

EVALUATING THE PERFORMANCE OF THE LOCATION-AIDED ROUTING-1P ROUTE DISCOVERY ALGORITHM

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ABSTRACT

Dynamic Routing Protocols (DRPs) are widely-used for routing information among mobile nodes in Mobile Ad Hoc Network (MANET) and establish and maintain connectivity within the network. A DRP comprises two main phases: route discovery and route maintenance. The route discovery phase involves transmission of large number of redundant control packets consuming significant portion of the nodes power and increase communication overheads. Recently, a new efficient and effective route discovery algorithm has been developed, namely, the LAR-1P algorithm, which combines two well-known routing protocols; these are: The Location-Aided Routing scheme 1 (LAR-1) and probabilistic algorithms. This study evaluates and compared the performance of the LAR-1P algorithm against the performance of a number of route discovery algorithms through simulation. For each simulation, the number of retransmissions and reachability are estimated and compared. The simulations results demonstrated that LAR-1P provides better performance than all other algorithms it is compared with, as it significantly reduces communication overheads while maintaining almost the same network connectivity.

Keywords: MANET, Route Discovery, LAR-1P, LAR-1, Probabilistic Algorithm, Pure Flooding

1. INTRODUCTION

A MANET is a set of wireless mobile nodes which are able to communicate with each other without relying on any established infrastructures or centralized administration. Therefore, each node in the network must be able to operate as router and needs to be capable of discovering and maintaining routes to every other node in the network (Al-Bahadili, 2013; Loo *et al.*, 2011). Data in MANETs is usually forwarded to other mobile nodes in the network through reliable and efficient DRPs, which are part of the network layer software (Sensarma and Majumder, 2013). The DRPs are responsible for finding and deciding which output route data should be transmitted on. Example of DRPs include the Dynamic Source Routing (DSR), Ad Hoc On-Demand Distance Vector (AODV), Zone Routing Protocol (ZRP). DRPs usually consists of two main phases; these are: Route discovery and route maintenance (Hnatyshin, 2013; Mani *et al.*, 2013).

Route discovery is usually executed when a source node desires to send a packet to some destination and does not already have a valid route to that destination; in this case, the source initiates a route discovery process to locate the destination (Wang *et al.*, 2009). During the route discovery phase, the source node broadcasts a Route Request (RREQ) packet to its neighbors, which then forward the request to their neighbors and so on until the expiration of the packet. During the forwarding process, the nodes record in their route tables the address of the node from which first copy of the broadcast packet is received. Once the RREQ reaches the destination, the destination node responds with a route reply (RREP) packet back to the source through the route from which it first received the RREQ. Otherwise, if the RREQ packet expired before reaching the destination, then the node at which it expires, sends a Route Error (RERR) packet back to the source to initiate a new route discovery process (Yassein *et al.*, 2011).

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Pure flooding is the simplest and most reliable mechanism proposed in the literature for route discovery in MANETs (Yassein *et al.*, 2011). In pure flooding, each node rebroadcasts the message to its neighbors upon receiving it for the first time, starting at the source. However, pure flooding is costly where it costs N transmissions in a network of N reachable nodes. Thus, pure flooding results in serious redundancy, contention and collisions in the network; such a scenario is undesirable and it is oftenly called the Broadcast Storm Problem (BSP) (Azizi, 2013).

Various flooding optimization algorithms have been developed to alleviate the effects of BSP during route discovery in MANETs by reducing the number of redundant retransmissions without significantly affecting network reachability. Such as the LAR-1 algorithm (Hnatyshin, 2013; Husain *et al.*, 2010; Deb *et al.*, 2009) and probabilistic broadcast (Hadji-nejad *et al.*, 2010; Nand and Sharma, 2012; Al-Bahadili, 2010a; Al-Bahadili and Kaabneh, 2010).

The performance of LAR-1 significantly suffers from the high number of redundant retransmissions in high-density zones (networks) (Hnatyshin and Asenov, 2010). While dynamic probabilistic usually provides excellent performance in high-density zones subject to using proper retransmission probability (p_r) adjustment mechanism (Nand and Sharma, 2012; Al-Bahadili, 2010a).

A new route discovery algorithm has been proposed in Al-Bahadili (2013). It combines two algorithms, namely, the LAR-1 and probabilistic algorithms and it is referred to as the LAR-1P algorithm. In this algorithm, when receiving a RREQ, a node within the request zone rebroadcasts the RREQ with dynamically adjusted p_r . LAR-1P combines the better of the two algorithms. In low-density zones; the nodes assigned p_r equal or close to unity, so that the algorithm acts as LAR-1, while a satisfactory p_r is determined assigned in high-density zones, which means the algorithm acts as probabilistic algorithm.

The simulation results in (Al-Bahadili, 2013) demonstrated that for a uniform random node distribution on specific network area and for a certain simulation setup, LAR-1P reduces the number of retransmissions with slight reduction in reachability. The reduction in reachability can be avoided by proper p_r adjustment at low-density zones. Furthermore, LAR-1P can provide better average performance if the route discovery processes is performed more in high-density zones than in low-density zones.

This study evaluates the performance of the LAR-1P algorithm using the MANET simulator (MANSim) (Al-

Bahadili, 2010b). First, the effect of nodes density (total number of nodes in the network divided by the network area) on the performance of LAR-1P is investigated and compared against other algorithms like pure flooding, dynamic probabilistic and LAR-1. Second, for a certain nodes density (4×10^{-4} node/m²), the effects of zones density on the performance of the LAR-1 and LAR-1P algorithms are investigated for one particular source node (Node 1).

The paper is organized as follows. Section 1 presents in addition to the above introduction, a review of the most recent and related work, description of the LAR-1, probabilistic broadcast and LAR-1P algorithms and the computational procedures adopted in this work. The materials and methods used in this study are described in Section 2. The simulation results and discussions are presented in Sections 3 and 4. Finally, Section 5 points-out a number of conclusions and recommendations for future work.

1.1. Literature Review

A review of some of the most recent and related work to LAR-1P, LAR-1 and probabilistic algorithms is presented. In particular, this review summarizes the development steps of these algorithms. A fixed retransmission probability LAR-1P algorithm proposed, first, by Al-Bahadili *et al.* (2007). Later on, Al-Bahadili (2013) developed a new version of LAR-1P with dynamic probability, which will be described later. The effect of node density on the performance of the LAR-1P algorithm was investigated by Al-Bahadili *et al.* (2012).

Location information initially used by Ko and Vaidya (2000) to develop two different LAR schemes, LAR-1 and LAR-2 to reduce flooding communication overhead in ad hoc networks. Li *et al.* (2000) presented a modified version of LAR protocol, which was called LAKER (location aided knowledge extraction routing) protocol for MANETs. Boleng and Camp (2004) combined location information and nodes mobility feedback and pattern to create more efficient routing protocol that is capable of reducing routing communication overheads.

Deb *et al.* (2009) proposed a new location-aided routing protocol for GPS scarce MANET called the location-aided cluster based energy-efficient routing (LACBER). Another cluster-based LAR protocol for large scale MANETs was developed by Wang *et al.* (2009). Husain *et al.* (2010) presented a study on using LAR protocols for vehicular ad hoc networks (VANETs) in highway scenario.

Hnatyshin and Asenov (2010) and Hnatyshin (2013) provided a study summarizing the use of geographical location information to reduce the control traffic overhead associated with the route discovery process of the AODV routing protocol. They introduced a new Geographical AODV (GeoAODV) protocol that relies on location information to reduce the flooding area to a portion of the network that is likely contains a path to destination. Furthermore, they compared GeoAODV performance with that of the LAR protocol and examined four mechanisms for reducing the size of the flooding area: LAR zone, LAR distance, GeoAODV static and GeoAODV rotate. They employed OPNET Modeler version 16.0 software to implement these mechanisms and to compare their performance through simulation.

Nand and Sharma (2012) proposed a probability-based broadcasting technique for routing protocol to trim down flooding problem. It uses node's remaining energy strength and threshold random delay to generate rebroadcast probability dynamically for the efficient broadcasting in route discovery. This technique was analyzed over reactive AODV protocol. The performance of modified protocol is analyzed over broadcast packets sent and end-to-end delay using NS2 simulator. Simulation results were observed and found that redundant transmission were reduced by 19 to 28 percent and hence improve network performance.

Probabilistic algorithm was first used by Haas *et al.* (2006) for route discovery in ad hoc networks and they called it a gossip-based (GOSSIP1) protocol. They used a predefined p_t to decide whether or not a node forwards the control packets. Later on, Haas *et al.* (2006) developed a modified protocol, in which they gossip with $p_t = 1$ for the first h hops before continuing to gossip with $p_t < 1$. Their results showed that they can save up to 35% message communication overheads compared to simple flooding in various network environments.

Tseng *et al.* (2002) examined the performance of probabilistic flooding for various network densities. They presented results for three network parameters, namely, reachability, saved rebroadcast and average latency, as a function of p_t and network density. Sasson *et al.* (2003) developed probabilistic algorithm in which nodes would dynamically adjust their p_t based on local topology information. Kim *et al.* (2004) introduced a probabilistic scheme in which a node dynamically adjusts its p_t according to its additional coverage area. The additional coverage is estimated by the distance from the sender.

Scott and Yasinsac (2004) presented a dynamic probabilistic solution that is appropriate to solving BSPs

in dense mobile networks. Barrett *et al.* (2005) introduced a probabilistic routing protocol for sensor networks, in which a sensor decides to forward a message with p_t that depends on various parameters, such as the distance of the sensor to the destination, the distance of the source sensor to the destination, or the number of hops a packet has already travelled.

Viswanath and Obraczka (2005) developed an analytical model to study the performance of plain and probabilistic flooding in terms of its reliability and reachability in delivering packets showing that probabilistic flooding can provide similar reliability and reachability guarantees as plain flooding at a lower overhead. A probabilistic scheme that dynamically adjusts p_t as per node distribution and node movement was proposed in (Zhang and Agrawal, 2005). The scheme combines between probabilistic and counter-based approaches.

Abdulai *et al.* (2006) studied the performance of the AODV protocol over a range of p_t . They focused on the route discovery part of the routing algorithm; they modified the AODV implementation to incorporate p_t . Simulations showed that setting efficient p_t has a significant effect on the performance of the protocol. The results also revealed that the optimal p_t for efficient performance is affected by the prevailing network conditions such as traffic load, nodes density and mobility. Abdulai *et al.* (2007) also proposed two probabilistic methods for on-demand route discovery, that is simple to implement and can significantly reduce the overhead involved in the dissemination of RREQs. The two methods are: The adjusted probabilistic (AP) and Enhanced AP (EAP).

Yassein and Ould-Khaoua (2007) proposed a dynamic probabilistic algorithm to improve network reachability and saved rebroadcast. It determines p_t by considering nodes density and speed. Abdulai *et al.* (2006) combined probabilistic and knowledge based approaches on the AODV protocol to enhance the performance of existing protocol by reducing the communication overhead incurred during the route discovery process. Hanash *et al.* (2009) proposed a dynamic probabilistic approach that can reduce broadcast redundancy in MANETs. Al-Bahadili (2010a) developed a new p_t adjusting model, in which the neighbourhood densities are divided into three regions of different density ranges (low, medium and high). The performance of the new model was compared against pure and probabilistic algorithms.

Hadji-nejad *et al.* (2010) introduced a routing scheme for MANETs, which works well under a wide range of network topologies, nodes-density, coverage area size

and nodes-mobility. The scheme is based on a novel enhancement of the hint-based probabilistic protocol. Instead of broadcasting extensive control packets for network topology information retrieval as that of conventional routing schemes, the scheme carefully reuses the feedback information carried in unicast packets for this purpose without overhead. The scheme is evaluated through both mathematical analysis and an extensive simulations study.

Nand and Sharma (2012) developed a probability-based broadcasting technique for routing protocol to trim down flooding problem. It uses node's remaining energy strength and threshold random delay to generate rebroadcast probability dynamically for the efficient broadcasting in route discovery. This technique was analyzed over reactive AODV protocol. The performance of modified protocol is analyzed over broadcast packets sent and end-to-end delay using NS2 simulator. Simulation results were observed and found that redundant transmission were reduced by 19 to 28 percent and hence improve network performance.

1.2. The LAR-1 Algorithm

The LAR-1 algorithm is based on two important concepts, namely, the Expected Zone (EZ) and the Request Zone (RZ). For EZ, consider a source node S that needs to find a route to a destination node D assuming S knows the location of D at time t_0 and the current time is t_1 . Then, EZ of D, from the viewpoint of S at time t_1 , is the region that expected by S to contain D at time t_1 . S can determine EZ based on the knowledge that D was at location L at time t_0 and travels with speed

u , then S may assume that EZ is circular region of radius $R_e = u(t_1 - t_0)$, as illustrated in Fig. 1a (Husain *et al.*, 2010).

If the actual speed happens to be larger than the average, then the destination may actually be outside EZ at time t_1 and vice versa. Thus, EZ is only an estimate made by S to determine a region that potentially contains D at time t_1 . If S does not know a previous location of D, then S cannot reasonably determine EZ, in this case, the entire region that may potentially be occupied by the MANET is assumed to be EZ and the algorithm reduces to the basic flooding algorithm. In general, having more information regarding mobility of D can result in more appropriate EZ.

For RZ, again, consider S needs to determine a route to D. LAR-1 uses pure flooding with one modification. S defines (implicitly or explicitly) a RZ for the RREQ that contains both S and D and the locations of S and D as its opposite corners. A node forwards a RREQ only if it belongs to RZ (unlike pure flooding). To increase the probability that RREQ will reach D, RZ should include EZ (Fig. 1a). Additionally, RZ may also include other regions around RZ (Al-Bahadili *et al.*, 2012). Note that the probabilities of finding a path (in the first attempt) can be increased by increasing the size of RZ. However, route discovery overhead also increases with increasing size of RZ. Thus, there exists a trade-off between latency of route determination and the message overhead.

Now, let us move to discuss LAR-1 scheme. It uses an RZ that is rectangular in shape (Fig. 1).

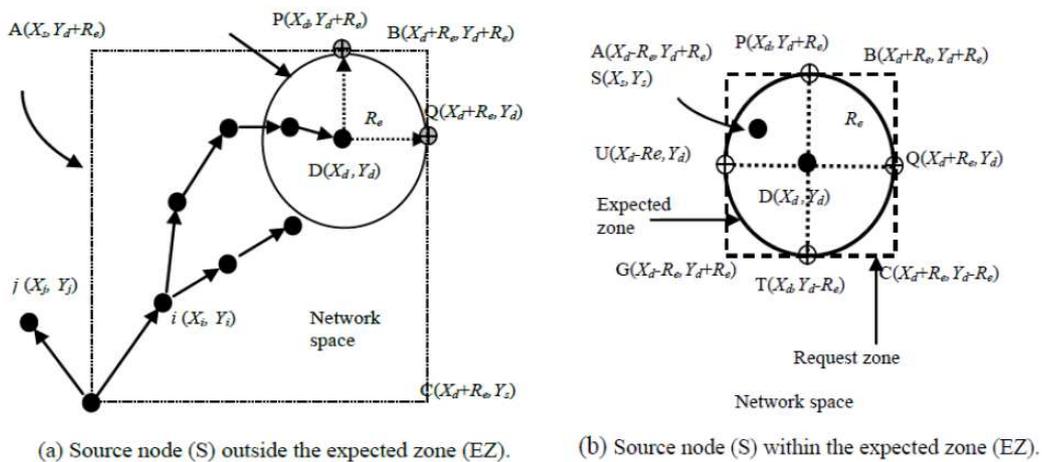


Fig. 1. The LAR-1 algorithm

It is assumed that S knows that D at location (X_d, Y_d) at t_0 . At t_1 , S initiates a new route discovery for D. It is also assumed that S knows the speed u with which D can move. Using this, S defines EZ at t_1 to be the circle of radius $R_c = u(t_1 - t_0)$ centred at location (X_d, Y_d) . As stated before, instead of the average speed, u may be chosen to be the maximum speed or some other function of the speed distribution. RZ is defined to be the smallest rectangle that includes current location of S and EZ, such that the sides of the rectangle are parallel to the X and Y axes. In **Fig. 1a**, RZ is the rectangle whose corners are S, A, B and C, whereas in **Fig. 1b**, the rectangle has corners at point A, B, C and G. In **Fig. 1**, current location of S is denoted as (X_s, Y_s) and consequently S can determine the four corners of RZ.

S includes their coordinates with the initial RREQ when initiating route discovery. When a node receives a RREQ, it discards the request if it is not within the rectangle specified by the four corners included in the RREQ. For instance, in **Fig. 1a**, if i receives the RREQ from another node, i forwards the request to its neighbours, because i determines that it is within the rectangular RZ. When j receives the RREQ, it discards the request, as it is not within RZ.

When D receives the RREQ packet, it replies by sending a RREP packet. In case of LAR-1, D includes its current location and current time in the RREP packet. When S receives this RREP packet (ending its route discovery), it records the location of D. S can use this information to determine RZ for a future route discovery. It is also possible for D to include its current speed or average speed with the RREP packet. This information can be used in a future route discovery. Further details on LAR schemes can be found in (Hnatyshin, 2013; Deb *et al.*, 2009; Wang *et al.*, 2009).

1.3. The Probabilistic Algorithm

Probabilistic algorithm aims at reducing number of retransmissions, in an attempt to minimize the effects of the BSP in MANETs (Nand and Sharma, 2012). In this scheme, when receiving a RREQ, a node retransmits it with probability p_t and with probability $1 - p_t$ it discards the RREQ. A node is allowed to retransmit the same RREQ only once, i.e., if a node receives a RREQ, it checks to see if it has retransmitted it before, if so then it just discards it, otherwise it probabilistically retransmits it. Nodes identify the RREQ through its sequence number. The source node p_t is always set to 1, to ensure the source initializing a new RREQ.

The p_t for intermediate nodes (all nodes except the source and the destination) is determined using either

static or dynamic approach. In a static approach, a pre-determined p_t ($0 \leq p_t \leq 1$) is assigned for each node in the networks. While, in a dynamic approach, each node in the network locally determines its p_t depending on the number of first-hop neighboring nodes using certain probability distribution function; usually, $p_t = f(k)$, where k is the number of first-hop neighbors.

In this study, the distribution function in Al-Bahadili (2010a) is used. This is because it demonstrated an excellent performance in comparison with other distribution functions under various network environments and configurations.

1.4. The LAR-1P Algorithm

The LAR-1P algorithm is straightforward as it is simply, when receiving a broadcast message, a node within the RZ rebroadcasts the message with dynamically calculated p_t and each node is allowed to rebroadcast the received message only once. This reduces the number of retransmissions and also the node average duplicate reception, subsequently, the number of collisions and contentions at the receiver. The reduction in the number of retransmission will of course depend on the assigned p_t and the algorithm is reduced to LAR-1 if the nodes' p_t is set as unity.

It is important to recognize that reduction in the number of retransmission may introduce some reduction in network reachability. This is because if the number of intermediate nodes within RZ is small (low-density zones) and some of them will not rebroadcast the RREQ, which may result in a failure of delivery of the RREQ to destination, so that the source has to reinitiate a new RREQ.

It is expected that if the number of intermediate nodes within RZ is large (high-density zones), there will be insignificant reduction in reachability. **Figure 2** outlines the procedure of the LAR-1P algorithm.

There are two values for the first-hop neighbors (k) that can be considered for calculating p_t in dynamic probability LAR-1P:

- The first represents the total number of first-hop neighbors regardless of whether they are inside or outside RZ (same as in probabilistic algorithm)
- The second considers nodes inside RZ only, which is usually equal to or less than the first value

Normally, every node in the network updates the lists (records) of its first-hop neighbors at the start of each time interval, which is usually lasted for what is referred to as the pause time (τ).

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The LAR-1P algorithm.
Determine RZ for specific source (S) and destination (D) nodes
Determine No. of nodes within RZ ( $N_z$ ) and their IDs (node 1 is the
source node and node  $N_z$  is the destination node)
Loop over the No. of nodes within the RZ ( $i=2$  to  $N_z - 1$ )
Perform probabilistic algorithm to find out Ret. index iRet(i):
On receiving a RREQ at node  $i$ , do the following:
If iRet(i)=0 Then (The node has not retransmit the RREQ before)
     $\xi = \text{rnd}()$  ( $\xi$  some random No. between 0 and 1)
    If  $\xi \leq p_r$ , Then
        Retransmit request
        iRet(i)=1 {Update Ret. index iRet(i) by equating it to 1}
    End if
End if
    
```

Fig. 2. The LAR-1P algorithm

It can be seen from the above description of LAR-1P that at high-density zones, the nodes will be given low p_r s inflicting a reduction in the number of retransmissions that depends on the assigned p_r s. Which means the probabilistic algorithm is effective. While at low-density zones, the nodes will be allowed to retransmit the RREQ packet with high p_r , if it is unity or close to unity, then LAR-1P acts as LAR-1.

1.5. Computational Procedures

There are two computational procedures that have been implemented in MANSim (Al-Bahadili, 2010b). The first computational procedure computes the average parameters for a pre-specified S-D pair. In this procedure, the source initiates Q RREQs each time interval. The computation is repeated for a number of time intervals (M), for each time interval, the nodes in the network are allowed to change their positions in the network. Therefore, the computed parameters should be averaged over Q and M. The computed average values represent the average parameters associated with this particular S-D pair, but they may not reflect the average behavior of other S-D pairs. However, it has been found that for a network that has no probabilistic behavior, i.e., $p_r = 1$, Q has no effect on the computed parameters and Q can be set to 1.

The second computational procedure computes the average network parameters that can be considered as the average parameters for any S-D pair. This is calculated by looping over all nodes in the network as source nodes and each source tries to establish a route to all other nodes in the network as destination nodes. Furthermore, for each S-D pair, the source initiates Q RREQs as described in the first computation procedure.

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Loop over the No. of time intervals ( $M$ ) ( $t=1, M$ )
Loop over the No. of nodes ( $N$ ) as S nodes ( $s=1, N$ )
Loop over the No. of nodes ( $N$ ) as D nodes ( $d=1, N$ ) ( $s \neq d$ )
Loop over the No. of transmitted request message ( $q=1, Q$ )
Compute IRec() and IRet()
Compute averages of computed parameters ( $Q$ ) for  $s-d$  pair
Compute averages of computed parameters ( $N-1$ ) for node  $s$ 
Compute averages of network parameters ( $N$ ) for time interval  $t$ 
Compute averages of computed network parameters ( $M$ ).
    
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Fig. 3. Second computational procedure in MANSim

The computed parameters for each source are averaged over $Q(N-1)$ and then the average values are averaged over N. In other words, the computed parameters are averaged over $(Q \cdot N(N-1))$.

In order to consider nodes mobility, the above calculations are repeated, in an outer loop of size M and the computed parameters are averaged over M. In this case, the computed parameters may well represent the average behavior of any of the nodes in the network. For non-mobile (fixed) nodes, M has no effect on the computed parameters and can be set to 1. Figure 3 outlines the second computation procedure.

2. MATERIALS AND METHODS

The LAR-1P is simulated using MANSim network simulator, which is especially developed for evaluating the performance of various types of route discovery algorithms in MANETs (Al-Bahadili, 2010b). The performance of the algorithms is evaluated in terms of two well-known parameters (Al-Bahadili, 2013):

- Number of Retransmissions (RET), which is defined as the average number of retransmissions normalized to the total number of nodes in the network (N)
- Reachability (RCH), which is defined as the average number of reachable nodes by any node in the network normalized to N; or the probability by which a RREQ packet will be successfully delivered from source to destination

In order to investigate the effect of nodes density ($N_d = N/A$) on the performance of LAR-1P, a number of simulations were performed using MANSim. The network environment and simulation setup can be described as follows: Each simulation starts by generating N nodes randomly distributed across a network area (A) of 500×500 m. All nodes are assumed to be transmitting with the same radio transmission Range (R) of 100 m and move with an average speed (u) of 5 m sec^{-1} .

One important parameter that needs to be carefully specified to obtain a more realistic network performance is the pause time (τ), which is defined as a period of time in which all nodes in the network are assumed motionless. In MANSim, τ is calculated as: $\tau = 0.75 \cdot R/u$. Each simulation is carried-out for a certain period of time called simulation time (T_{sim}), which is divided into a number of intervals that are called mobility loops (M), each loop is of a period τ . The input data for the simulations are given in **Table 1**.

In order to compare the performance of LAR-1P with other route discovery algorithms, we use MANSim to compute RET and RCH for three well-known route discovery protocols; these are: Pure flooding, dynamic probabilistic and LAR-1 (LAR-1P with $p_t = 1$) using the same network parameters and simulation data. Let us now remind ourselves with two important issues:

- The main requirement of any route discovery algorithm is to reduce RET without sacrificing RCH
- p_t in LAR-1P is calculated considering the first-hop neighbors positioned inside the RZ only

For each nodes density, the percentage reduction in RCH and RET are calculated by Equation 1 and 2:

$$R_{RCH} = \frac{RCH_{LAR-1} - RCH_{LAR-1P}}{RCH_{LAR-1}} \tag{1}$$

$$R_{RET} = \frac{RET_{LAR-1} - RET_{LAR-1P}}{RET_{LAR-1}} \times 100 \tag{2}$$

3. RESULTS

The results obtained for RET and RCH by the various algorithms (pure flooding, dynamic probabilistic, LAR-1 and LAR-1P) are listed in **Table 2** and also plotted in **Fig. 4 and 5**. **Table 3** presents the average p_t ($p_{t,avg}$) and the average k (k_{avg}) for the dynamic probabilistic and LAR-1P algorithms.

In order to demonstrate the advantage of LAR-1P, let us consider the following example. Assume node 1 is the source and all other nodes are examined as destinations one at a time. For each S-D pair we count the number of nodes within the RZ (N_z) including the source and the destination. Then, we count the number of cases in which N_z lies within the ranges (2-10, 11-20, 21-30, ...). For each range, we estimate RCH and RET for both LAR-1 and LAR-1P algorithms and the results obtained are summarized in **Table 4**.

4. DISCUSSION

Table 2 shows that the performance of LAR-1P varies in the same pattern as other algorithms. Also, it is found that in comparison with LAR-1, R_{RCH} fluctuated around a very small percent with increasing nodes density, while R_{RET} is increasing, which means more reduction in number of collisions and contentions.

Table 1. Simulation input data

Parameters	Value
Geometrical model	Random node distribution
Network area (A)	500x500 m
Number of nodes (N)	50, 75, 100, 125, 150 nodes
Transmission radius (R)	100 m
Average node speed (u)	5 m/sec
Simulation time (T_{sim})	1800 sec
Pause time (τ)	15 sec
Mobility loop size (M)	120

Table 2. RET and RCH Comparison

N	N_d (N/A)	Pure flooding	Dynamic probability	LAR-1	LAR-1P	(%)
RET						
50	2×10^{-4}	0.715	0.652	0.087	0.084	3.45
75	3×10^{-4}	0.932	0.771	0.129	0.108	16.28
100	4×10^{-4}	0.975	0.718	0.147	0.115	21.77
125	5×10^{-4}	0.983	0.643	0.159	0.115	27.67
150	6×10^{-4}	0.987	0.589	0.161	0.109	32.30
RCH						
50	2×10^{-4}	0.767	0.750	0.396	0.394	0.51
75	3×10^{-4}	0.961	0.946	0.641	0.612	4.52
100	4×10^{-4}	0.995	0.981	0.772	0.720	6.74
125	5×10^{-4}	0.999	0.990	0.857	0.813	5.13
150	6×10^{-4}	1.000	0.995	0.894	0.859	3.91

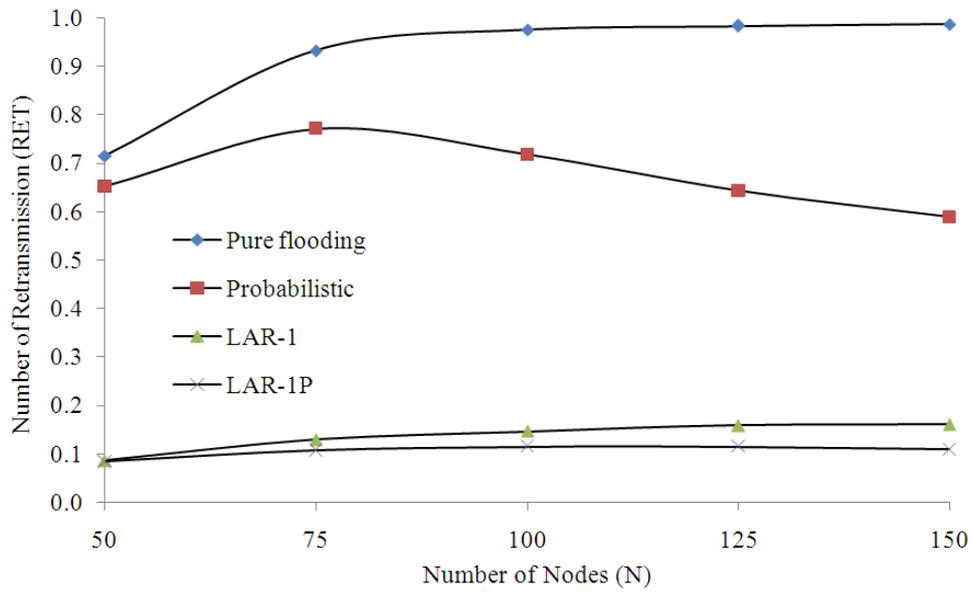


Fig. 4. RET comparison

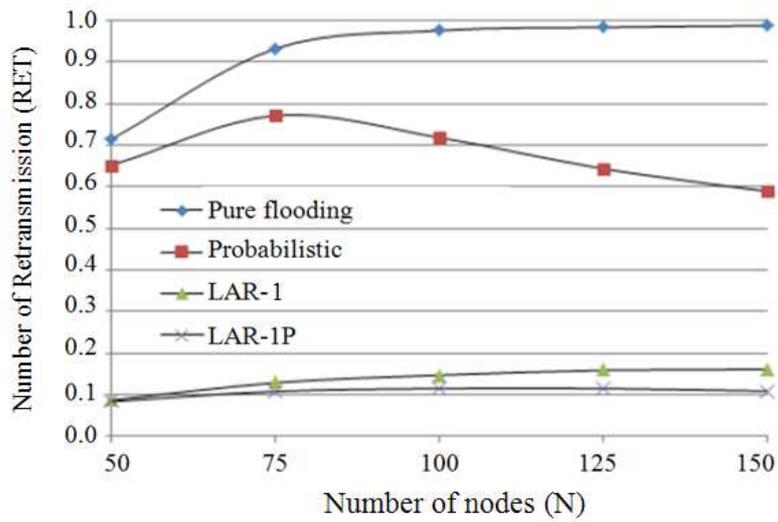


Fig. 5. RCH comparison

Table 3. Comparing $p_{t,avg}$ and k_{avg}

N	$N_d (N/A)$	$p_{t,avg}$		k_{avg}	
		Dynamic probability	LAR-1P	Dynamic probability	LAR-1P
50	2×10^{-4}	0.935	0.981	4.913	3.418
75	3×10^{-4}	0.844	0.946	7.262	4.945
100	4×10^{-4}	0.749	0.904	9.562	6.247
125	5×10^{-4}	0.661	0.848	12.092	7.865
150	6×10^{-4}	0.601	0.796	14.373	9.401

Table 4. Comparison between the LAR-1 and LAR-1P

N_z	Z	LAR-1			LAR-1P		
		RET	RCH	RCH	RET	RCH	RCH
2-10	40	0.048	32	0.800	0.043	31	0.775
11-20	27	0.127	22	0.815	0.113	21	0.778
21-30	11	0.222	10	0.909	0.186	10	0.909
31-40	11	0.328	11	1.000	0.263	11	1.000
41-50	10	0.431	10	1.000	0.310	10	1.000

Table 3 shows k_{avg} is increasing with increasing nodes density. For each node density, k_{avg} for dynamic probabilistic is greater than that for LAR-1P. This is because we only consider first-hop neighbors that are positioned inside RZ. As a result of that $p_{t,avg}$ is decreasing with increasing nodes density for the two algorithms and for the same node density, $p_{t,avg}$ for dynamic probabilistic is less than LAR-1P. Next, to analyze the performance of the algorithms for a single node density value of 4×10^{-4} nodes/m². Pure flooding provides the highest RCH of 99.5% at 97.5% of the nodes in the network engaged in RREQ retransmission. The probabilistic algorithm achieves a very high RCH of 98.1% but only reduces RET by ~28 to 72%.

LAR-1 reduces RET to a very low level of 14.7% at the cost of reducing RCH to 77.2%. In other words, LAR-1 introduces a significant reduction of ~85% in RET but at the same time reducing RCH by ~22%. These results represent an average behavior over uniform distribution of zones densities. But if most of route discovery processes involve searching the route in high-density zones, then RET will be definitely higher than 14.7%. For example, for RZs that confine all nodes, RCH and RET will be the same as or close to that in pure flooding. Furthermore, in high-density zones the delay is much higher than in low-density zones.

It can be seen in **Table 2** that for LAR-1P, RCH is 5.2% less than LAR-1 and the associated RET is also less by 3.2%. However, when we look at zone scale, for example, for high-density zones, LAR-1P attains the performance of dynamic probabilistic of 98.1% reachability at ~30% reduction in RET. Thus, if most route discovery processes involve high-density zones, a reduction in RET is always equal to or close to 30%. On the other hand, for low-density zones, the estimated p_s are always close to 1, i.e., inflicting pure flooding within RZ, which means LAR-1 is the acting algorithm.

Now, let us explain the results in **Table 4**. Z in the second column gives the number of RZs that contains a number of nodes within the range indicated in the first

column, i.e., the number of RZs that contains number of nodes within the range from 2 to 10 is 40 and 27 contains a number of nodes between 11 to 20.

For LAR-1, consider the case of low-density zone (2-10), in 32 out of the 40, the source and destination were able to establish a connection and 8 of them were not, giving RCH of 80%. Due to the small number of nodes within RZs, RET was only 4.8%. The LAR-1P provides slightly less RCH and RCH. For high-density zone (41-50), LAR-1P accomplishes the same RCH of 10 out of 10 at a significant reduction in RET from 43.1% for the LAR-1 to 31%. In high-density zone, reduces RET significantly and almost maintains the same RCH.

5. CONCLUSION

In this study, we present performance evaluation of the of the LAR-1P route discovery algorithm in MANETs. The algorithm is especially developed to enhance the performance of the LAR-1 algorithm as it combines two widely-used algorithms, namely, LAR-1 and probabilistic algorithms. The obtained results showed that the performance of the LAR-1 algorithm can be enhanced when combined with the probabilistic approach especially in high density zones, where we can achieve more reduction in the number of retransmissions against insignificant reduction in network reachability. Moreover, the LAR-1P algorithm provides the performance as LAR-1 in low-density zones.

For future work, we highly recommend to investigate other network parameters, such the node speed, mobility model, pause time, radio transmission range.

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