Fuzzy-controlled Rebroadcasting in Mobile Ad Hoc Networks

Anuradha Banerjee, Paramartha Dutta

Abstract—**The simplest and commonly used mechanism for broadcasting in ad hoc networks is flooding, where each node transmits every uniquely received message exactly once. Despite its simplicity, it can result in highly redundant retransmission, contention, collision in the network i.e. a phenomenon referred to as the broadcast storm problem. Several probabilistic approaches have been proposed to mitigate this problem. However, majority of these schemes use fixed rebroadcast probability, which is quite unlikely to be optimal. In this article, we propose a fuzzy-controlled rebroadcast probability function, which takes into account network density, maximum hop count, remaining energy of the current node, its rebroadcast responsibility as far as its downlink neighbors are concerned, and its radio-range compared to the minimum and maximum radio-range of the network.**

Index Terms—**Broadcast storm problem, contention, collision, fuzzy controller, rebroadcast probability.**

I. Introduction

There has been a growing research effort on wireless ad hoc network over the past years due to their potential usage in rescue/emergency situations in natural or environmental disaster areas, military operations, home networking etc. These networks are formed dynamically by an autonomous system of mobile nodes that are connected via wireless links without any centralized administration or infrastructure. The nodes are free to move randomly and organize themselves arbitrarily. Thus the network topology may change rapidly and unpredictably [1-10]. Nodes may act as end points or routers to forward packets in a wireless multi-hop environment.

In ad hoc networks, broadcasting plays a crucial role as a means of diffusing from source to all other nodes in the network. It is a fundamental operation, which is extensively used in route discovery, address resolution and many other network services in a number of routing protocols [2]. These protocols typically rely on simplistic form of broadcasting called flooding. Although flooding achieves high success rate in reaching all nodes in the network, it produces redundant rebroadcast messages, high contention and collision in the network. This leads to a huge loss of battery power [3-10].

To mitigate this problem, several rebroadcast schemes have been proposed. Cartigny and Simplot [10] proposed a probabilistic scheme where probability of a node to rebroadcast a packet is determined by local node density using "hello" packet. However, determination of optimal efficiency parameter is difficult, since it is independent of network topology. Zhang and Agrawal [8] described a dynamic probabilistic rebroadcast scheme, which is a combination of probabilistic and counter-based approaches. This scheme is implemented for route discovery process using AODV as base routing protocol. The rebroadcast probability is dynamically adjusted according to value of the local packet counter at each mobile node. Therefore, its value changes when the node moves to a new neighborhood. To suppress the effect of using packet counter as density estimates, two constant values are used to increment or decrement rebroadcast probability. However, the critical question is that how to determine the values of these constants.

A. Keshavarz et. Al[6] proposed a color-based broadcast scheme in which every broadcast message has a color field, with a rebroadcast condition to be satisfied after expiration of the timer, similar to the counter-based approaches [9,12]. A node rebroadcasts a message with a new color assigned to its color field if the number of colors of broadcast messages overheard is less than a color threshold.

In [12], an efficient counter-based scheme was proposed which combines the merits of probability-based and counter-based algorithms using a rebroadcast probability value around 0.65 as proposed in [3,9] to yield a better performance in terms of saved broadcast, end-to-end delay and reachability. Furthermore, in follow-on work [11], they showed that a better broadcast probability value is around 0.5, which achieves better performance than the earlier scheme. However, in both the schemes the rebroadcast probability is fixed and it is not likely to be globally optimal. An enhanced counter-based scheme is proposed in [18] which accepts parameters like number of network nodes, area of the network and uniform radio-range of nodes to compute rebroadcast probability. Its drawbacks are that it completely ignores local topological information and remaining battery life of nodes at the current time.

In this article, we propose a fuzzy-controlled rebroadcast scheme, which takes into account network density, maximum, hop count, remaining energy of the current node, its rebroadcast responsibility with respect to the set of its downlink neighbors and its radio-range compared to the minimum and maximum radio-ranges of the network. Intelligence is incorporated in the nodes by embedding a fuzzy controller named Rebroadcast Decider (RD) in each of them. RD accepts all the above-mentioned parameters and

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produces rebroadcast probability as output. Simulation results reveal that this adaptive rebroadcast scheme is superior in performance in terms of saved broadcast, number of retransmission node and end-to-end delay without sacrificing reachability of the network.

II. Input Parameters of RD

Rebroadcast Decider (RD) accepts the following input parameters:

A. Network Density

Let A and N denote area of the mobile ad hoc network being considered and total number of nodes in it. Then, density α of the underlying network is defined in (1).

$$\alpha = \begin{cases} 1 & \text{if } N/A \geq 1 \\ N/A & \text{otherwise} \end{cases} \quad (1)$$

Please note that the value of α lies between 0 and 1. Values of t close to 1 indicate that the network is highly dense and it increases rebroadcast probability of the current node.

B. Hop Count Quotient

Hop count quotient of the network up to node n_i is denoted as ϕ_i and defined in (2).

$$\phi_i = 1 - h_i / H \quad (2)$$

h_i and H indicate number of hops from broadcast sender up to current node n_i and maximum allowed hop count in the network. Since, for all n_i, $h_i \leq H$, it is evident from (2) that ϕ_i ranges between 0 and 1. High values of hi generate low values of ϕ_i. It indicates that the responsibility of broadcasting on n_i w.r.t. the current path is low. As a result, rebroadcast probability of n_i also decreases.

C. Radio quotient

Let R_i, R_{min} and R_{max} denote radio-range of node n_i, minimum and maximum radio-ranges of the network respectively. Radio quotient β_i of a node n_i is mathematically expressed in (3).

$$\beta_i = \frac{(R_i - R_{min})}{(R_{max} - R_{min})} \quad (3)$$

Since $R_{min} \leq R_i \leq R_{max}$, β_i also ranges between 0 and 1. High values of it signify the fact that the radio-range of n_i covers a significantly large circular network area. This phenomenon encourages rebroadcasting.

D. Residual energy quotient

Let E_i and $E'_i(t)$ indicate maximum battery power of the node n_i and its consumed charge till time t. Then residual energy quotient $\varepsilon_i(t)$ of n_i up to time t is formulated in (4).

$$\varepsilon_i(t) = 1 - E'_i(t) / E_i \quad (4)$$

It is evident from the mathematical expression of $\varepsilon_i(t)$ in (4) that residual energy quotient ranges between 0 and 1. High values of it increase rebroadcast capability of n_i. It must be noted here that a node can rebroadcast only when it is equipped with sufficient energy to do so.

E. Rebroadcast responsibility

Let $D_i(t)$ and $U_i(t)$ denote the set of downlink and uplink neighbors of any arbitrary node n_i at time t. Latitude and longitude of n_i at time t are $x_i(t)$ and $y_i(t)$ respectively. Assuming that the node ns is the broadcast source, rebroadcast responsibility $\theta_i(t)$ of n_i at time t is formulated in (5).

$$\theta_i(t) = \begin{cases} \left((1-\eta_i(t)) \sum_{n_j \in D_i(t)} \psi_j(t)\right)^{\eta_i(t)} & \text{if } |D_i(t)| > 0 \\ 0 & \text{Otherwise} \end{cases} \quad (5)$$

where $\eta_i(t) = 1 - 1 / |D_i(t)|$

If $|U_i(t)| \leq 1$, then $\psi_j(t) = 1$, otherwise

$$\psi_j(t) = \left(\rho_j(t) \sum_{n_j \in (U_j(t) - n_i)} (\mu_{i,j,k}(t)\, \mu_{i,k,s}(t))\right)^{(0.5 - 0.5\rho_j(t))}$$

$$\rho_j(t) = 1 / (|U_j(t)| - 1)$$

Please note that, for any two nodes n_m and n_q,
$\nabla_{m,q}(t) = \sqrt{(x_m(t) - x_q(t)^2 + (y_m(t) - y_q(t)^2)}$

$$\mu_{i,m,q}(t) = \begin{cases} \nabla_{q,m}(t) / \nabla_{i,m}(t) & \text{if } \nabla_{q,m}(t) < \nabla_{i,m}(t) \\ 1 & \text{Otherwise} \end{cases}$$

For all nodes, rebroadcast responsibility ranges between 0 and 1. Logic behind the formulation in (5) is that, rebroadcast responsibility of any node n_i decreases if its downlink neighbors have other uplink neighbors with better proximities. Moreover, if those uplink neighbors are nearer to the broadcast source n_s, chances of developing an alternative path from n_s to those uplink neighbors with number of hops lesser than that between n_s and n_i, are high. This encourages relaxation of n_i as far as its rebroadcasting is concerned.

III. Design of Rule Bases of RD

Table I shows division of values of parameters of RD into crisp ranges. According to the discharge curve of heavily used in batteries in ad hoc networks, at least 40% of total charge is required to remain in operable condition (represented as fuzzy variable a). 40% - 60% of the same is satisfactory (represented by the fuzzy variable b); 60% to 80% (fuzzy variable c) of the same is good, whereas 80% and above remaining charge ensures strong transmission capacity of the respective node.

Among other input parameters of RD, only rebroadcast responsibility keeps track of topological information around the node at that time. Hence, its range distribution is a bit stricter than network density, hop count quotient and radio

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quotient. 0 to 30% of it is expressed as fuzzy premise variable a, 30% to 60% as b, 60% to 85% as c and 85% to 100% as d.

Remaining parameters of RD are divided into four equal sized crisp ranges 0-0.25, 0.25-0.50, 0.50-0.75 and 0.75-1.00. The ranges 0-0.25 and 0.25-0.50 correspond to fuzzy variables a and b respectively. Similarly, the ranges 0.50-0.75 and 0.75-1.00 are expressed as fuzzy variables c and d, in that order. Let, output produced by RD be denoted as r which indicates rebroadcast probability of the current node. It follows same range distribution as input parameters of RD.

Table I
Crisp Ranges of Parameters of RD and Fuzzy Variables

Crisp ranges of ε	Crisp ranges of μ	Crisp ranges of α, ϕ, β and r	Fuzzy premise variables
0-0.40	0-0.30	0-0.25	a
0.40-0.60	0.30-0.60	0.25-0.50	b
0.60-0.80	0.60-0.85	0.50-0.75	c
0.80-1.00	0.85-1.00	0.75-1.00	d

Fuzzy composition of residual energy quotient (ε) and rebroadcast responsibility (μ) is presented in table II which produces temporary output t1. In lower ranges, residual energy quotient has been given more importance; while both are assigned equal weight in higher ranges. t1 is combined with network density α in table III generating another temporary output t2. Since t1 is a combination of two extremely significant parameters of RD, it gets more weight than α in table III. Composition of t2 and hop count quotient ϕ appears in table IV generating t3. t3 gets united with radio quotient β generating ultimate output r, of RD.

Table II
Combination of ε and μ producing t1

$\varepsilon\rightarrow$ $\mu\downarrow$	a	b	c	d
a	a	b	b	b
b	a	b	b	b
c	a	b	c	c
d	b	c	c	d

Table III
Combination of t1 and α producing t2

t1$\rightarrow$ $\alpha\downarrow$	a	b	c	d
a	a	b	c	c
b	a	b	c	c
c	a	b	c	d
d	b	c	d	d

Table IV
Combination of t2 and ϕ producing t3

t2$\rightarrow$ $\phi\downarrow$	a	b	c	d
a	a	b	c	c
b	a	b	c	d
c	a	b	c	d
d	a	b	c	d

Table V
Combination of t3 and β producing r

t3$\rightarrow$ $\beta\downarrow$	a	b	c	d
a	a	b	c	c
b	a	b	c	d
c	a	b	c	d
d	a	b	c	d

IV. PERFORMANCE EVALUATION

In this section we provide details of our simulation environment, performance metrics and simulation results. Performance of our proposed scheme "Fuzzy-controlled Rebroadcasting" is evaluated using ns-2 packet level simulator [13]. The radio-propagation model used in this study is based on characteristics similar to commercial radio interface, Lucent's Wavelan Card with a 2Mbps bit rate [14]. The distributed coordination function (DCF) of the IEEE 802.11g protocol [15], is utilized as the MAC layer protocol. As mobility models, we have used random-waypoint, random-walk and Gaussian models in various simulation runs. Total number of simulation runs is 30 and duration of each of these runs was 900 seconds. Details of the simulation environment appear in table VI.

Table V
Simulation Parameters

Parameter	Value
Simulator used	Ns-2 (version 2.29)
Transmission Range	25 – 100 m
Bandwidth	2 Mbps
Interface Queue Length	50 Packets
Packet Size	512 Bytes
Topology Size	1000×1000 m^2
Number Of Nodes	20, 40, 60, 80, 100, 120
Mobility Model	Random waypoint, Random walk, Gaussian
Node Speed	0 – 35 m/s
Simulation Time	900 seconds
MAC Protocol	IEEE 802.11g
Traffic Rate	10 Packets / seconds

Simulation metrics are defined below:

- Broadcast Success Rate (BSR) – this is the percentage of nodes that received the broadcast node with respect to total number of nodes in the network.

  BSR = $(\zeta / N) \times 100$

  As already mentioned, N is the total number of nodes in the network. ζ is the number of nodes that received the broadcasted packet successfully.

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- Saved Rebroadcast (SRB) - This is the percentage of nodes that received the broadcasted packet but did not rebroadcast it.

  $$SRB = ((\zeta - \theta) / \zeta) \times 100$$

  As in case of BSR, ζ is the number of nodes that received the broadcasted packet successfully and θ is the number of nodes that rebroadcasted the message.

- End-to-end Delay (EED) – It is the average time difference between the time a data packet is first broadcasted by its source and the time it is received a destination.

  $$EED = (1/N) \sum_{n_i \in Y} (\varsigma_i - \varsigma_s)$$

  Y is set of nodes that received the broadcasted packet successfully i.e. $Y = |\zeta|$. ς_s is the timestamp at which source of the broadcasted message transmitted it. n_i is any arbitrary node belonging to the set Y (i.e. n_i is any arbitrary node that received the broadcasted message successfully) at timestamp ς_i.

Figures 1, 2 and 3 graphically represent the efficiency of our proposed method “Fuzzy Controlled Rebroadcasting” compared to popular and state-of-the-art broadcast methods, for eg., “Flooding”, “Enhanced Counter-based Scheme (ECS)” and “Enhanced Counter-based Scheme with formula (ECS-formula)”. Each data point is an average of 30 simulation runs with 95% confidence interval.

Figure 1 demonstrates the effects of saved rebroadcast (SRB) with respect to the total number of nodes in the network. It shows that, for all rebroadcast schemes except flooding, SRB increases as number of nodes increase and Fuzzy-controlled Rebroadcasting saves maximum rebroadcasts throughout the simulation period and the improvement is very significant. Reasons behind the efficiency of our proposed scheme is that it considers both the global characteristics of the network (like network density, radio-quotient and hop-count quotient) as well as local topological information (i.e. rebroadcast responsibility) around the node which is about to take rebroadcast decision.

Figure 2 illustrates the degree of reachability (BSR) achieved by the schemes compared here. The results show that reachability improves as the number of nodes in the network increase. Flooding has the best performance in terms of reachability. ECS-formula and Fuzzy-controlled Rebroadcasting perform almost similarly as far as reachability is concerned. Both of them have low reachability than flooding in sparse network. On the other hand, in dense networks, all of them mentioned broadcast schemes are approximately equivalent.

Figure 3 depicts the effects of number of network nodes on end-to-end delay (EED). It shows that the delay is largely affected by network densities and it increases with total number of nodes in the network. The reason is that contention and collision increases with increase in network density. Fuzzy-controlled Rebroadcasting achieves better end-to-end delay compared to other schemes. This is due to the low number of retransmitting node associated with the scheme.

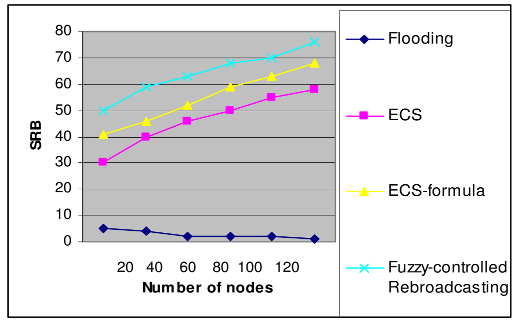

Fig. 1. Saved Rebroadcast vs. Number of Nodes

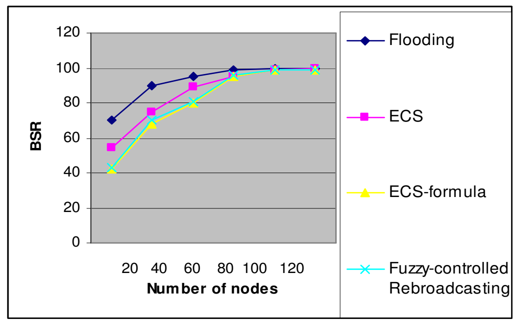

Fig. 2. Broadcast Success Rate vs. Number of Nodes

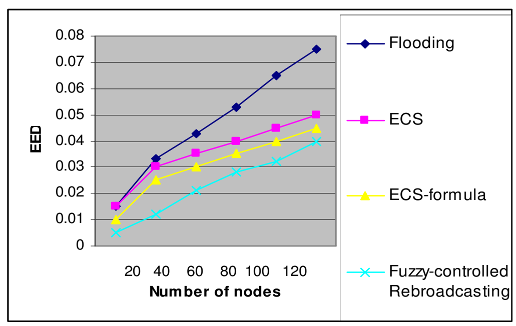

Fig. 3. End-to-end delay vs. Number of Nodes

V. Conclusion

This paper has proposed a fuzzy-controlled rebroadcast schemes for ad hoc networks that mitigates broadcast storm problem associated to flooding. It takes into consideration various global characteristics of the network (like network density, radio-quotient and hop-count quotient) as well as local topological information i.e. rebroadcast responsibility, around a node. Compared to the three popular rebroadcast schemes flooding, enhanced counter-based scheme (ECS) and enhanced counter-based scheme with formula (ECS-formula), our simulation results have revealed that fuzzy-controlled broadcasting achieves huge improvement in terms of saved rebroadcast, reachability and end-to-end delay.

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