Performance Analysis of an Adaptive Probabilistic Counter-Based Broadcast Scheme for Mobile Ad Hoc Networks

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***Abstract*: Flooding is the simplest mechanism for broadcasting in mobile ad hoc networks (MANETs), where each node retransmits a given broadcast packet exactly once. Despite its simplicity, flooding can result in high redundant retransmission, contention and collision, a phenomenon collectively referred to as the *broadcast storm problem*. Several probabilistic broadcast schemes have been proposed to mitigate this inherent phenomenon. However, probabilistic schemes that utilize a random assessment delay (RAD) mechanism suffer from poor performance in terms of end-to-end delay and reachability in congested networks. In this paper, we propose a new adaptive probabilistic counter-based broadcast scheme that enables a mobile node to adapt its RAD to reflect its current local congestion level. Simulation results reveal that this simple adaptation achieves superior performance in terms of saved rebroadcast, end-to-end delay and reachability over existing similar schemes.**

Keywords: Broadcast storm, Flooding, Mobile ad hoc network, Probabilistic broadcasting, Simulation

I. INTRODUCTION

Mobile Ad hoc Networks (MANETs) are formed by an autonomous system of mobile nodes that are connected via wireless links without using an existing network infrastructure or centralized administration [1]. The nodes are free to move randomly and act as end points as well as routers to forward packets in a multi-hop environment where all nodes may not be within the transmission range of the source. Scenarios that might benefit from MANETs technology include rescue and emergency operations in natural or environmental disaster areas, military operations, mobile conference, and home networking [1].

Broadcasting is a means of diffusing a message from a given source to all other nodes in the network. It is a fundamental operation in MANETs as it is extensively used in route discovery, address resolution, and many other network services in a number of routing protocols [2]. For example, Ad hoc On Demand Distance Vector (AODV)[3], Dynamic Source Routing (DSR)[4], Zone Routing Protocol (ZRP)[5], and Location Aided Routing (LAR)[6] use broadcasting or its derivative to establish routes. Other routing protocols such as the Temporally-Ordered Routing Algorithm (TORA) [7] use broadcasting to transmit an error packet for invalid routes.

Existing routing protocols typically assume a simplistic form of broadcasting widely known as *flooding*, in which each mobile node retransmits a broadcast packet exactly once. Despite its simplicity, it can result in high redundant retransmission, contention and collision, a phenomenon collectively referred to as the *broadcast storm problem*, which can greatly increase the network communication overhead [8]. To mitigate the deleterious effects of this problem, several broadcast schemes have been suggested [4-6]. These schemes are commonly divided into two categories; *deterministic* and *probabilistic*. Deterministic schemes use network topological information to build a virtual backbone that covers all the nodes in the network. In order to build a virtual backbone, nodes exchange information, typically about their immediate or two hop neighbours. However, they incur a large overhead in terms of time and message complexity for building and maintaining the backbone, especially in the presence of mobility [9].

Probabilistic schemes, in disparity, rebuild a backbone from scratch during each broadcast. Nodes make instantaneous local decisions about whether to broadcast a message not using information derived only from overheard broadcast packets. Consequently these schemes incur a low overhead and demonstrate superior adaptability in changing environments compared to the deterministic schemes [6]. However, these schemes have poor reachability as a trade-off against the low overhead.

Several probabilistic schemes have been proposed in the past [8, 10]. These include fixed probability, counter-based, location-based, distance-based and hybrid-based schemes [8, 10-13]. In fixed probability scheme, a mobile node rebroadcasts a message according to a fixed probability value while in counter-based schemes messages are rebroadcast only when the number of copies of the message received at a node is less than a threshold value. On the other hand location-based and distance-based schemes exploit position information or distance information between nodes to reduce the number of redundant retransmissions. However, nodes need to be equipped with a Global Positioning System (GPS) or a Received Signal Strength Indicator (RSSI) which incur more cost [14].

Recently, hybrid schemes [15, 16] have been proposed which combine the advantages of pure probabilistic and counter-based schemes to yield a significant performance improvement. However, most of these schemes [8, 15, 16] utilize a random assessment delay (RAD) and have been shown to suffer from low performance in terms of end-to-end delay and reachability in congested networks. To address the above concern, an adaptive scheme has been proposed in [17] which adapt a RAD in a given node to congestion level. However, a preliminary performance analysis has been conducted to assess the effect of varying network density only. Other important system parameters such as node mobility and traffic loads have not been considered. Thus, the results might not necessarily pin-point specific failures due to these unconsidered network parameters.

This paper provides a comprehensive performance analysis of an Adaptive Probabilistic Counter-based broadcast Scheme (or APCS for short). Firstly, we provides a comprehensive performance analysis of APCS in typical pure broadcast settings by varying network density (which is also presented in [17]) and traffic rate in order to show specific point of failures of each of these schemes. We compare this scheme against simple flooding, counter-based scheme and efficient counter-based scheme (ECS) that has been introduced in [16]. Simulation results reveal that *APCS* achieves better performance in various network conditions. Secondly, we propose an extension of *APCS* with uses 3 RAD values and evaluate it performance against *ECS* and *APCS*.

The rest of the paper is organized as follows. Section 2 introduces the related work on fixed probabilistic and counter-based broadcasting. Section 3 describes the new scheme (*APCS*) and its RAD adaptation. Section 4 presents the performance analysis of the scheme. Section 5 introduces further enhancement of APCS. Finally, Section 6 provides concluding remarks and suggestions for further work.

II. RELATED WORK

Ni *et al* [8] have proposed a fixed probabilistic scheme to reduce redundant rebroadcast by differentiating the timing of rebroadcast to avoid collision. The scheme is similar to flooding, except that nodes only rebroadcast with a predetermined probability *P*. Each mobile node is assigned the same forwarding probability regardless of its local topological information. In the same work, counter-based scheme is proposed after analysing the additional coverage of each rebroadcast when receiving *n* copies of the same packet.

Cartigny and Simplot [13] have proposed an adaptive probabilistic scheme. The probability *p* for a node to rebroadcast a packet is determined by the local node density and a fixed value *k* for the efficiency parameter to achieve the reachability of the broadcast. However, the critical question thus becomes how to optimally select *k*, since *k* is independent of the network topology.

In a follow-on work [10], Ni *et al* have described an adaptive counter-based scheme in which each node dynamically adjust its threshold value *C* based on its number of neighbors. Specifically, they extend the fixed threshold *C* to a function *C(n)*, where *n* is the number of neighbors of the node. In this approach there should be a neighbor discovery mechanism to estimate the current value of *n*. This can be achieved through periodic exchange of 'HELLO' packets among mobile nodes.

In Miranda *et al* [18], a power aware message propagation algorithm has been suggested which improves the efficiency of broadcasting by eliminating some of the randomness associated with the selection of retransmitting node. The algorithm uses a function *delay* which gets the reception power of a transmission and returns a delay. This function is expected to map an increasing distance to the source (given by a smaller reception power of the message) in a decreasing value. Unlike in counter-based scheme, the message forwarding node is locally determined from its distance to the sender. However, signal propagation can be easily affected by number of impairments which can significantly degrade the scheme performance.

Zhang and Agrawal [11] have described a dynamic probabilistic broadcast scheme which is a combination of probabilistic and counter-based approaches. The scheme is implemented for route discovery process using AODV as base routing protocol. The rebroadcast probability *P* is dynamically adjusted according to the value of the local packet counter at each mobile node. Therefore, the value of *P* changes when the node moves to a different neighborhood. To suppress the effect of using packet counter as density estimates, two constant values d and d_1 are used to increment or decrement the rebroadcast probability. However, the critical question is how to determine the optimal value of the constants d and d_1.

Alireza *et al* [9] have introduced a color-based broadcast scheme in which every broadcast packet has a color-field with a rebroadcast condition to be satisfied after expiration of the timer similar to counter-based scheme. A node rebroadcast a packet with a new color assigned to its color-field if the number of colors of broadcast packets overheard is less than a color threshold μ.

Recently, in [16] an efficient counter-based scheme has been described which combines the merits of fixed probabilistic and counter-based algorithms using a rebroadcast probability value of around 0.65 as recommended in the study of [8, 12]. This yield good performance levels in terms of saved-rebroadcast, end-to-end delay and reachability. Furthermore, in follow-on work [15], the authors have shown that a better rebroadcast probability value was around 0.5, that can achieve better performance than their earlier scheme. Recently, the scheme has been extended in [17] by adapting its RAD value to network congestion. However, its performance evaluation focuses on varying network density only while important parameter like traffic load is not considered.

This paper evaluates the performance of *APCS* in typical pure broadcast settings by varying network density and traffic rate and compared against flooding, counter-based and efficient counter-based schemes. The study also suggests an enhancement to the scheme and presents some preliminary results. An overview of the *APCS* is presented in the next section.

III. AN OVERVIEW OF ADAPTIVE PROBABILISTIC COUNTER-BASED BROADCAST SCHEME (APCS)

In this section, we present the adaptive probabilistic counter-based broadcast scheme (APCS) also refer to Adaptive-ECS in [17] which adapt its RAD to network congestion.

An efficient counter-based scheme (ECS) have been proposed in [16]. In ECS, a node upon reception of a previously unseen packet initiates a counter *c* that record the number of times a node receives the same packet. Such a counter is maintained by each node for each broadcast packet. After waiting for a random assessment delay (RAD), which is randomly chosen between 0 and RAD T_{max} seconds), if *c* reaches a predefined threshold *C*, the node does not rebroadcast the received packet. Otherwise, if *c* is less than the predefined threshold *C*, the packet is rebroadcast with a probability $P = 0.5$ [15] as against automatically rebroadcasting the message in a counter-based scheme (more details in [16]). The use of a rebroadcast probability stems from the fact that packet counter value does not necessarily correspond to the exact number of neighbours of a node, since some of its neighbours may have suppressed their rebroadcast according to their local rebroadcast probability. For more detail refer to [15].

A. Adaptive Probabilistic Counter-Based Broadcast Scheme (APCS)

Essentially, the selection of an appropriate RAD time plays a vital role in the performance of any broadcast scheme that employed the use of counter. In the original counter-based scheme [8], each node is assigned a fixed constant value RAD_T_{max} which is used to determine RAD value at random. Thus, node does not utilize any network information such as congestion or number of neighbors in determining this value. Generally, in MANETs congestion can be obtained by increasing the packet size or increasing the packet generation rate or both. However, in this paper we choose to fixed the packet size but vary the packet generation rate because we anticipated that broadcast packets, as control type packets, to be generally small in size [12]. Therefore to adapt ECS's RAD T_{max} to congestion levels, each node keeps track of the number packets received per second. Table 1 provides the average packet reception rate for ECS given various packet origination rates in a network with 100 nodes.

In [17], APCS have been presented and operates as follows. If a node is receiving more than 200 packets per second on average (which roughly correlates to a broadcast packet origination rate of 50 packets per second), the node uses a RAD_T_{max} time of 0.05 seconds. Otherwise, the node uses a RAD_T_{max} time of 0.01 seconds.

TABLE I. AVERAGE PACKET RECEPTION RATE FOR DIFFERENT ORIGINATION RATE

Packet Origination Rate	Reception Rate (Pkt/sec)
10	51
20	102
30	147
40	191
60	287
70	321

IV. PERFORMANCE ANALYSIS

In order to verify the effect of the RAD adaptation, numerous Ns-2 [19] simulations have been performed using a side by side implementation with ECS, counter-based, and flooding, and compare the results against those obtained from the three approaches. The performance analysis is based on the assumptions widely used in literature [4, 20].

1. All nodes are identical and equipped with IEEE 802.11 transceivers with the same nominal transmission range.
2. All nodes participate fully in the protocol of the network. In particular each participating node should be willing to forward packets to other nodes in the network.
3. The number of nodes in a given topology remains fixed throughout the simulation time.
4. Each node has sufficient power to function throughout the simulation time.

A. Simulation parameters and metrics

The radio propagation model used in this study is the ns-2 default, which uses characteristic similar to a commercial radio interface, Lucent's WaveLAN card with a 2Mbps bit rate [21]. The distributed coordination function (DCF) of the IEEE 802.11 protocol [22] is utilized as MAC layer protocol while random waypoint model [23] is used as the mobility model. In a random waypoint mobility model, each node at the beginning of the simulation remains stationary for a pause time seconds, then chooses a random destination and starts moving towards it with a randomly selected speed. After the node reaches its destination, it again stops for a pause-time interval and chooses a new destination and speed. This cycle repeats until the simulation terminates. The simulation is allowed to run for 900 seconds for each simulation scenario. Other simulation parameters that have been used in our experiment are shown in Table II.

TABLE II. SIMULATION PARAMETERS

Simulation Parameter	Value
Simulator	NS-2 (v.2.29)
Transmission range	100 meters
Bandwidth	2 Mbps
Interface queue length	50
Packet size	64 byte
Traffic type	CBR
Packet rate	10-70 packets/sec
Topology size	1000m x 1000 m
Number of nodes	20, 40, …, 100
Number of trials	30
Simulation time	900 sec
Maximum speed	3 m/s

Each data point represents an average of 30 different randomly generated mobility scenarios with 95% confidence interval. The error bars in the graphs represent the upper and lower confidence limits from the means and in most cases they have been found to be quite small. For the sake of clarity and tidiness, the error bars have not been included in some of the graphs. We evaluate the broadcast schemes using the following performance metrics:

- Reachability (RE) – The percentage of network mobile nodes that receive a given broadcast packet over the total number of nodes that are reachable, directly or indirectly [24].
- Saved Rebroadcast (SRB) – This is defined as *(r – t)/r*, where *r* and *t* are the number of nodes that received the broadcast message and the number of nodes that transmitted the message respectively[24].
- End-to-end delay - is the average time difference between the time a data packet is sent by the source node and the time it is successfully received by the last node in the network.

B. Simulation results

Extensive simulation experiments have been carried out to compare the performance of the *APCS* against *ECS*, flooding and counter-based schemes which were also presented in [17]. First, we evaluate the impact of density by varying the number of nodes within the network area from 20 - 100 nodes using traffic rate of 10 packets/second and 3m/s node speed. Second, we evaluate the impact of broadcast packet origination rate (traffic load) on the performance of these scheme using 100 nodes and 3m/s speed.

- Impact of Network Density

We assess the impact of network density on the performance of the different broadcast schemes by varying the number of nodes from 20 to 100 deployed randomly on a fixed area of 1000 x 1000 m^2.

Figure 1 demonstrates the effects of density on the saved rebroadcasts achieved by the four broadcast schemes. The figure shows that APCS has superior saved rebroadcast performance than ECS in sparse networks and comparable performance in dense network. This might be as a result of increase in the number node covered within the network. In sparse network most of the schemes saved less rebroadcast as a result of less connectivity within the network.

Figure 2 depicts the degree of reachability of the different broadcast schemes. The figure shows the reachability achieved by the schemes as the node densities increases. The result shows that reachability increases with increased network density regardless of which scheme is used. The flooding and counter-based algorithms have the best performance. However, APCS has a better reachability performance than ECS.

Figure 3 depicts the effects of density on end-to-end delay as network density increases. It shows that the delay is largely affected by network density and thus, increases with increase in density. APCS has least end-to-end delay as a result of the RAD adaptation which insures that low RAD T_{max} values are utilize when network is not congested while high RAD T_{max} are used when network is congested.

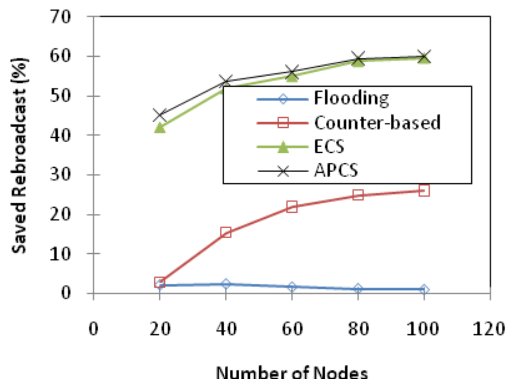

Figure 1. Impact of density on saved rebroadcast using 3 m/s node speed and 10 packet/second traffic rate.

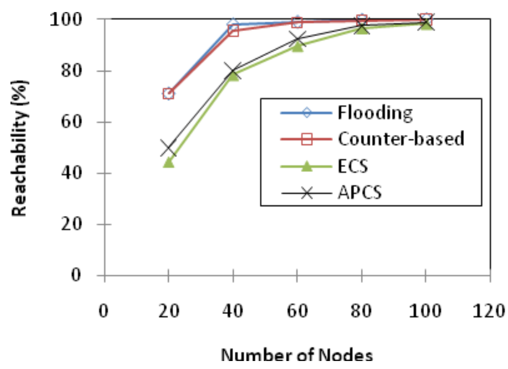

Figure 2. Impact of density on reachability using 3 m/s node speed and 10 packet/second traffic rate.

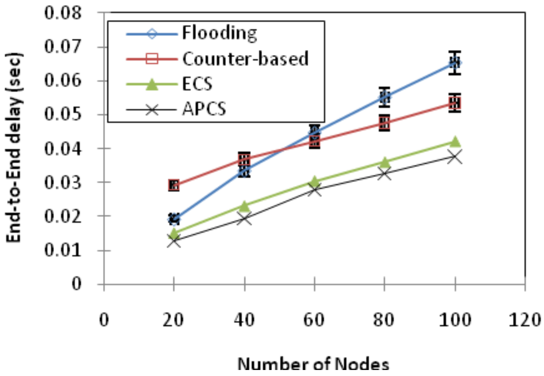

Figure 3. Impact of density on end-to-end delay using 3 m/s node speed and 10 packets/second traffic rate.

- Impact of Traffic Load

The purpose of this study is to measure the performance impact of traffic load on the four broadcast schemes. It will also illustrate the general limits of each broadcast scheme for a given traffic rates and provide a cursory indication of which broadcast scheme reacts best over a range of network traffics.

The results in Figure 4 show the impact of traffic load on the performance of the four schemes in terms of saved-rebroadcast (SRB). ECS maintains a steady and constant SRB for traffic rates of 10-20 packets per second while at traffic rate of 30-60 packets per second the SRB decreases and above 60 packets per second the SRB starts to increase again. However, APCS achieved higher and steady SRB than the other schemes for traffic rate of 20-70 packets per second. For counter-based scheme the SRB decreases as traffic rate increase (10-30 packets per second) but as the traffic rate exceed 30 packets per second the SRB achieved starts to increase again. This trend is as a result of delay due to the transmission times, back-offs from failed clear channel assessment and blocked interface queues. In essence, higher traffic load prohibits redundant packets to be delivered during RAD; therefore more nodes rebroadcast. More rebroadcasts further congest the network resulting in this abridge effect. However, SRB increases as traffic rate increases in the case of flooding, which directly illustrates the effect of collision and queue overflows in congested networks.

Figure 5 demonstrate the effect of load on reachability achieved by the broadcast schemes. The figure shows that the reachability of each broadcast scheme degrades as the network becomes more congested. Clearly, both APCS and ECS maintain a steady reachability for a traffic rate of 10-30 packets per second, beyond which the reachability falls sharply, i.e. reaching its break point. On the other hand, the reachability of other broadcast schemes falls sharply as traffic rate exceed 20 packets per second. This phenomenon is as a result of high contention and collision in the network. Thus, APCS shows similar resilient to load as ECS which is more resilient to load than the other broadcast schemes.

The impact of traffic load on performance of the schemes in terms of end-to-end delay is presented in Figure 6. Both APCS and ECS maintained a steady low end-to-end delay for a traffic rate of 10-40 packets per second beyond which the end-to-end delay rose sharply to around 4s. The other broadcast schemes also portray similar trend but with different rising point. Both counter-based and flooding end-to-end delay performance rose sharply as traffic rate exceed 20 packets per second. Essentially, this figure verifies that there is a strong correlation between end-to-end delay and the origination rate of a packet in a given network. Nevertheless, APCS and ECS are more resilient to high traffic load.

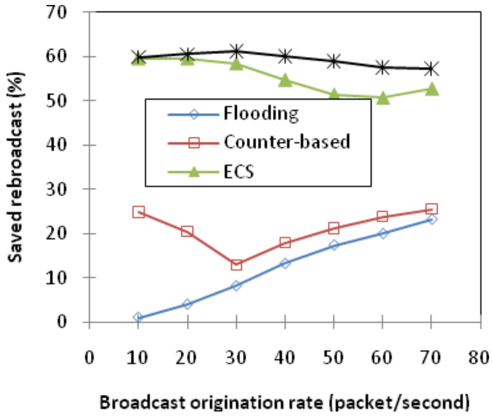

Figure 4. Impact of traffic rates on saved rebroadcast using 100 nodes density and 3 m/s node speed.

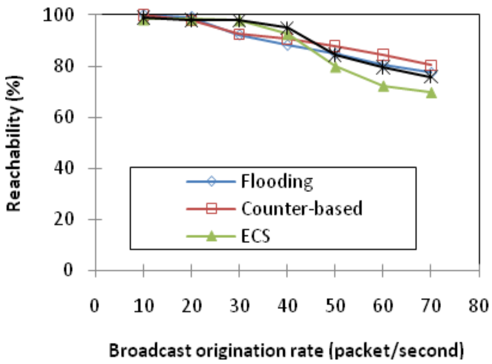

Figure 5. Impact of traffic rates on reachability using 100 nodes density and 3 m/s node speed..

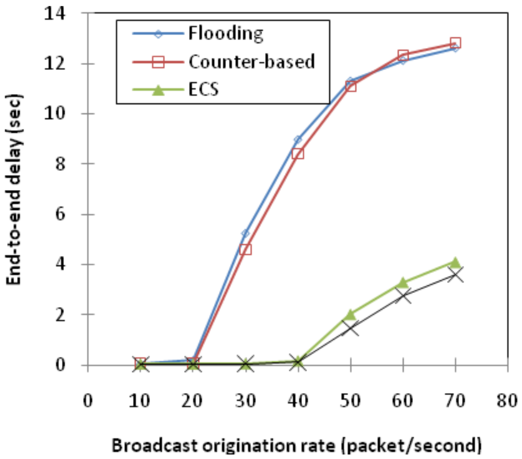

Figure 6. Impact of traffic rates on end-to-end delay using 100 nodes density and 3 m/s node speed..

V. FURTHER ENHANCEMENT OF APCS

Fundamentally, APCS adapts it RAD value to network congestion by using two RAD_T_{max} values (i.e. 0.05 and 0.01) as presented in Section 3. Clearly, a high RAD value is effective in increasing the delivery ratio in a congested network while lower RAD values are needed in non congested network. Adapting RAD in this way would maximize delivery ratio and minimizes end-to-end delay. To further support this claim we conduct a simulation experiment to evaluate the impact of packet origination rate on the performance of some selected RAD_T_{max} values using ECS broadcast scheme as shown in Figures 7 and 8. Clearly, Figure 7 shows the reachability and Figure 8 shows the end-to-end delay of ECS for different RAD T_{max} values. The results in Figures 7 and 8 offer the following two conclusions. First, when a network is not congested, low RAD values are needed. Second, when a network is congested, high RAD values are needed. A similar conclusion is also presented in [12]. In order to be more flexible in our categorization of network based on congestion level we divide the network into three groups (i.e. congested, moderate(less) congested and not congested). Based on this grouping, we propose an extension of the previous scheme which also adapts its RAD values to network congestion level in a similar way.

Unlike *APCS*, the new enhancement (*APCS-with 3 RAD)* uses three RAD values as follows: if the node is receiving more than 200 packets per second on average (which roughly correlates to a broadcast packet origination rate of 50 packets per second), the node uses a RAD_T_{max} time of 0.05 seconds. While if the node is receiving between 145 and 200 packets per second on average (which roughly correlates to a broadcast packet origination rate of 30-40 packets per second), the node uses a RAD T_{max} time of 0.01 seconds. Otherwise, the node uses a RAD_T_{max} time of 0.1 seconds. The choice of this three RAD_T_{max} values stem from the results in Figures 7 and 8.

We evaluate the performance of the new scheme using the same simulation setup and parameters as in Section 4. The APCS-with 3 RAD values is compared against *ECS* and *APCS.* The impact of network density on the performance of the three broadcast schemes is assesses by varying the number of nodes from 20 to 100 deployed randomly on a fixed area of 1000 m x 1000 m.

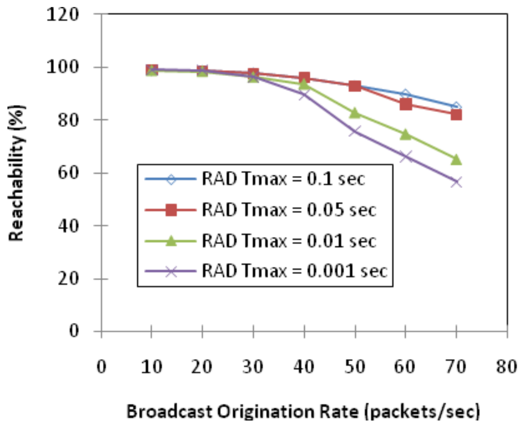

Figure 7. Sensitivity of reachability to RAD T_{max} using 100 nodes and 3 m/s node speed.

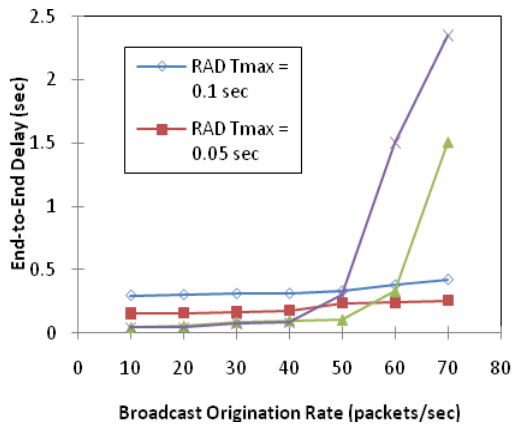

Figure 8. Sensitivity of end-to-end delay to RAD $T_m$using 100 nodes and 3 m/s node speed.

Figure 9 demonstrates the effects of density on the saved rebroadcasts achieved by the three broadcast schemes. The figure shows that APCS-with 3 RAD values has superior saved rebroadcast performance than the other schemes. It's saved rebroadcast increases as density of the nodes increases, i.e. as the number of nodes covering a particular area increases. In sparse network most of the schemes saved less rebroadcast as a result of less connectivity within the network.

The degree of reachability achieved by the broadcast schemes is depicted in Figure 10. The result shows that reachability increases when network density increases regardless of which scheme is used. The new scheme achieves better reachability than the other schemes in most of the network density considered.

Figure 11 depicts the effects of density on end-to-end delay as network density increases. It shows that the delay is largely affected by network density and thus, increases with increase in density. The *APCS extension* has a comparable end-to-end delay with *APCS*. In summary this simple modification on *APCS* can improve the performance of *APCS* in terms of better saved-rebroadcast and reachability with a comparable end-to-end delay to *APCS.*

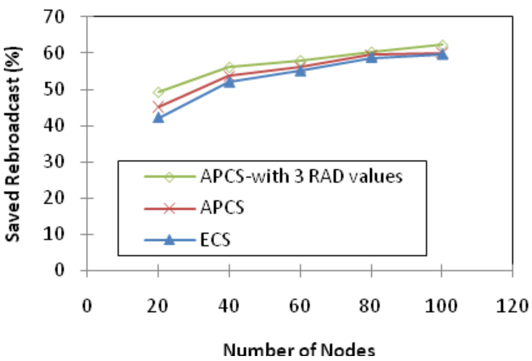

Figure 9. Impact of density on saved rebroadcast using 3 m/s node speed and 10 packet/second traffic rate.

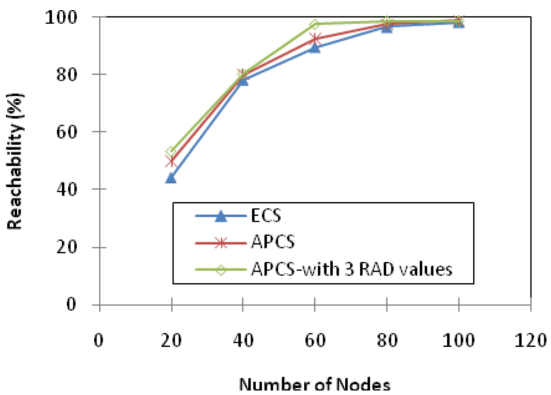

Figure 10. Impact of density on reachability using 3 m/s a node speed and 10 packet/second traffic rate.

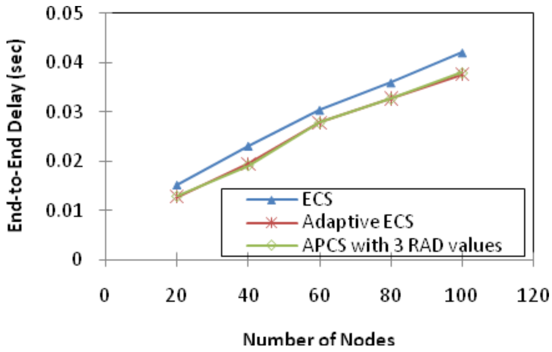

Figure 11. Impact of density on end-to-end delay using 3 m/s node speed and 10 packet/second traffic rate.

VI. CONCLUSIONS

This paper has presented the performance analysis of an adaptive probabilistic counter-based scheme (or APCS for short) for broadcasting in mobile ad hoc networks that further mitigate the broadcast storm problem associated with flooding under increased node density and traffic rate. APCS adapts it RAD (random assessment delay) value to network congestion level and uses packet origination rate as an indicator of network congestion by keeping track of the number of packets received per second at each node. Simulation results reveal that this simple adaptation minimizes end-to-end delay and maximizes delivery ratio, and thus achieves superior performance in terms of saved rebroadcast, end-to-end delay and reachability over the other schemes.

There are couple of areas worth investigating in the future. One area in which we see the potential for even further improvement is to make the adaptation of the RAD value to other network parameters like number of neighbours, node speed and transmission range. Another area for future work is to explore further the performance of the scheme under combined network conditions (i.e. density, mobility and congestion together).

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