

Enhancing the Performance of Adjusted Probabilistic Broadcast in MANETs

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ABSTRACT

Probabilistic broadcast has been widely used as a flooding optimization mechanism to alleviate the effect of broadcast storm problem during route discovery and other services in mobile ad hoc networks (MANETs). In current dynamic probabilistic algorithms, the retransmission probability of the intermediate nodes is expressed as a function of the first-hop neighbors. Usually, two neighborhood densities are identified (low and high), and for each of them a certain constant probability is assigned regardless of the actual value of neighbors. Using such model makes it hard to efficiently adjust the probability to ensure optimal network performance. In this paper, in order to enhance the performance of the probabilistic algorithms, we developed a new 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.

Keywords

MANETs, routing protocols, route discovery, pure flooding, dynamic probabilistic algorithm.

1. INTRODUCTION

A MANET is a collection of low-power wireless mobile nodes forming a temporary network without any fixed infrastructure [1, 2]. Because of the limited radio transmission range of nodes, routes can often be multi-hop. Hence, every node may act as a router (data packet forwarder) as well as a traffic source or destination. A data packet is forwarded to other nodes on the network through reliable and efficient routing protocols.

The most widely-used routing protocols in MANETs are the dynamic routing protocols (DRPs), such as: the ad hoc on-demand distance vector routing (AODV) [3], dynamic source routing (DSR) [4], and location-aided routing (LAR) [5]. DRPs consist of two phases: route discovery, in which a route between source and destination nodes is established for the first time, and 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 [6].

Broadcasting is a fundamental communication primitive for route discovery in MANETs. One of the earliest broadcast mechanisms proposed in the literature is pure flooding, which is also known as simple or blind flooding [1]. Although it is simple and reliable, pure flooding results in serious redundancy, contention, and collisions in the network; such a scenario has often been referred to as the broadcast storm problem (BSP) [7]

To eliminate the effects of the BSP during route discovery, a variety of flooding optimization techniques have been developed to reduce the number of retransmission. 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 algorithms: probabilistic broadcast [1], LAR [5], multipoint relaying [8, 9], counter-based and distance-based [7], cluster-based [10], etc.

In this paper, we concern with probabilistic broadcast algorithm. In this algorithm, each intermediate node (any node on the network except the source and the destination) is assigned a certain p_i . There are two approaches that can be used to set a satisfactory p_i for any node on the network, namely, static and dynamic approaches.

In the static approach, a pre-determined p_i is set for each node on the networks, while for the later, intermediate nodes adjust their p_i s locally depending on the number of first-hop neighbors (k), therefore, p_i can be expressed as: $p_i=f(k)$, where $f(k)$ is a linear or a non-linear function of k .

Several adjusting models have been proposed in the literature and they will be described in Section 2. The most recent models have considered two distinct values for $f(k)$ assign to the nodes depending on the node neighborhood density. The neighborhood density is usually divided into two regions (low and high), and for each of them a certain constant p_i is assigned regardless of the actual value of k . A node is assigned the higher p_i in the low density region and lower p_i in the high density region. Such adjusting model makes it hard to adjust the node's p_i to ensure optimal network performance.

This paper presents a description of an enhanced adjusting model, in which the neighborhood densities are divided into three regions (low, medium, and high). The node is assigned the higher/lower p_i , if it is moving in the low/high density region, while in the medium region, the node may assign its p_i according to a medium fixed p_i or a p_i calculated using linear function of k .

The new model was implemented on the MANET simulator (MANSim) [11], which is used to perform a number of simulations to evaluate and compare the performance of the new model against pure flooding, fixed probabilistic, and other adjusted probabilistic algorithms.

The rest of the paper is organized as follows: A previous work is presented in Section 2. Section 3 described the concept of the route discovery in MANETs. The probabilistic algorithm and the general approaches of assigning the nodes p_i s are discussed in Section 4. In Section 5, we provide a description of the proposed model. Results and discussions are presented in Section 6. Finally, in Section 7, based on the results obtained conclusions are drawn, and a number of recommendations for future work are pointed-out.

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2. REVIOUS WORK

In this section, we review some of the most recent and related work on probabilistic broadcast in MANETs. Probabilistic algorithm was first used for ad hoc route discovery by Haas et. al. [12], and they called it a gossip-based 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 as AODV 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.

Kim et. al. [13] 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 that this approach generates fewer rebroadcasts than pure flooding approach. It also incurs lower broadcast collision without sacrificing high reachability.

S. Tseng et. al. [7] investigated the performance of the 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. Scott and Yasinsac [2] presented a dynamic probabilistic solution that is appropriate to solving BSP 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.

Zhang and Agrawal [14] 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 simple flooding and fixed probabilistic algorithms. Simulation results showed that their new approach performs better than the two algorithms.

Abdulai et. al. [15] 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. Their results revealed that the optimal p_t is around 0.5 in the presence of dense network conditions and around 0.6 for sparse network conditions.

Bani-Yassein et. al. [1] proposed a dynamic probabilistic algorithm 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.

Abdulai et. al. [16] 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 BSP in the existing OADV routing protocols.

Bani Yassein et. al. [17] 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.

Khan et. al. [18] 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 the probability based schemes.

Hanash et. al. [19] proposed a dynamic probabilistic broadcast approach that can efficiently reduce broadcast redundancy in MANETs. The algorithm dynamically calculates p_t as a function of k . They compared their approach against simple flooding, fixed probabilistic, and adjusted probabilistic 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 demonstrated lower broadcast latency than all existing approaches it was compared against.

3. ROUTE DISCOVERY

This section introduces the concept of route discovery [20]. In DRPs, if a source node (S) tries to communicate with a destination node (D), and after searching its routing table, S cannot find a route to D or it fails to communicate with D through the existing routes, then S should initiate a route discovery. For any node to initiate a route discovery, it transmits a route request (RREQ) packet as a single local broadcast packet, which should be received by (approximately) all nodes currently within the radio transmission range of the node.

The RREQ carries the IP addresses of S and D, and also contains a unique request sequence number or identification number (ID), determined by S. In addition, the header of the RREQ contains information on the lifetime of the RREQ, which is expressed in terms of the maximum number of intermediate nodes (hop-count) that are allowed to forward the RREQ. The RREQ also contains a record listing the addresses of intermediate nodes through which this particular copy of the RREQ has been forwarded. This route record is initialized to an empty list by S.

During route discovery, each intermediate node checks to see if it is D, if not, it checks the hop-count, if it is more than 0, then it appends its IP address to the route record, reduces the hop count by 1, and rebroadcasts the RREQ. If the node detects that it is D, then it sends back a unicast route reply (RREP) packet. The RREP usually follows the same route followed by the RREQ that has reached D, but in reverse order.

If at a particular node, the hop-count approach 0 before the RREQ reaches D, an error is detected and this is considered as an unsuccessful route discovery. In this case, the node sends back a unicast route error (RERR) packet S following the same route followed by the RREQ that has reached this node, but in reverse order. Upon receiving this RERR, S initiates a new RREQ with different sequence number [6].

4. PROBABILISTIC ALGORITHM

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 p_t of the source node is always set to 1, to enable the source node to initialize the RREQ [1, 12, 16, 17].

There are two approaches that can be used for assigning the p_t s of the intermediate nodes. These are [1, 2]:

1. Static approach in which a pre-determined p_t is assigned for each node on the networks and it can be expressed as: $p_t = P_t$, where P_t is a constant value ($0 < P_t \leq 1$). $P_t = 1$ for pure flooding.
2. Dynamic approach in which each node on the network locally calculates its p_t as a function of k and it can be expressed as: $p_t = f(k)$, where $f(k)$ is a linear or a non-linear function of k .

Many functions have been developed for dynamically adjusting p_t [1-2, 12-14]. Most of these functions were developed as simple single-variable functions, namely, k . Figure 1 outlines the probabilistic broadcast algorithm.

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Probabilistic Broadcast Algorithm
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.
    IRange=0 means the receiver is not
    within the transmission range of the
    sender}
If (IRet(i)=0) Then {The node has not retransmitted the
    request before (IRet(i)=0)}
     $\xi_i = \text{rnd}()$  { $\xi_i$  some random number between 0 and 1}
     $p_t = \text{function\_}p_t()$ 
    If ( $\xi_i < p_t$ ) Then
        Retransmit RREQ
        IRet(i)=1 {Update the node retransmission index
        IRet(i) by equating it to 1}
    End if
End if
End if
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}
     $p_t = \text{constant value}$ 
Else (IProb="Dynamic")
     $p_t = f(k)$ 
End If
    
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Figure 1. The probabilistic broadcast algorithm.

5. THE PROPOSED ADJUSTED MODEL

This section presents a description of a flexible model that can be used for calculating the p_t s of intermediate nodes for adjusted probabilistic broadcast in MANETs. In this model, the value of k is divided into three ranges (low, medium, and high), where for each range different function may be used for adjusting p_t . This can be expressed mathematically as:

$$p_t = p_t(k) = \begin{cases} f_{low}(k) & \text{for } k \leq N_1 \\ f_{med}(k) & \text{for } N_1 < k < N_2 \\ f_{hig}(k) & \text{for } k \geq N_2 \end{cases} \quad (1)$$

Where

p_t is the node retransmission probability.

k is the number of first-hop neighbor for the transmitting node.

$f_{low}(k)$, $f_{med}(k)$, $f_{hig}(k)$ are distribution functions for calculating p_t at low, medium, and high ranges of k .

N_1 is the number of nodes at or below which p_t is calculated using the function $f_{low}(k)$.

N_2 is the number of nodes at or above which p_t is calculated using the function $f_{hig}(k)$.

In this paper, $f_{low}(k)$ and $f_{hig}(k)$ are always expressed as constant values representing the maximum and minimum p_t (p_{max} and p_{min}), while $f_{med}(k)$ is either a constant value or expressed as a linear function of (k). The reasons for selecting three ranges can be explained as follows:

1. Low node density neighborhood ($k \leq N_1$). In this case, p_t of the intermediate node is set to p_{max} to increase the probability of forwarding the RREQ packet across this low density neighborhood to ensure high reachability. Due to the small number of neighboring nodes this may incur an insignificant increase in the number of retransmissions.
2. Medium node density neighborhood ($N_1 < k < N_2$). In this case, p_t of the intermediate node is either a constant value or calculated using a linear function of k . In a linear relation, for example, p_t decreases linearly from p_1 to p_2 with increasing k . This looks very acceptable, because as k increases, then despite the fact that some of the intermediate nodes may fail retransmitting the RREQ packets, but still some will succeed, so that the chance of forwarding the RREQ packets remains high incorporating insignificant reduction in network reachability.
3. High node density neighborhood ($k \geq N_2$). In this case, p_t of the intermediate node is set to p_{min} to reduce the probability of forwarding the RREQ packet. But, due to the high node density some nodes will success in forwarding the RREQ packet. Thus, the number of retransmissions is reduced incurring lower broadcast collision without sacrificing high reachability.

(1) can be re-expressed as:

$$\text{Constant: } p_t = \begin{cases} p_{max} & \text{for } k \leq N_1 \\ p_{med} & \text{for } N_1 < k < N_2 \\ p_{min} & \text{for } k \geq N_2 \end{cases} \quad (2)$$

$$\text{Linear: } p_t = \begin{cases} p_{max} & \text{for } k \leq N_1 \\ p_1 - \frac{k - N_1}{N_2 - N_1} (p_1 - p_2) & \text{for } N_1 < k < N_2 \\ p_{min} & \text{for } k \geq N_2 \end{cases} \quad (3)$$

Where p_{med} is the retransmission probability assigned to a node surrounded by k nodes ($N_1 < k < N_2$). p_1, p_2 are the retransmission probabilities assigned to intermediate nodes surrounded by $k=N_1+1$ and $k=N_2-1$ nodes, respectively. p_1 and p_2 should lie between p_{max} and p_{min} (i.e., $p_{max} \geq p_1 \geq p_{min}$), and also $p_1 \geq p_2$. Figure 2 shows the variation of p_t with k . In general, selection of satisfactory distribution in the interval $[N_1+1, N_2-1]$ and the values of $p_{max}, p_{med}, p_{min}, p_1, p_2, N_1,$ and N_2 depend on a number of factors and need to be carefully considered.

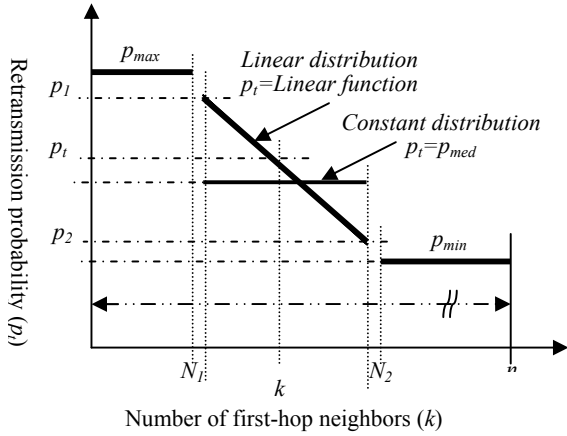


Figure 2. Retransmission probability as a function of k .

5.1 Predicting the values of $p_{max}, p_{med}, p_{min}, p_1, p_2, N_1,$ and N_2

Before we proceed with the process of predicting the values of the variables in (2) and (3), let us define the following parameters:

1. The average retransmission probability of the nodes ($p_{t,avg}$)
Assume that a route discovery is initiated at an interval j started at time t and for a period of time τ (known as pause time). During the interval j , the network is assumed to have a certain fixed topology, and each node can determine its p_t according to k (which we refer to as $p_{t|i,j}$, where $i=1$ to n , and n is the number of nodes on the network. Thus; the average retransmission probability of the nodes at j ($p_{t,avg|j}$) can be calculated as:

$$p_{t,avg|j} = \frac{1}{n} \sum_{i=1}^n p_{t|i,j} \quad (4)$$

Then, for m consecutive intervals, the average retransmission probability of the nodes ($p_{t,avg}$) can be calculated as:

$$p_{t,avg} = \frac{1}{m} \sum_{j=1}^m p_{t,avg|j} = \frac{1}{n \cdot m} \sum_{j=1}^m \sum_{i=1}^n p_{t|i,j} \quad (5)$$

Similarly, the average retransmission probability of a node i ($p_{t,avg|i}$) for m consecutive intervals can be calculated as:

$$p_{t,avg|i} = \frac{1}{m} \sum_{j=1}^m p_{t|i,j} \quad (6)$$

2. The average number of first-hop neighbors (k_{avg})
As we have discussed above that during an interval j , the network is assumed to have a fixed topology, so that each node has a number of first-hop neighbors ($k_{i,j}$). Thus, the average number of first-hop neighbors of the nodes at j ($k_{avg,j}$) can be calculated as:

$$k_{avg,j} = \frac{1}{n} \sum_{i=1}^n k_{i,j} \quad (7)$$

Then, the average number of first-hop neighbors of the nodes for m consecutive intervals (k_{avg}) can be calculated as:

$$k_{avg} = \frac{1}{m} \sum_{j=1}^m k_{avg,j} = \frac{1}{n \cdot m} \sum_{j=1}^m \sum_{i=1}^n k_{i,j} \quad (8)$$

Also, the average number of first-hop neighbors of a node i for a session of m intervals ($k_{avg,i}$) can be calculated as:

$$k_{avg,i} = \frac{1}{m} \sum_{j=1}^m k_{i,j} \quad (9)$$

The standard deviation associated with each of the computed averages in (4) to (9) is also calculated. (2) and (3) are multi-variable equations, and the question now is how can we predict or determine the values of the variables ($p_{max}, p_{med}, p_{min}, p_1, p_2, N_1,$ and N_2) in these two equations, such that an optimum probabilistic broadcast performance can be achieved.

It can be easily recognized that it is impossible to determine these optimum values analytically. In order to simplify the optimization or tuning process, p_1 and p_2 are set equal to p_{max} and p_{min} . This incurs a smooth and consistence variation of p_t with k . Practically, we believe a simulation-based approach is a good way to fine tune these values according to network environment. In this approach, a number of simulations are carried out for different sets of values for these parameters, and then the set that provides the best performance can be taken on.

6. RESULTS AND DISCUSSIONS

The proposed p_t adjusting model for probabilistic broadcast in MANETs is implemented on MANSim [11], which is a network simulator 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. The algorithm module was modified to accommodate the proposed model.

MANSim calculates a number of network performance measures, such as: network reachability (RCH), number of retransmission (RET), average duplicate reception (ADR), average hop count (AHP), saved rebroadcast (SRB), and disconnectivity (DIS). These parameters are recommended by the Internet Engineering Task Force (IETF) group to judge the performance of the flooding optimization algorithms. Definition of these parameters can be found in [8]. In addition, it is modified to compute $p_{t,avg}$ and k_{avg} .

In this paper, we present results for RCH and RET, which they defined as follows:

1. RCH is defined as the average number of reachable nodes by any node on the network normalized n . RCH can also be defined as the probability by which a RREQ packet successfully delivered to a destination node.
2. RET is defined as the average number of retransmissions normalized to n .

Furthermore, results for $p_{t,avg}$ and k_{avg} are also presented.

In order to evaluate the performance and to demonstrate the flexibility of the proposed model, a number of simulations were carried-out using MANSim. These simulations are grouped into two scenarios, which are described below.

6.1 Scenario #1: Estimation of N_1 , N_2 , p_{max} , and p_{min}

This scenario demonstrates how, for a certain network configuration and environment, the variables N_1 , N_2 , p_{max} , and p_{min} can be estimated. In particular, it shows the effect of these variables on the performance of probabilistic broadcast. The input parameters for this scenario are listed in Table 1. This scenario is divided into four sets; each set investigated the effect of one of the variables above, while fixing the other three variables as given in Table 2. The results obtained are shown in Figures 3 to 6.

Table 1. Input parameters for Scenario #1.

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
Simulation time (T_{sim})	600 sec
Pause time (τ)	$\tau=0.75*(R/u)=15$ sec
Size of mobility loop ($nIntv$)	40

Table 2. Input variables for Scenario #1.

Set	N_1	N_2	p_{max}	p_{min}
1	2,4,6,8	15	0.8	0.5
2	4	10,15,20,25	0.8	0.5
3	4	15	0.7,0.8,0.9,1.0	0.5
4	4	15	0.8	0.3,0.4,0.5,0.6

The main outcomes of this scenario can be summarized as follows:

- Reasonable values for N_1 and p_{max} are $N_1 \leq 8$ and $p_{max} \geq 0.7$. It means assigning a high p_t to the intermediate nodes in low node density neighborhood. This increases the probability of forwarding the RREQ packets by the node, while they are passing through such neighborhood to their destinations. However, this may increase the number of redundant retransmissions, but since it is only at low node density neighborhoods, its effect is not that significant or huge.
- Reasonable values for N_2 and p_{min} are $N_2 \geq 2k_{avg}$ and $p_{min} \leq 0.5$. It means assigning a low p_t to intermediate nodes relatively high node density neighborhood. This reduces the number of nodes participating in forwarding the RREQ packets, while they are passing through such neighborhood to their destinations, and consequently reducing the number of retransmission without sacrificing high reachability.

Since, the main objective of probabilistic broadcast is to reduce RET without sacrificing high RCH, let us assume that a RCH of $\geq 80\%$ is an acceptable performance. Simulation results showed that a RCH of 0.811 can be achieved by setting the variables N_1 , N_2 , p_{max} , and p_{min} to 4, 15, 0.8, and 0.5, respectively. The computed $p_{t,avg} = 0.708$, while $k_{avg} = 7.142$. These values then can be iteratively tuned to achieve better performance; practically, we are not expecting a significant difference.

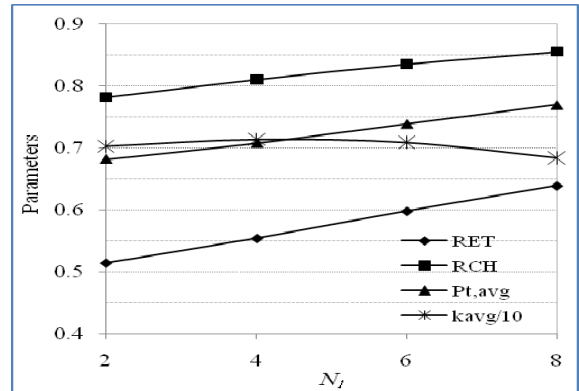


Figure 3. Variation of RET/RCH/ $p_{t,avg}/k_{avg}$ against N_1 .

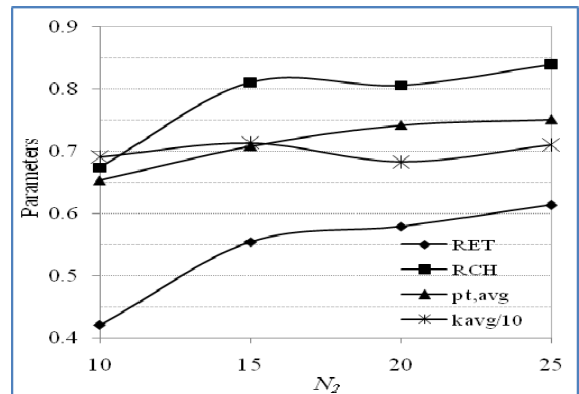


Figure 4. Variation of RET/RCH/ $p_{t,avg}/k_{avg}$ against N_2 .

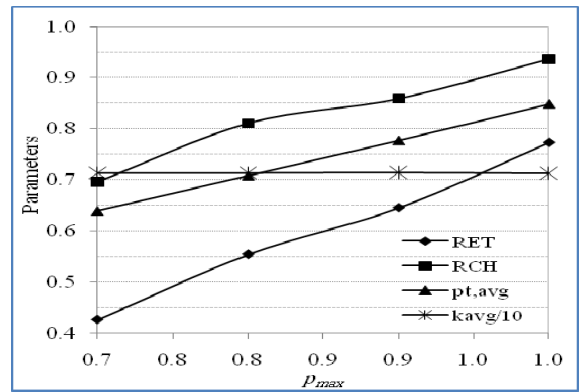


Figure 5. Variation of RET/RCH/ $p_{t,avg}/k_{avg}$ against p_{max} .

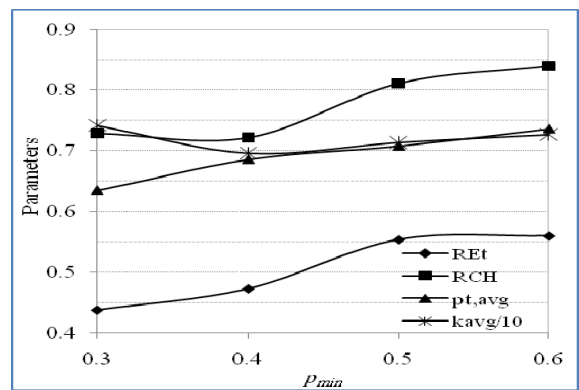


Figure 6. Variation of RET/RCH/ $p_{t,avg}/k_{avg}$ against p_{min} .

6.2 Scenario #2: Comparing Performance of the New Model

In this scenario, a number of simulations were performed using MANSim with the same input parameters in Table 1, to compare the performance of our adjusted probabilistic broadcast with pure flooding, fixed probabilistic, and other adjusted probabilistic algorithms. The simulation results are listed in Table 3, and it shows that broadcast redundancy can be further reduced by using our adjusting model while keeping almost the same reachability; i.e., enhancing the performance of probabilistic broadcast.

Consequently, the new adjusting linear model, whether using a constant or linear distribution in the medium region, achieves the highest SRB among all compared probabilistic models. The linear model achieves better performance in terms of SRB when compared with constant value. The linear achieves 40% while the constant value achieves 37%.

Table 3. Comparing the performance of the new p_t adjusting model.

Algorithm	k_{avg}	$p_{t,avg}$	RCH	RET	SRB*
Pure flooding	7.018	0.997	0.949	0.927	-
Fixed-probabilistic	6.974	0.750	0.820	0.598	36%
Adj-probabilistic $p_{max}=0.8 (k \leq 8)$ $p_{min}=0.55 (k \geq 9)$	6.805	0.732	0.814	0.582	37%
Adj-probabilistic $p_{max}=0.8 (k \leq 4)$ $p_{med}=0.725 (4 < k < 15)$ $p_{min}=0.5 (k \geq 15)$	7.207	0.735	0.812	0.578	38%
Our adj-probabilistic $p_{max}=0.8 (k \leq 4)$ Linear ($4 < k < 15$) $p_{min}=0.5 (k \geq 15)$	7.142	0.708	0.811	0.554	40%
SRB=100(RET _{Pure} -RET _{Algorithm})/RET _{Pure}					

7. CONCLUSIONS

The main conclusion of this work is that the proposed p_t determination model provided better cost-effective performance than the current adjusted probabilistic algorithms. The model can achieve the same network reachability with less redundant broadcasts (retransmissions), which is the main objective of any flooding optimization algorithm. The model can be easily implemented and configured to act as pure flooding, fixed probabilistic, or any other probabilistic algorithms. The main drawback of this model is that the estimation of the optimum values for the variables N_1 , N_2 , p_{max} , p_{med} , and p_{min} . For future work it is recommended to investigate the effect of nodes density, nodes speed, nodes radio transmission range, ..., etc. on the performance of the new model.

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