# A Hybrid LAR-1DNDP Route Discovery Algorithm for Mobile Adhoc Networks

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**Summary**

In this paper we propose and evaluate the performance of a hybrid route discovery algorithm in mobile ad hoc networks (MANETs), namely, the LAR-1DNDP. It utilizes two route discovery algorithms, the location-aided routing scheme 1 (LAR-1) algorithm and the novel dynamic noise-dependent probabilistic (DNDP) algorithm. In this algorithm, when receiving a broadcast message, a node within the requested zone rebroadcasts the message with a retransmission probability ($p_t$), and each node is allowed to rebroadcast the received message only once. In DNDP algorithm $p_t$ is determined locally by each node considering both number of first-hop neighbors ($k$) and probability of reception ($p_c$). The proposed algorithm is implemented on the MANET simulator (MANSim). A number of simulations were performed using MANSim to evaluate the performance of the proposed algorithm and to estimate the enhancement it achieves over the current LAR-1, and combined LAR-1 and probabilistic algorithms (LAR-1P) algorithm. The simulation results obtained showed that the LAR-1DNDP algorithm presents higher network reachability than the LAR-1P algorithm with both fixed and dynamic $p_t$ at a reasonable increase in the number of retransmissions for a wide range of $p_c$'s or noise-levels.

***Keywords:***

*MANET, Route discovery, flooding optimization algorithms, probabilistic flooding, location-aided routing.*

## 1. Introduction

A mobile ad hoc network (MANET) is defined as a collection of low-power wireless mobile nodes forming a temporary network without the aid of any established infrastructure or centralized administration [1, 2]. A data packet in a MANET is forwarded to other mobile nodes within the network through a reliable and an efficient route established by routing protocols [3]. The most widely used routing protocols in MANETs are known as dynamic routing protocols, such as ad hoc on-demand distance vector routing (AODV) [4], dynamic source routing (DSR) [5], zone routing protocol (ZRP) [6], and location-aided routing (LAR) [7]. Dynamic routing protocols consist of two major phases, these are: (i) route discovery in which a route between source and destination nodes is established for the first time, and (ii) route maintenance in which the route is maintained; and if it is broken for any reason, then the source node either finds other known route on its routing table or initiates new route discovery procedure [8]. The cost of information exchange during route discovery is higher than the cost of point-to-point data forwarding after the route is established [9].

Broadcasting is a fundamental communication primitive for route discovery in routing protocols in MANETs. One of the earliest broadcast mechanisms proposed in the literature is pure flooding, which is also called simple or blind flooding. Although it is simple and reliable, pure flooding is costly where it costs $n$ transmissions in a network of $n$ reachable nodes. In addition, pure flooding in wireless networks results in serious redundancy, contention, and collisions in the network; such a scenario has often been referred to as the broadcast storm problem [10].

To eliminate the effects of broadcast storm problem during route discovery in MANETs, a variety of flooding optimization techniques have been developed to reduce the number of retransmission for the route request (RREQ) messages. As the number of retransmissions required for broadcasting is decreased, the bandwidth is saved and contention and node power consumption are reduced, and this will improve the overall network performance. Examples of flooding optimization techniques algorithms: probabilistic [1], LAR [7], multipoint relaying [11], counter-based and distance-based [9], cluster-based [12].

Probabilistic algorithm has been widely-used for route discovery in MANETs [1, 2]. However, it has been demonstrated that the performance of the probabilistic algorithm is severely suffered in presence of noise due to increasing packet-loss, and consequently decreasing the probability of reception ($p_c$), which in turn reduces the overall network performance [13, 14]. A dynamic noise-dependent probabilistic (DNDP) algorithm was proposed by Al-Bahadili and Sabri in [15] for route discovery in noisy MANETs. In this algorithm, the retransmission probability of the transmitting node ($p_t$) is modeled as a function of two independent variable; these are: the number of first-hop neighbors ($k$) and the noise level within the network area which can be indicated by the probability of reception $p_c$. The model also shows another

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independent variable, namely, the maximum retransmission probability that can be assigned to the transmitting node ($p_{t,pcmin}$), which is assumed to be a fixed value.

In this paper, we develop and investigate the performance of a new route discovery algorithm, namely LAR-1DNDP. It utilizes two flooding optimization algorithms, the location-aided routing scheme 1 (LAR-1) algorithm and the novel DNDP algorithm. In this algorithm, we reduce the number of retransmission during the route discovery phase for a wide range of noise-levels, whereas this number of retransmission is the same as LAR-1 in a high noisy environment. The basic idea behind LAR-1DNDP, is that when receiving a RREQ packet, a node within the requested zone rebroadcasts the message with a certain retransmission probability $p_t$ , and each node is allowed to rebroadcast the received message only once. $p_t$ is calculated locally by each intermediate node as a function of $k$ and $p_c$.

In order to evaluate and analyze the performance of the new algorithm, a number of scenarios are simulated using the mobile ad hoc network simulator (MANSim) [16, 15]. The outcomes of these simulations demonstrate that the LAR-1DNDP algorithm presents higher network reachability (RCH) than the (fixed and dynamic) combined LAR-1 and probabilistic (LAR-1P)[16] algorithm at a reasonable increase in the number of retransmissions for a wide range of $p_c$'s or noise-levels.

The rest of the paper is organized as follows. Related works are discussed in Section 2. In Section 3, a description is given for probabilistic, DNDP and LAR-1 algorithms. The proposed LAR-1DNDP algorithm is described in Section 4. Section 5 presents simulation results. Finally, in Section 6, a number of conclusions are drawn and recommendations for future work are pointed-out.

## 2. Previous Work

In this section, we present some of the works that is related to location-based routing and probabilistic route discovery algorithms, to provide the reader with development steps in these two algorithms.

### 2.1 Probabilistic Flooding Protocol

Probabilistic algorithm was used for ad hoc route discovery by Haas et. al. [17], and they called it a gossip-based ad hoc route discovery (GOSSIP1) approach. They used a predefined $p_t$ to decide whether or not an intermediate node forwards the RREQ packets. GOSSIP1 has a slight problem with initial conditions. If the source has relatively few neighbors, there is a chance that none of them will gossip, and the gossip will die. To make sure this does not happen, Haas et. al. proposed 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 overhead compared to pure flooding. Furthermore, adding gossiping to a protocol such AODV and ZRP not only gives improvements in the number of messages sent, but also results in improved network performance in terms of end-to-end latency and throughput.

S. Tseng et. al. [10] investigated the performance of the probabilistic flooding for various network densities in noise-free environment. 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. [3] explored the phase transition phenomenon observed in percolation theory and random graphs as a basis for defining probabilistic flooding algorithms. They also suggested exploring algorithms in which nodes would dynamically adjust their $p_t$ based on local topology information. Because in their work they made the assumption that all nodes possess the same transmission range, they suggested another potential area for study which is to modify $p_t$ of the transmitting according to its radio transmission range.

Kim et. al. [18] introduced a dynamic probabilistic broadcasting approach with coverage area and neighbors confirmation for MANETs. Their scheme combines probabilistic approach with the area-based approach. A mobile host can dynamically adjust $p_t$ according to its additional coverage in its neighborhood. The additional coverage is estimated by the distance from the sender. The simulation results showed this approach generates fewer rebroadcasts than pure flooding approach. It also incurs lower broadcast collision without sacrificing high reachability.

Scott & Yasinsac [2] presented a dynamic probabilistic solution that is appropriate to solving broadcast storm problems in dense mobile networks, also referred to as gossip protocol. The approach can prevent broadcast storms during flooding in dense networks and can enhance comprehensive delivery in sparse networks.

Bani-Yassein et. al. [1] proposed a dynamic probabilistic flooding algorithm in MANETs to improve network reachability and saved rebroadcast. The algorithm determines $p_t$ by considering the network density and node movement. This is done based on locally available information and without requiring any assistance of distance measurements or exact location determination devices. The algorithm controls the frequency of rebroadcasts and thus might save network resources without affecting delivery ratios.

Viswanath & Obraczka [19] developed an analytical model to study the performance of plain and probabilistic flooding in terms of its reliability and reachability in delivering packets. They provided simulation results to validate the model. The preliminary simulation results indicated that probabilistic flooding can provide similar reliability and reachability guarantees as plain flooding at a lower overhead.

Zhang & Agrawal [20] proposed a probabilistic approach that dynamically adjusts $p_t$ as per the node distribution and node movement. The approach combines between probabilistic and counter-based approaches. They evaluated the performance of their approach by comparing it with the AODV protocol (which is based on simple flooding) as well as a fixed probabilistic approach. Simulation results showed that the approach performs better than both simple flooding and fixed probabilistic schemes.

Bani Yassein et. al. [21] 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. The simulation results revealed that equipping AODV with fixed and adjusted probabilistic flooding helps to reduce the overhead of the route discovery process whilst maintaining comparable performance levels in terms of saved rebroadcasts and reachability as achieved by conventional AODV. Moreover, the results indicated that the adjusted technique results in better performance compared to the fixed one.

Abdulai et. al. [22] analyzed the performance of AODV protocol over a range of possible $p_t$. Their studies focused on the route discovery part of the routing algorithm, they modified the AODV routing protocol implementation to incorporate $p_t$; the RREQ packets are forwarded in accordance with a predetermined $p_t$. Results obtained showed that setting efficient $p_t$ has a significant effect on the general 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, node density, and node mobility. During their study they observed that the optimal $p_t$ is around 0.5 in the presence of dense network conditions and around 0.6 for sparse network conditions.

Abdulai et. al. [23] 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 probabilistic methods are: the adjusted probabilistic (AP) and the enhanced adjusted probabilistic (EAP) which address the broadcast storm problem in the existing OADV routing protocols.

Khan et. al. [24] proposed a coverage-based dynamically adjusted probabilistic forwarding scheme and compared its performance with simple flooding and fixed probabilistic schemes. The proposed scheme keeps up the reachability of pure flooding while maintaining the simplicity of probability based schemes.

Hanash et. al. [25] proposed a dynamic probabilistic broadcast approach that can efficiently reduce broadcast redundancy in MANETs. The algorithm dynamically calculates $p_t$ according to $k$. They compared their approach against simple flooding approach, fixed probabilistic approach, and adjusted probabilistic flooding by implementing them in a modified version of the AODV protocol using the GloMoSim network simulator. The simulation results showed that broadcast redundancy can be significantly reduced through their approach while keeping the reachability high. It also demonstrates lower broadcast latency than all the existing approaches presented.

Al-Bahadili [26] developed a new retransmission probability adjusting model, in which the neighborhood densities are divided into three regions (low, medium, and high). The performance of the new model was evaluated and compared with pure and other probabilistic algorithms. The model enhances the performance of probabilistic broadcast by reducing the number of transmissions while keeping almost the same network reachability.

Al-Bahadili and Kaabneh [13] investigated the effect of noise-level on the performance of the probabilistic algorithm in MANETs. They investigated the effect of node density, node average speed, radio transmission range, $p_t$, and $p_c$ on number of retransmissions, duplicate reception, average hop count, and reachability. Their results showed that the performance of the network is severely suffered as $p_c$ increases, i.e. the noise-level increases.

A dynamic noise-dependent probabilistic DNDP algorithm was proposed by Al-Bahadili and Sabri in [15] for route discovery in noisy MANETs. In this algorithm, the retransmission probability of the transmitting node $p_t$ is modeled as a function of two independent variable; these are: the number of first-hop neighbors ($k$) and the noise level within the network area which can be indicated by the probability of reception $p_c$.

## 2.2 Location-Aided Routing Protocol

Zeng et. al [27] proposed geography based ad hoc on demand disjoint multipath (GAODM) routing protocol to be used instead of pure flooding in wireless ad hoc networks. In this protocol, an informed and independent unicast decision is made by each node so that the traffic flow for the route discovery is efficiently directed towards the destination. The simulation result showed that (1) GAODM has better ability of finding more disjoint paths than AOMDV, especially when nodes are further apart; (2) GAODM finds shorter paths, and incurs much less route discovery overhead, than AODV and AOMDV.

Bolena and Camp [28] combined location information and mobility feedback to create an innovative MANET routing protocol. They developed a hybrid MANET routing protocol which adapts between two MANET routing protocols in order to combine the strengths of both component protocols while avoiding their weaknesses. This protocol achieved data packet delivery ratios above 80% in very demanding network mobility conditions. In more stable networks, their protocol achieved data packet delivery ratios above 90%.

Vyas and Mahgoub [29] presented a location and mobility pattern based routing algorithm for MANET. The proposed algorithm was an enhancement of the LAR algorithm that utilizes both location information as well as mobility pattern of mobile hosts to further reduce route discovery overhead. The results showed reduction in the routing messages when the information of predictable mobility pattern of the mobile hosts is utilized.

Ko and Vaidya [7] described how location information may be used to reduce the routing overhead in ad hoc networks. They present two LAR protocols, namely, LAR scheme 1 (LAR-1) and LAR scheme 2 (LAR-2). Results indicate that using location information results in significantly lower routing overhead, as compared to an algorithm, which does not use location information. They also suggested several optimizations on the basic LAR schemes that may improve performance.

Li et al. [30] presented a modified version of the LAR protocol; it was called LAKER (location aided knowledge extraction routing) protocol for MANETs. It was a combination of caching strategy in DSR and limited flooding in LAR protocols. LAKER gradually learns of the topological characteristics of the network, such as node density, during the route discovery process and uses this information to enhance the network performance. Simulations showed that LAKER can save up to 30% broadcast messages compared LAR, while achieving better delivery ratio and almost the same delay.

H. Al-Bahadili et. al [31] developed and evaluated the performance of a new flooding optimization algorithm, namely, the LAR-1P algorithm, which utilizes two well-known flooding optimization algorithms, the location-aided routing scheme 1 (LAR-1), and the probabilistic algorithms. In this algorithm, when receiving a broadcast route request (RREQ) message, a node within the requested zone rebroadcasts the request message with a pre-defined retransmission probability, and each node is allowed to rebroadcast the received RREQ message only once.

H. Al-Bahadili [16] extended the work in [31] to accommodate a dynamic retransmission probability. The simulation results obtained demonstrated an excellent enhancement in the performance of the LAR-1P algorithm.

## 3. Broadcast Flooding Algorithms in MANETs

Probabilistic algorithm is widely-used for flooding optimization during route discovery in MANETs. It aims at reducing number of retransmissions, in an attempt to alleviate the broadcast storm problem in MANETs [10]. In this scheme, when receiving a RREQ packet, a node retransmits the packet with a certain $p_t$ and with probability $(1-p_t)$ it discards the packet. A node is allowed to retransmit a given RREQ packet only once, i.e., if a node receives a packet, it checks to see if it has retransmitted it before, if so then it just discards it, otherwise it performs its probabilistic retransmission check. Nodes usually can identify the RREQ packet through its sequence number. The source node $p_t$ is always set to 1, to enable the source node to initialize the RREQ. While, $p_t$ for intermediate nodes (all nodes except the source) is determined using a static or dynamic approach.

### 3.1 Probabilistic Flooding Protocol

There are two approaches that can be used to set a satisfactory $p_t$ for intermediate nodes within a noiseless wireless environment. These are:

1. Static approach in which a pre-determined (pre-adjusted) $p_t$ is set for each node on the networks and it can be expressed as: $p_t=P_t$ , where $P_t$ is a constant value ($0\leq P_t\leq 1$).
2. Dynamic approach in which each node on the network locally calculates its $p_t$ according to the number of first-hop neighboring nodes ($k$) and it can be expressed as: $p_t=f(k)$, where $f(k)$ is a linear or a non-linear function of $k$.

### 3.2 Determination of Dynamic $P_t$ in Noiseless Environment.

Many functions have been developed for dynamically calculating $p_t$ [1, 2, 3, 6, 18, 20]. However, in this paper, the discrete function presented in [26] is used for calculating $p_t(k)$. This is because it demonstrated better performance than other distribution functions in various network conditions, where the dynamic $p_t$ in noiseless environment is calculated as:

$$p_t(k)=\begin{cases} p_{\max} & for\ k\leq N_1 \\ p_1-\dfrac{k-N_1}{N_2-N_1}(p_1-p_2) & for\ N_1<k<N_2 \\ p_{\min} & for\ k\geq N_2 \end{cases} \quad (1)$$

here $p_{min}$ and $p_{max}$ are the minimum and maximum retransmission probabilities, $N_1$ is the number of nodes at or below which $p_t(k)=p_{max}$, $N_2$ is the number of nodes at or above which $p_t(k)=p_{min}$, and $p_1$ and $p_2$ are the retransmission probabilities assign to intermediate nodes when they have $N_1$+1 and $N_2$-1 first-hop neighboring nodes. $p_1$ and $p_2$ should lie between $p_{max}$ and $p_{min}$,

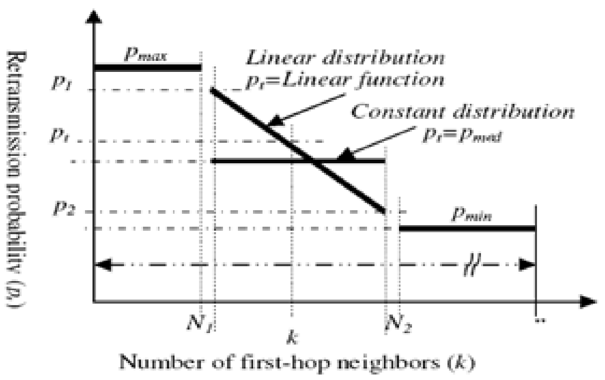


Figure 1. Retransmission probability as a function of $k$. [26]

## 3.3 Dynamic Probabilistic Algorithm in Noisy Environment

The probabilistic route discovery algorithm in noisy MANETs can be implemented as follows: When the distance between the transmitting and receiving nodes is less than the radio transmission range of the transmitting node, a random test is performed to decide whether the RREQ is successfully delivered to the receiving node or being lost due to error. The random test is performed by generating a random number $\xi$ ($0 \leq \xi < 1$) and compared it with $p_c$, if $\xi \leq p_c$, then the RREQ is successfully delivered to the receiving node; otherwise, the RREQ is not delivered or being lost. The value of $p_c$ is either predetermined or instantly computed using a certain probability distribution function (PDF). If the RREQ packet is successfully delivered to the node, then the receiving node performs its probabilistic algorithm to find out whether it should retransmit the RREQ packet or not.

## 3.4 The DNDP Algorithm

The DNDP algorithm was proposed to enhance the performance of dynamic probabilistic algorithm in noisy MANETs. In this algorithm, instead of calculating $p_t$ as a function of $k$ only, $p_t$ is determined locally by the retransmitting nodes considering both $k$ and $p_c$($p_t(k, p_c)$) as:

$$p_t(k, p_c) = p_t(k) + p_t(p_c) \qquad (2)$$

Where, $p_t(p_c)$ is the noise-dependent $p_t$.

The value of $p_t(k)$ can be calculated using equation (1). The following main constraints should be considered when calculating $p_t(p_c)$:

1. The value of $p_t(p_c)$ should be ≥0 and ≤1- $p_t(k)$, so that $p_t(k, p_c)$ will always be ≤1.
2. The value of $p_t(k, p_c)$ lies between $p_t(k)$ and pre-adjusted maximum allowable $p_t$ at a certain minimum value of $p_c$ ($p_{c,min}$), namely, $p_{t,pcmin}$.
3. The value of $p_{t,pcmin}$ should be ≤1 and $\geq p_t(k)$ (i.e. $p_t(k) \leq p_{t,pcmin} \leq 1$).

Considering the above discussion, $p_t(p_c)$ can be calculated as:

$$p_t(p_c) = \alpha \, (p_{t,pcmin} - p_t(k)) \qquad (3)$$

Where, $\alpha$ is called the noise-correction factor, which is a function of $p_c$, and has a value that lies between 0 and 1. Substituting equation (3) into equation (2) yields:

$$p_t(k, p_c) = p_t(k) + \alpha \, (p_{t,pcmin} - p_t(k)) \qquad (4)$$

In [16], the value of $\alpha$ is calculated using the following simple linear equation:

$$\alpha = \frac{1 - p_c}{1 - p_{c,\min}} \qquad (5)$$

Now, substituting equation (5) into equation (4) yields the following equation for calculating $p_t(k, p_c)$:

$$p_t(k, p_c) = p_t(k) + \frac{1 - p_c}{1 - p_{c,\min}} (p_{t,pc\min} - p_t(k)) \qquad (6)$$

It can be seen from equation 6 that $p_t$ ($k$, $p_c$) depends on $p_t$ ($k$), $k$, $p_c$, $p_{c,min}$, and $p_{t,pcmin}$.

In a noiseless environment $p_c$=1, $\alpha$ = 0, and consequently $p_t(k, p_c)$=$p_t(k)$, i.e., $p_t$ is a function of $k$ only. In a noisy environment, when $p_c$=$p_{c,min}$, then $\alpha$=1 and $p_t(k, p_c)$=$p_{t,pcmin}$. If $p_c$ is any value between $p_{c,min}$ and 1, then $p_t(k, p_c)$ varies between $p_t(k)$ and $p_{t,pcmin}$ depending on $p_c$. According to the above discussion, $p_t(k, p_c)$ always lies between $p_t(k)$ and $p_{t,pcmin}$ as shown in Fig. 2.

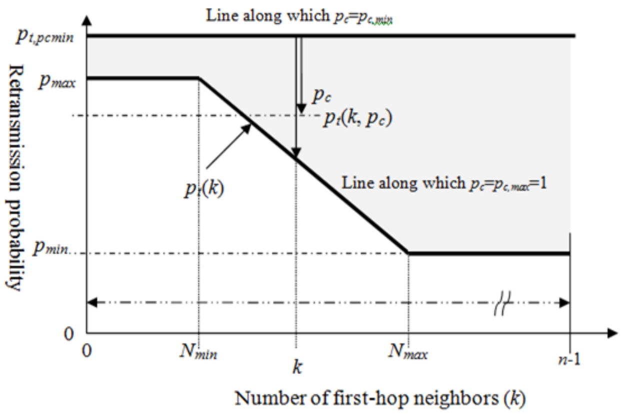


Fig. 2. Variation of $p_t(k, p_c)$ with $k$ (constant $p_{t,pcmin}$).

### 3.5 Location-Aided Routing (LAR) Algorithms

LAR algorithms make use of location information to reduce routing overhead. Location information used in LAR protocols may be provided by a Global Positioning System (GPS) [7]. There are basically two LAR algorithms, namely, LAR- 1 and LAR-2. They differ in the manner they use to determine the request zone. However, in this work, we mainly concern with the LAR-1 scheme.

The LAR-1 scheme uses a request zone that is rectangular in shape [7]. It is assumed that source node (S) knows that destination node (D) was at location ($X_d$, $Y_d$) at time $t_0$. At time $t_1$, node S initiates a new route discovery for D. It is also assumed that node S knows the speed $u$ with which D can move. Using this, node S defines the expected zone at time $t_1$ to be the circle of radius $R_e=u(t_1-t_0)$ centered at location ($X_d$, $Y_d$). Instead of the average node speed, $u$ may be chosen to be the maximum speed or some other function of the speed distribution.

In LAR-1, the request zone is defined as the smallest rectangle that includes current location of S and the expected zone (the circular region defined above), such that the sides of the rectangle are parallel to the X and Y axes. When the source node is outside the expected zone, the request zone is the rectangle whose corners are S, A, B and C, whereas when the source node is within the expected zone, the rectangle has corners at A, B, C and G. The current location of node S is denoted as ($X_s$, $Y_s$). The source node S can determine the four corners of the request zone. S includes their coordinates with the RREQ packet transmitted when initiating route discovery. When a node receives a RREQ, it discards the request if the node is not within the rectangle specified by the four corners included in the RREQ. For instance, if node i receives the route request from another node, node i forwards the request to its neighbours, because i determines that it is within the rectangular request zone. However, when node j receives the RREQ, node j discards the request, as node j is not within the request zone.

## 4. The Proposed LAR-1DNDP Algorithm

**LAR-1DNDP algorithm**

Determine the requested zone for a specific source (S) and destination (D) nodes

Determine the number of nodes within the request zone (z) and their IDs (node 1 is the source node and node z is the destination node)

Loop over the number of nodes within the request zone (i=2 to z-1)

**Perform DNDP computation to find out the parameter IRec(i) and IRet(i) as follows:**

**If** (IRange=1) **Then** {The receiving node is within the transmission range of the sender, in a noiseless environment this guarantees request reception by the receiver, while in a noisy environment a random test must be performed to find out whether a successful delivery occurs or not. IRange=0 means the receiver is not within the transmission range of the sender}

$\xi_1$=rnd() {$\xi_1$ some random number between 0 and 1}

**If** ($\xi_1$<= $p_c$) **Then** {Reception random test}

IRec(i)++ {Update the node reception index IRec(i)}

**If** (IRet(i)=0) **Then** {The node has not retransmitted the request before (IRet(i) = 0)}

$\xi_2$=rnd() { $\xi_2$ some random number between 0 and 1}

$p_t$=function_$p_t$()

**If** ($\xi_2$<=$p_t$) **Then**

Retransmit RREQ

IRet(i)=1 {Update the node retransmission index IRet(i) by equating it to 1}

**End if**

**End if**

**End if**

**End if**

**Function_$p_t$()** {Determining $p_t$}

**If** (IProb="Static") **Then** {IProb is an integer indicates the approach to be used for determining $p_t$ whether it is static or dynamic}

$p_t$=constant value
**Else** (IProb=”Dynamic”)
$p_t=f(k,p_c)$

**End If**

LAR-1DNDP algorithm utilizes two flooding optimization algorithms discussed earlier, namely, the DNDP and the LAR-1 algorithms. Fig. 3 outlines the description of this algorithm is straightforward. It is simply, when receiving a broadcast message, a node within the requested zone rebroadcasts the RREQ with a certain $p_t$ determined using equation (6), and each node is allowed to rebroadcast the received message only once. This, of course, reduces the number of retransmissions compared with LAR-1whithin a low or noiseless environment. This is at the cost of reducing network reachability. However the number of retransmissions will be the same as LAR-1whithin a noisy environment, since LAR-1DNDP will increase the number of retransmission to accommodate the presence of noise within a noisy environment which will lead to approximately the same reachability as LAR-1. Fig. 3 outlines the LAR-1DNDP algorithm.

## 5. Simulations and Results

The network simulator used in this work is MANSim [32], which is developed to simulate and evaluate the performance of a number of flooding optimization algorithms for MANETs. It is written in C++ language, and it consists of four major modules: (1) Network module, (2) Mobility module, (3) Computational module, and (4) Algorithm module.
In order to evaluate and compare the performance of the proposed LAR-1DNDP algorithm in noisy MANETs, a number of simulations were performed using MANSim. These simulations investigate the variation of rechability (RCH) and number of retransmission (RET) with $p_c$. The simulation results obtained using the LAR-1DNDP algorithm are compared with those obtained by using the following flooding optimization algorithms:
- LAR-1 ($p_t$=1)
- Noise-independent fixed LAR-1P ($p_t$=0.7)
- Noise-independent dynamic probabilistic algorithm. In which the values of $p_{min}$, $p_{max}$, $N_1$, and $N_2$ in equation (3) are taken to be 0.5, 0.8, 4, and 20, respectively. For this simulation, the average $p_t$ is 0.7.
The input parameters for these simulations are listed in Table 1. The simulations results are plotted in Figures 4 & 5.

Table 1. Input Parameters

| Parameters | Values |
|---|---|
| Geometrical model | Random distribution |
| Network area | 600x600 m |
| Number of nodes ($n$) | 100 nodes. |
| Transmission radius ($R$) | 100 m |
| Average node speed ($u$) | 5 m/sec |
| Probability of reception ($p_c$) | From 0.5 to 1.0 in step of 0.1 |
| Simulation time ($T_{sim}$) | 1200 sec |
| Pause time ($\tau$) | $\tau$=0.75*($R$/$u$)=15 sec |
| Size of mobility loop ($nIntv$) | 80 |

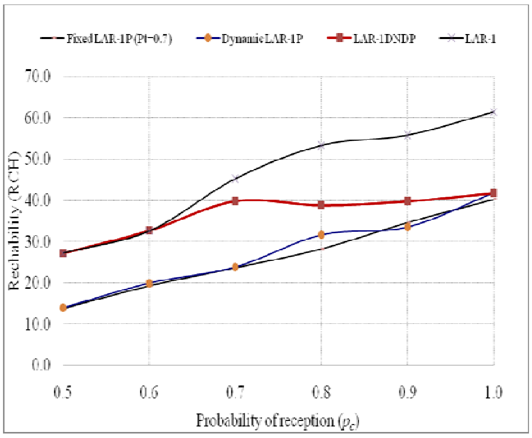


Fig. 4. Variation of RCH with $p_c$ for various algorithms

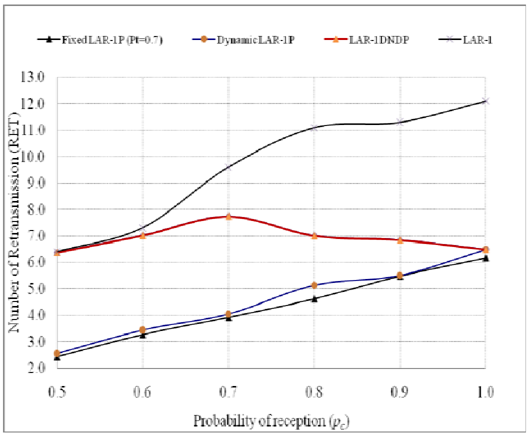


Fig. 5. Variation of RET with $p_c$ for various algorithms

The main points that are concluded from this scenario can be summarized as follows:
1. For LAR-1, LAR-1DNDP, and (fixed/dynamic) LAR-1P, RCH decreases as $p_c$ decreases (i.e., noise-level increases). This is as a consequence of: (1) High packet-loss introduced by the high noise-level, and (2) No measure is taken by the existing probabilistic algorithms to accommodate the negative effect of the noise-level or to replace the high packet-loss.

2. The proposed LAR-1DNDP algorithm presents an excellent performance in terms of increasing RCH in presence of noise by effectively adjusting (increasing/decreasing) $p_t$ based on both $k$ and $p_c$. The results obtained demonstrated that the LAR-1DNDP algorithm provides the highest RCH for various network noise-level, when compared with and (fixed/dynamic) LAR-1P.

3. It can be seen from Fig. 4 that the LAR-1DNDP algorithm almost produces the same RCH. However, enhancing RCH is paid by increasing RET as shown Fig. 5. Since the main objective of using flooding optimization during route discovery is to achieve a cost-effective RCH, which means achieving the highest possible reachability at a lowest possible number of retransmission. The simulation results demonstrate that the LAR-1DNDP algorithm provides better performance as it can achieve better cost-effective reachability than other (fixed/ dynamic) LAR-1P route discovery algorithms.

Fig. 4 shows that the LAR-1P and LAR-1DNDP algorithms provide the same performance in noiseless environments ($p_c$=1). But, in terms of network reachability, the LAR-1DNDP algorithm overwhelms the performance of the other (fixed/ dynamic) LAR-1P algorithms in noisy environment. For example, for $p_c$=0.5, the LAR-1DNDP algorithm achieves a reachability of 27.2% the same as LAR-1algorithm 27.2%, while for the same environment, the (fixed/ dynamic) LAR-1P algorithm achieves 13.9% and 13.7% respectively. But, the fixed and dynamic LAR-1P algorithm achieves this reachability at a cost of RET 2.4% and 2.6% compared with RET 6.4% and 6.4% for the LAR-1DNDP and LAR-1 algorithms.

The LAR-1DNDP algorithm provides an excellent performance as it can achieve an excellent cost-effective reachability, for various network noise levels, as compared to LAR-1 algorithm. For example, when $p_c$=1, the LAR-1DNDP algorithm costs a RET of 6.5% compared with RET= 12.1% in LAR-1 algorithm, whereas the achieved reachability is 41.8% and 61.4% respectively, and for a noisy environment when $p_c$<0.7, it approximately works like LAR-1.

## 6. Conclusions

The main conclusion of this work is that the proposed LAR-1DNDP algorithm demonstrated better cost-effective performance than the current (fixed/dynamic) LAR-1P algorithm in noisy environment. The LAR-1DNDP algorithm provides a higher RCH as compared to (fixed/dynamic) LAR-1P algorithm for various network noise-levels. The results also demonstrated that the RCH of the LAR-1DNDP algorithm is close to the RCH of LAR-1 algorithm for various network noise levels at less number of retransmission. The LAR-1DNDP algorithm provides the same RCH and RET as the dynamic LAR-1P algorithm in noiseless environment ($p_c$=1).

For future work it is recommended to compare the results of the LAR-1DNDP using the combination of LAR-1 and the enhanced DNDP algorithms, in which $p_{t,pcmin}$,is calculated as a function of $k$ and this is for a purpose of decreasing the value of $p_t$ which in turn will increase the network performance due to decrease the number of redundant retransmission in the network and as a result contention and collisions will also decrease. Furthermore, it is recommended to investigate the effects of nodes density and nodes mobility on the performance of the LAR-1DNDP algorithm.


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