmitting 1000 packets) for proposed work. We also observe that, as the number of nodes increase (from 50 to 250) in the network, the delivery of packets increases since there is a possibility of decreased hop length between the nodes with increase in number of nodes, which enhances the link stability and reduces packet drops. The noise signal dominates at low transmission power levels than at higher levels that resulted in less PDR at lower power levels. The increase in PDR is fairly stable at higher power levels (more than 400 mW), where the network reaches saturation level since the traffic exceeds $BW_{one\text{-}hop}$ at every node leading to constant packet drops.

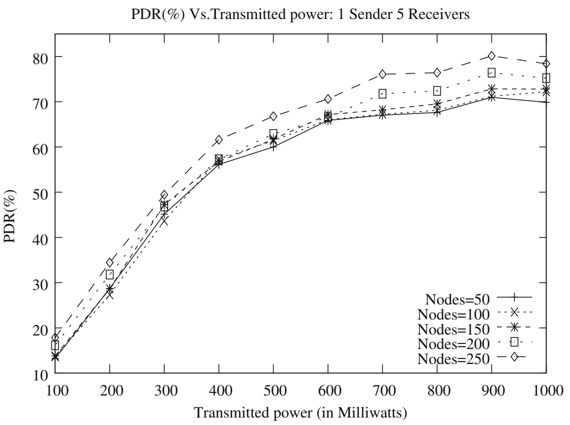


**Fig. 9.** PDR vs. transmitted power.

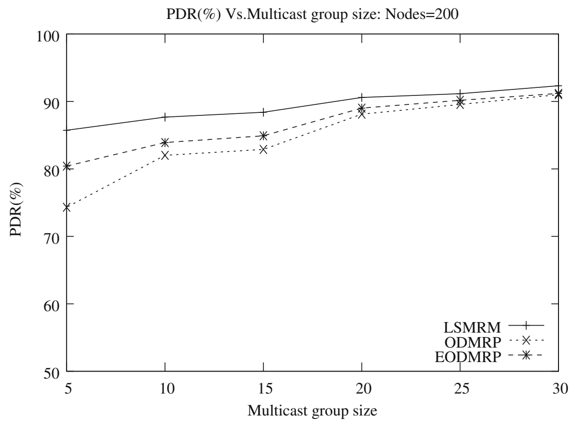


**Fig. 12.** PDR vs. multicast group size (nodes = 200).

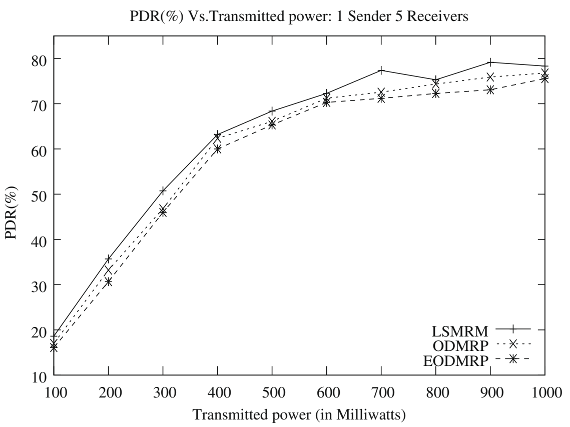


**Fig. 10.** PDR vs. transmitted power.

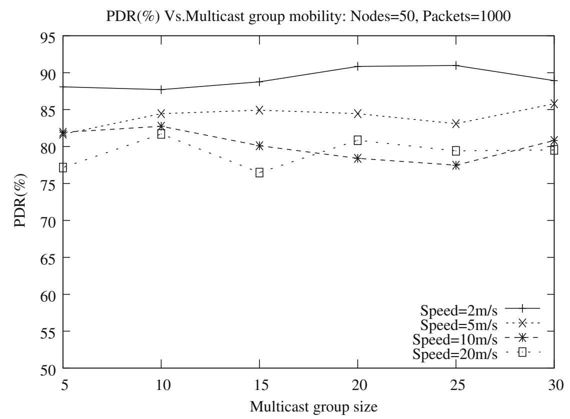


**Fig. 13.** PDR vs. multicast group size.

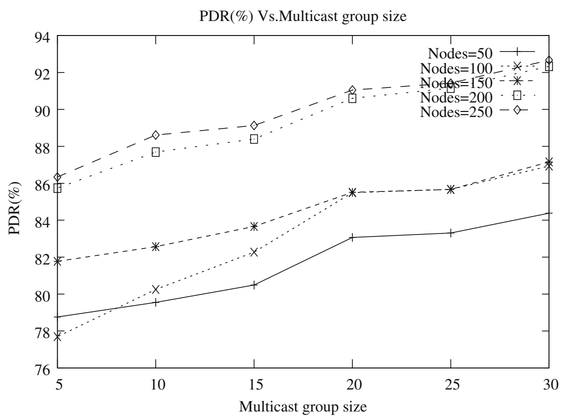


**Fig. 11.** PDR vs. group size.

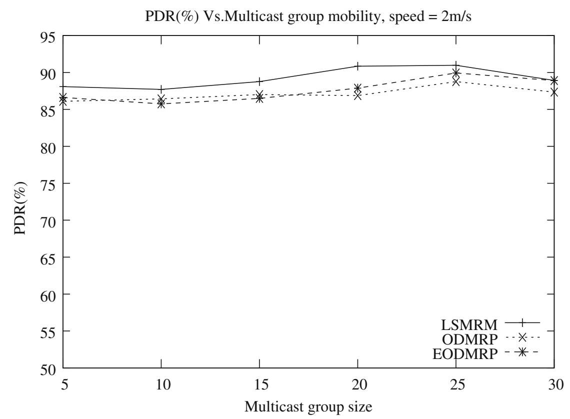


**Fig. 14.** PDR vs. multicast group size (mobility = 2 m/s).

We also compared the PDR performance of LSMRM with ODMRP and EODMRP for 250 node network with 1 source, 5 receivers and 5000 packets transmission (see Fig. 10). It is observed that LSMRM gives better PDR compared to ODMRP and EODMRP since ODMRP and EODMRP does not consider link stability for data transmission, i.e., they treat all links of the mesh in the same manner.

PDR increases as the group size increases (see Fig. 11) with each group member source transmitting the packets in case of proposed work. This is because the number of forwarding nodes increase with increase in group size and thus the probability of having stable forwarding node in the network is more. Also, it is observed that PDR increases with increase in the number of nodes in the network due to more stable links exist in the mesh and thus provide high probability of link connectivity.

LSMRM provides better PDR compared to ODMRP as shown in Fig. 12, in which the results are given for 200 node network. For group size of 5, PDR is 86% for LSMRM whereas it is 74% and 80% for ODMRP and EODMRP, respectively. This is because, ODMRP and EODMRP rely on links which are vulnerable to packet drops in contrast to LSMRM that are established based on high stability factor. The gap between PDR curve of LSMRM and ODMRP decreases with increase in group size since connectivity improves in ODMRP with increase in group size. But LSMRM maintains consistent PDR with increase in group size.

Fig. 13 depicts the effect of mobility on PDR for different group sizes for proposed work. Lower mobility of nodes corresponds to higher PDR. Group size increase does not cause perfect increase in PDR, but PDR oscillates with increase in group size and the mobility. Higher mobility causes slightly higher oscillations than lower mobility. Mobility of node triggers new SFN selection to find a new stable path towards the source causing the packet drops and hence decrease in PDR.

PDR of LSMRM compared to that of ODMRP and EODMRP is better with node mobility since ODMRP and EODMRP use route refresh cycles to handle mobility of nodes (see Fig. 14). After a group size of 25, the PDR falls to lower value since forwarding node may select less stable link due to false power level measurement at a moving node interface. LSMRM provides around 5% increase in PDR compared to ODMRP and EODMRP.

### 4.2. Analysis of control overhead

Fig. 15 shows the number of control packets increase to establish a mesh with the increase in number of nodes in the network for proposed work. For a given number of nodes, control packets increase with increase in group size. It is to be noticed that, when network size increases (beyond 200 nodes), the number of control packets decrease at higher multicast group sizes. This is due to the possibility of selecting the same SFN by two or more receivers since this SFN happens to be the nearest neighbor for all those receivers as per the SFN selection rule and thus reducing the number of control packets to construct a mesh. LSMRM uses less number of control packets compared to the overheads required by ODMRP and EODMRP for a group size of 5 as shown in Fig. 16.

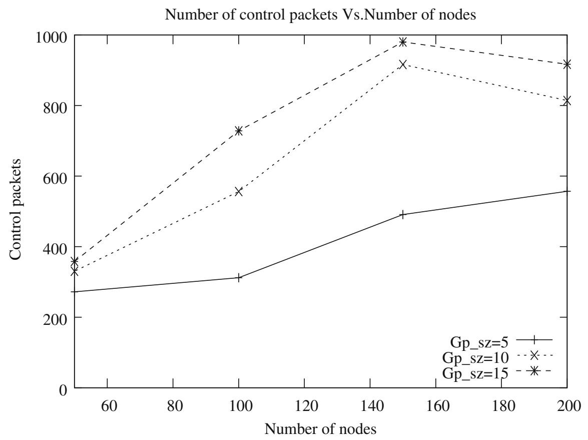


**Fig. 15.** Control packets vs. number of nodes.

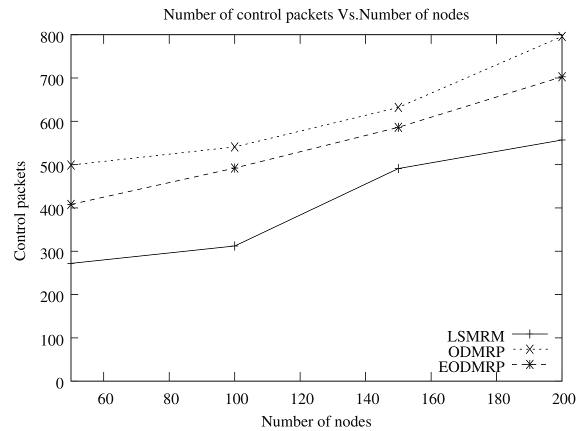


**Fig. 16.** Control packets vs. number of nodes (group size = 5).

### 4.3. Analysis of memory overhead

Since LSMRM needs various parameters to be stored in MRIC and LSD database to select SFN. This necessitates additional memory requirement (in bytes) that depends upon the number of SFN's in a network at any time. Two reasons for reduced memory overhead are (a) MRIC and LSD entries are made at SFN only for those neighbors that satisfy the condition $S_{ij} \geqslant Th_{SFN}$ and (b) Node removes information from its MRIC as it learns that existing routes in the ad hoc network have failed due to link and node failures.

Fig. 17 shows memory overhead of LSMRM at discrete simulation time for 50 and 100 node topology. The overhead in 100 node topology is more than that of 50 node topology, since, as the number of nodes increase, there are chances that more number of neighbors satisfy SFN threshold condition and there are more entries in MRIC and LSD increasing the overhead. ODMRP memory overhead is higher than LSMRM (see Fig. 18) due to following reasons. (1) ODMRP forwarding nodes store join table and join reply packets and the number of these packets correspond to all of their neighbors as there is no learning and filtering mechanism on storage as in LSMRM. (2) Number of bytes in join request and join reply packets are more compared to the number of bytes in MRIC and LSD of LSMRM.

However, memory overhead in EODMRP outperforms both ODMRP and LSMRM since EODMRP uses expanding ring search mechanism upon joining or detection of a broken route. Expanding ring search mechanism helps EODMRP node to graft to the forwarding mesh reducing route reconstruction overhead under above said conditions.

### 4.4. Analysis of computation overhead

Fig. 19 shows the number of computations required to select SFN based upon stability factor in LSMRM with 50 and 100 node topology. The computation overhead for

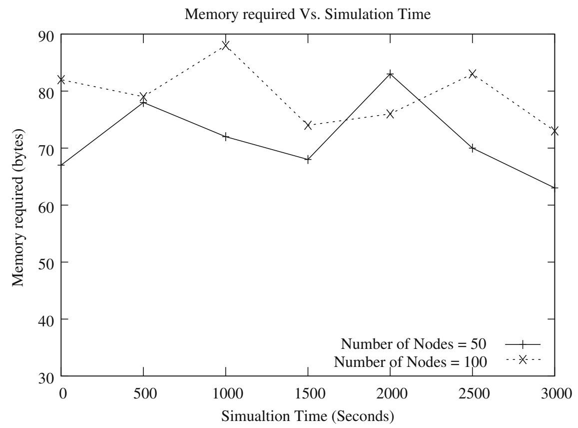


**Fig. 17.** Memory required vs. simulation time.

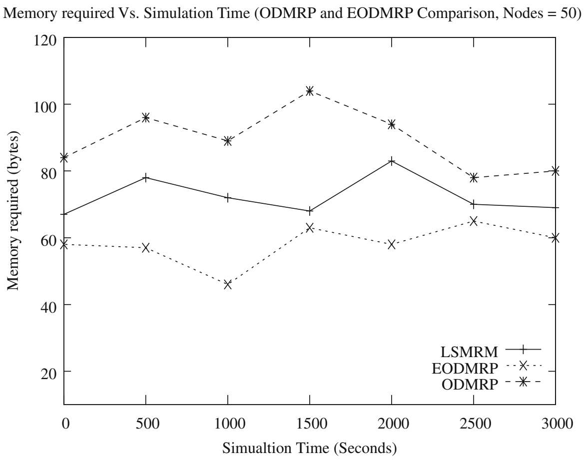


**Fig. 18.** Memory required vs. simulation time (group size = 5).

100 node topology is more than that of 50 node topology, since, as the number of nodes increase, there are chances that number of neighbors of SFN increase. Thus, it increases computations with respect to each neighbor.

Since there is no SFN concept in ODMRP, and to accommodate mobility and route breakage, it has to reconstruct entire multicast routes requiring more number of computations, if there are frequent refresh of routes needed in a given time interval. The situation worsens in EODMRP since the protocol depends on an estimate of the route time to live duration that should refresh the forwarding mesh before it breaks down causing more number of computations compared to LSMRM and ODMRP as in Fig. 20.

### 4.5. Analysis of message overhead

Messages that are exchanged among the neighbors to select SFN in LSMRM is shown in Fig. 21 for 50 and 100 node topology. Message overhead in 100 node topology is more than that of 50 node topology as more messages are needed to select SFN with many number of its neighbors.

Because of fixed duration refreshing in ODMRP, messages exchanged to set up a mesh of routes is high for short refresh duration due to frequent mobility and route breaks whereas in LSMRM, the route breaks are less frequent since it establishes routes with stable forwarding nodes as shown in Fig. 22. Since EODMRP uses dynamic refreshing and local recovery of routes, the messages exchanged are less compared to ODMRP.

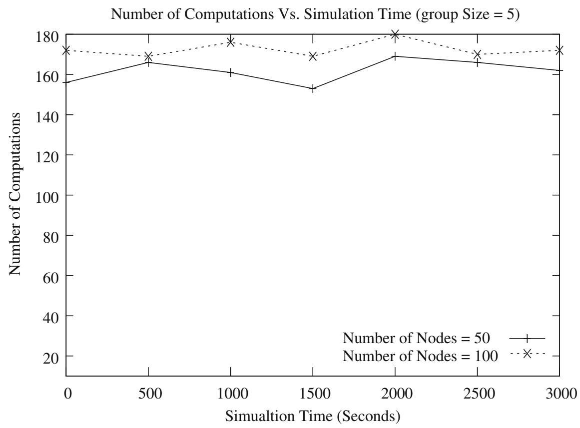


**Fig. 19.** Number of computations vs. simulation time.

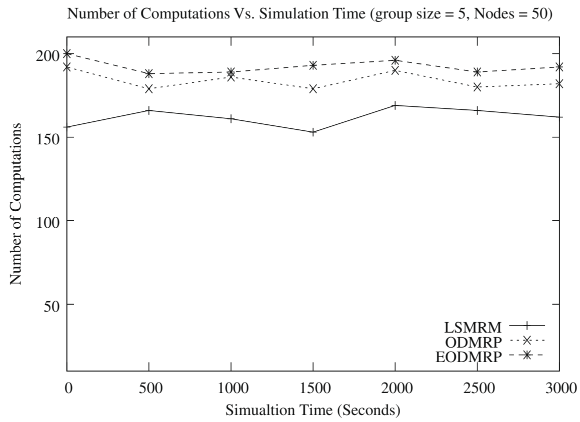


**Fig. 20.** Number of computations vs. simulation time (group size = 5).

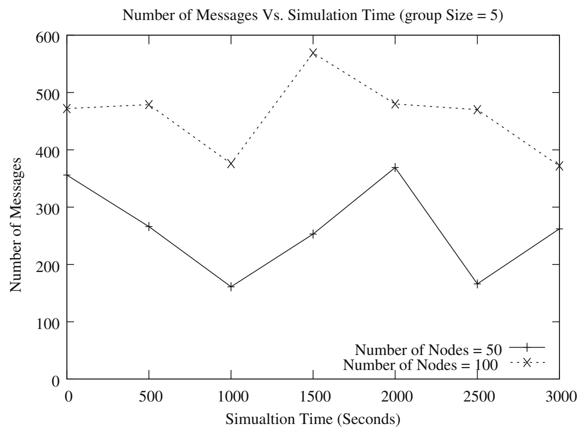


**Fig. 21.** Number of messages vs. simulation time.

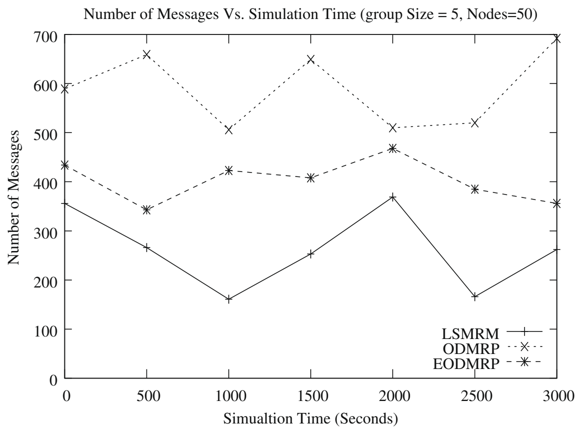


**Fig. 22.** Number of messages vs. simulation time (group size = 5).

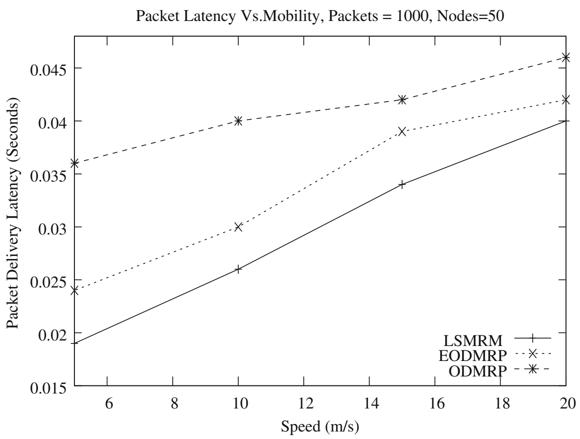


**Fig. 23.** Packet delay vs. mobility (group size = 5 and 10).

### *4.6. Analysis of packet delay*

Fig. 23 shows the packet delays to transmit 1000 packets with group size 5 for varying speed of nodes. The time required to transmit the packets to all destinations in LSMRM is less than that of ODMRP because LSMRM finds nearest stable link to forward packets when nodes start moving, where as in ODMRP, node mobility triggers new path set up. The mobility of nodes and link failures are augmented in EODMRP as local recovery process, delays for such actions are less compared to ODMRP.

During high node mobility (more than 15 m/s), link failures will cause packet delays to increase. In LSMRM, the SFN detecting link failure will try to find the next stable link in the mesh and route the packet through such a link. In case, if all the forwarding node's links fail, RE packet is sent to the source to rediscover the routes. In such a condition, the packet delay of LSMRM almost reaches nearer to the packet delay of ODMRP and EODMRP.

## 5. Conclusions

In this paper, we proposed a stability based multicast routing scheme in MANET. The scheme finds multicast routes to receivers by using route request and route reply packets with the help of routing information maintained in MRIC and link stability parameters maintained in LSD on every node in a MANET. Multicast mesh of alternate paths between every source-destination pair is established in mesh creation phase. Stable path within a mesh is established by choosing an SFN that possess higher value of link stability among its neighbors. This assures better quality of links and minimizes the possibility of link failures and the overhead needed to construct the paths. Link failure conditions are notified to the source with route error packets so as to enable the source to start route discovery for new route establishments. Extensive simulation is performed to assess the network with six performance metrics such as packet delivery ratio, packet delay and four types of overheads, i.e., control overhead, memory overhead, computation overhead and message overhead. The performance metrics are compared with ODMRP and EODMRP. The proposed scheme showed significant improvements in terms of packet delivery ratio, packet delay and various overheads compared to ODMRP and EODMRP. We would like to extend the work by employing software agents to perform mesh creation and stable route selection by embedding intelligence into the agents, which can improve the scalability, flexibility (bandwidth constrained routing, delay constrained routing, cost constrained routing) and customize services for multicasting in MANETs.

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