Performance Evaluation of an Efficient Counter-Based Scheme for Mobile Ad Hoc Networks based on Realistic Mobility Model

Aminu Mohammed, Mohamed Ould-Khaoua, Lewis M. Mackenzie and Jamal Abdulai

Abstract— **Flooding is the simplest and commonly used mechanism for broadcasting in mobile ad hoc networks (MANETs). Despite its simplicity, it can result in high redundant retransmission, contention and collision in the network, a phenomenon referred to as *broadcast storm problem*. Several probabilistic broadcast schemes have been proposed to mitigate this problem inherent with flooding. Recently, we have proposed a hybrid-based scheme as one of the probabilistic scheme, which combines the advantages of pure probabilistic and counter-based schemes to yield a significant performance improvement. Despite these considerable numbers of proposed broadcast schemes, majority of these schemes' performance evaluation was based on random waypoint model. In this paper, we evaluate the performance of our broadcast scheme using a community based mobility model which is based on social network theory and compare it against widely used random waypoint mobility model. Simulation results have shown that using unrealistic movement pattern does not truly reflect on the actual performance of the scheme in terms of saved-rebroadcast, reachability and end to end delay.**

Index Terms—**broadcasting, broadcast storm problem, community based model, mobile ad hoc networks, random waypoint.**

I. Introduction

Mobile Ad hoc Networks (MANETs) are wireless networks formed by an autonomous system of mobile nodes that are connected via wireless links without using an existing network infrastructure or centralized administration. Such networks are suitable for scenarios which includes rescue/emergency operations in natural or environmental disaster areas, military operations, mobile conference, and home networking [1].

In MANETs, broadcasting plays a crucial role as a means of diffusing a message from source node 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]. For example, ad hoc on demand distance vector (AODV), dynamic source routing (DSR), zone routing protocol (ZRP), and location aided routing (LAR) use broadcasting or its derivative to establish routes. These protocols typically rely on simplistic form of broadcasting called *flooding*, in which each mobile node retransmits every unique received packet exactly once. Although flooding achieved high success rate in reaching all nodes in the network, it produces excessive redundant rebroadcast messages. In a dense network, this redundant rebroadcasts can often causes high contention and collision in the network, leading to loss of precious bandwidth and battery power, a phenomenon called the *broadcast storm problem* [3].

To mitigate this problem, several broadcast schemes have been proposed [4-6]. These schemes are commonly divided into two categories; *deterministic schemes* and *probabilistic schemes*. 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 neighbors. 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.

Probabilistic schemes, in disparity, rebuild a backbone from scratch during each broadcast. Nodes make instantaneous local decisions about whether to broadcast a message or not using information derived only from overheard broadcast messages. Consequently these schemes incur a smaller overhead and demonstrate superior adaptability in changing environments when compared to deterministic schemes [6]. However, these schemes have poor reachability as a tradeoff against overhead. The goal of an efficient broadcast technique is to minimize the number of retransmissions without sacrificing reachability or having any significant degradation.

Several probabilistic schemes have been proposed in the past [3, 7]. These include *probability-based, counter-based, location-based, distance-based* and *hybrid-based* schemes [3, 7-10]. In probability-based scheme, a mobile node rebroadcasts a message according to certain probability while in counter-based schemes messages are rebroadcast only when

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the number of copies of the message received at a node is less than a threshold value. Pure probabilistic schemes assume a fixed probability value and it was shown in [3] that an optimal rebroadcast probability is around 0.65 which is based on their underlying network settings. Recently, hybrid schemes [11, 12] are proposed which combines the advantages of pure probabilistic and counter-based schemes to yield a significant performance improvement. One important method for evaluating these MANET's protocols is through simulation because of its advantages in allowing repeatable scenario, isolation of parameters and exploration of a variety of performance metrics [13]. Topology and node movement in simulation play a key role in the performance of a scheme under study. The movement of nodes within a network area is dictated by the mobility model used. However, majority of the existing mobility models are very simplistic which focus on ease of implementation rather than soundness of foundation [14] and therefore does not provide realistic mobility scenarios. As a consequence performance evaluation results of scheme obtained with unrealistic mobility model might not correctly reflect the true performance of the scheme.

In this paper, we evaluate the performance of our counter-based broadcast scheme in terms of saved-rebroadcast, reachability and end to end delay using a realistic mobility model called community based mobility model [14] and the widely used random waypoint mobility model [15]. We compare this scheme with simple flooding, fixed probability, and counter-based schemes. Simulation results reveal that using unrealistic movement pattern does not truly reflect on the actual performance of the scheme.

The rest of the paper is organized as follows. Section 2 introduces the related work on probabilistic and counter-based broadcasting. An overview of our counter-based scheme and mobility models are presented in Section 3 and 4. We evaluate the performance of our scheme and present the simulation results in Section 5. Finally, concluding remarks are presented in Section 6.

II. Related Work

This section sheds some light on the research work related to probabilistic and counter-based broadcasting schemes.

Ni *et al.* [3] have proposed a probability-based scheme to reduced 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 [10] have proposed probabilistic scheme which combine advantages of probability-based and distance-based schemes. The probability p for a node to rebroadcast a packet is determined by the local node density using "hello" packet and a fixed value $k \in [11,31]$ for the efficiency parameter to achieve the reachability of the broadcast. However, the use of "hello" packet induces more overhead and also the determination of an optimal efficiency parameter k is difficult, since k is independent of the network topology.

In Ni et al. follow-on work [7], the authors 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.

Zhang and Agrawal [8] have described a dynamic probabilistic broadcast scheme which is a combination of the 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 d1 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 d1.

In recent work, Alieza 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 counter-based scheme. A node rebroadcast 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 μ.

Recently, 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 of around 0.65 as proposed in [3, 9] to yield a better performance in terms of saved-rebroadcast, end-to-end delay and reachability. Furthermore, in follow-on work [11], they showed that a better rebroadcast probability value was around 0.5, which achieve better performance than their earlier scheme. However, in both schemes performance evaluation was based on random waypoint mobility model [15] which does not reflect a realistic node movement patterns.

In this paper, we evaluate the performance of our counter-based scheme [11] using a more realistic mobility model called the community based mobility model [14] which is based on social network theory. An overview of our scheme is presented in the next section.

III. An Efficient Counter-Based Broadcast Scheme

In this section, we present the efficient counter-based scheme (ECS) that aims to mitigate the broadcast storm problem associated with flooding. The use of ECS for broadcasting enables mobile nodes to makes localized rebroadcast decisions on whether or not to rebroadcast a message based on both counter threshold and forwarding probability values. Essentially, this adaptation provides a more efficient broadcast solution in sparse and dense networks.

In ECS, a node upon reception of a previously unseen packet initiates a counter *c* that will 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 T_{max} seconds), if *c* reaches a predefined threshold *C*, we inhibit the node from this packet rebroadcast. Otherwise, if *c* is less than the predefined threshold, *C,* the packet is rebroadcast with a probability P = 0.5 as against automatically rebroadcasting the message in counter-based scheme. The use of a rebroadcast probability stem 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 details refer to [11].

IV. Mobility Models

In this section, we present an overview of the two mobility models that are used in the performance evaluation of our scheme, i.e. the Random Waypoint Mobility Model (RWP) and the Community Based Mobility Model (CBM).

A. Random Waypoint Mobility Model

Random Waypoint (RWP) model is a commonly used synthetic model for node mobility in MANETs. It is a simple and straightforward stochastic model that describes the movement behaviour of a mobile network node in a given system area. A node randomly chooses a destination point (waypoint) in the area and moves with constant speed on a straight line to this point. After waiting a certain pause time, it chooses a new destination and speed, moves with constant speed to this destination, and so on [15].

In most of the performance investigations that use the Random Waypoint Mobility Model, the mobile nodes are initially distributed randomly around the simulation area. This initial random distribution of nodes is not representative of the manner in which nodes distribute themselves when moving [16]. Therefore, a warm up or initialization period is required for the node mobility model to reach steady state. Camp, et al. [16] suggest a warm up period of 1,000 seconds for the random waypoint model, but offer no justification. Warm up periods less than 1,000 seconds are used in many simulation studies that use the random waypoint model [3, 7-9].

Another most common problem with simulation studies using random waypoint model is a poor choice of velocity distribution [17] e.g., uniform distribution U(0,Vmax). Such velocity distributions (commonly used in NS-2 simulations!) lead to a situation where at the stationary state each node stops moving. This is because nodes moving according to random waypoint model tend to congregate in the middle of the simulation area, resulting in a non-uniform network density [13].

B. Community Based Mobility Model

Community based mobility model [14] is founded on social network theory. One of the inputs of the mobility model is the social network that links the individuals carrying the mobile devices based on these results in order to generate realistic synthetic network structures [18]. The model allows collections of hosts to be grouped together in a way that is based on social relationships among the individuals. This grouping is only then mapped to a topographical space, with topography biased by the strength of social ties. The movements of the hosts are also driven by the social relationships among them. The model also allows for the definition of different types of relationships during a certain period of time (i.e., a day or a week). For instance, it might be important to be able to describe that in the morning and in the afternoon of weekdays, relationships at the workplace are more important than friendships and family one, whereas the opposite is true during the evenings and weekends [14].

The model is conceptually organized into 3 key steps. Firstly, it uses the social networks as input of the model which involves modelling the social relationships and detection of community structures. The social networks are represented by *weighted graphs* where each node represent one person and the weights associated with each edge of the network is used to model the strength of interactions between individuals [19]. This measure is used in this model as a measure of social ties or interactions. The degree of social interaction between two people is model using a value in the range [0, 1], where 0 indicate no interaction and 1 indicates a strong social interaction. The social network or weighted graph is then represented by a matrix called an *Interaction Matrix* where the names of nodes correspond to both rows and columns and are ordered alphabetically.

Consequently, the *Interaction Matrix* is also used to generate a *Connectivity Matrix* i.e. from *Interaction Matrix* M we generate a binary matrix C where a 1 is placed as an entry $C_{i,j}$ if and only if $M_{i,j}$ is greater than a specific connection or interaction threshold value t (i.e. 0.25). Thus, two people are interacting as they have a strong relationship if they have a weighted link greater than the threshold value *t.* Both the two matrices can be derived by available data or using mathematical models that are available to reproduce characteristic of real social networks. However, the default implementation of community based mobility model uses Caveman model [18] for the generation of synthetic social networks with realistic characteristics. After the definition of the social network, the highly connected set of nodes are isolated using an algorithm proposed in [20] to detect the presence of community structures in social networks represented by matrices as described earlier. This algorithm is based on the calculation of the so-called *betweenness* of edges which provides a measure of the centrality of nodes.

Secondly, after the communities are identified, each of them is randomly associated to a specific location on the grid. However, a non random association to the particular simulation areas can be possible, by deciding a predefined area of interest corresponding to for instance real geographical space. Although this aspect is orthogonal to the work discussed by the authors in [14]. Once the nodes are placed on the grid, the model is established and the nodes moves around according to social attraction laws as explained in the next step.

Lastly, after model is established in the previous step, the goal of each node is randomly chosen inside the square associated to its community (i.e. the first goals of all the host of the community will be chosen inside the square associated with the community). When a goal is reached, the new goal is chosen according to social attractivity exerted by a certain host. The social attractivity of a square in position (p, q) towards a host i is defined as sum of the interaction indicators that represent the relationship between i and other hosts that belong to that particular square, normalized by the total number of hosts associated to that square. If the square is empty the social attractivity is set to 0 [14]. The new goal is then randomly chosen inside the square characterised by the highest social attractivity; it may be again inside the same square or in a different one. New goals are chosen inside the same area when the input social network is composed by loosely connected communities (in this case, hosts associated with different communities have, in average, weak relationships between each others). On the other hand, a host may be attracted to a different square, when it has strong relationships with both communities.

Periodically, the social networks at the basis of the mobility model can be changed. The interval of time between changes is an input of the model. When the reconfiguration of the underlying social network happens, nodes are assigned to the new communities that are detected in the network using the algorithms described in the first step. Communities are then randomly associated to squares in the simulation space. This assignment does not imply immediate relocation of the nodes, instead, it conditions the choice of the next goal. In fact, goals are chosen inside the square of the grid to which the community they belong to is assigned. So hosts will move towards their destination gradually. The nodes start moving towards the geographical region where other nodes that have strong interactions with them will converge. This mirrors the behaviour, for instance, of commuters who travel home every evening to join their families.

According to this model, every edge of the initial network in input is re-wired to point to a node of another cave (community) with a certain probability *p*. The re-wiring process is used to represent random interconnections between the communities. Therefore, individual nodes of one cave/community are closely connected, whereas populations belonging to different caves are sparsely connected.

V. Simulation Study

In this section, we provide the details of our simulation environment, performance metrics used and simulation results.

A. Simulation Environment and Metrics

We evaluate the performance of our scheme using ns-2 packet level simulator (v.2.29) [21]. The performance analysis is based on the assumptions widely used in literature [22].

1) 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.
2) Packet may be corrupted or lost in the wireless transmission medium during propagation.
3) Nodes are homogeneous. The wireless transmission range and the interface card are the same. Likewise the wireless channel is shared by all nodes and can be accessed by any node at random time. Therefore, packet collision is possible due to simultaneous transmission by different nodes.

The radio propagation model used in this study is based on similar characteristic to commercial radio interface, Lucent's WaveLAN card with a 2Mbps bit rate. The distributed coordination function (DCF) of the IEEE 802.11 protocol [23] is utilized as MAC layer protocol while the random waypoint [15] and community based mobility [14] models are used as the mobility models. 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 from a uniform distribution [0, max-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. As it takes time for the random way point model to reach a stable distribution of mobile nodes, the modified random waypoint mobility model [15] used take care of this node distribution problem.

In community based mobility model, we simulate a scenario area divided into different grid of 4 squares (i.e. number of rows and column were set to 2), 16 squares, 36 squares, 64 squares and 100 squares composed of 20, 40, 60, 80 and 100 nodes with a starting number of groups for the Caveman model, respectively equal to 2, 4, 6, …, 10 and a rewiring probability of 0.2. The re-wiring process is used to represent random interconnections between the communities. We chose a relatively low to moderately dense population in order to observe the difference in results obtained with random waypoint model.

The speeds of the nodes were randomly generated according to a uniform distribution in the range [1 – 5] m/s and a pause time 10 seconds. The simulation is allowed to run for 900 seconds for each simulation scenario and the reconfiguration interval is equal to 225 seconds, which is the time interval before nodes are assigned new communities. Other simulation parameters that have been used in our experiment for both random waypoint and community based models are shown in Table 1. More specifically the last four items in the table relate to community based mobility model (for details refer to [14]). The travelling speed is nodes speed within a community used in community based model which typically relate to the speed of a normal walking human.

TABLE I
SIMULATION PARAMETERS

Simulation Parameter	*Value*
Simulator	NS-2 (v.2.29)
Transmission range	250 meters
Bandwidth	2 Mbps
Interface queue length	50
Packet size	512 byte
Traffic type	CBR
Packet rate	10 packets/sec
Topology size	1000 x1000 m2
Number of nodes	20, 40, …, 100
Simulation time	900 sec
Pause time	10 sec
Counter threshold (C)	4
Maximum speed	5 m/s
Connection threshold (t)	0.25
Rewiring probability	0.2
Reconfiguration interval	225 sec
Travelling speed	1 m/s

In this study we varied the number of nodes randomly placed in the network area from 20 to 100, and evaluate the broadcast schemes using the following performance metrics:

1) Reachabilty (RE) – This is the percentage of nodes that received the broadcast message to the total number of nodes in the network.
2) Saved Rebroadcast (SRB) – This is the percentage of nodes that have received but not rebroadcast the message. Thus, SRB is defined as ((r – t)/r)*100, where r and t are the number of nodes that received the broadcast message and the number of nodes that transmitted the message respectively.
3) 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 destination node.

B. Simulation Results

We present the performance results of our scheme (efficient counter-based scheme) side by side with those for counter-based, fixed probability, and flooding. The simulation output is collected using replication mean method [24] where each data point represents an average of 30 different randomly generated mobility models with 95% confidence intervals.

1) Saved Rebroadcast

Fig. 1 shows the performance comparisons of fixed probability, counter-based, flooding, and efficient counter-based scheme (ECS) in terms of SRB with varying network density for random waypoint and community based mobility models. The four schemes achieve different SRB percentages with increasing network density. The figure reveals that ECS can significantly mitigate the contentions and collisions incur during broadcasting especially in dense networks for both mobility models. In sparse networks, ECS has superior SRB of around 50% and about 60% in medium and high dense networks using random waypoint model. Under the same network conditions, the SRB achieved by the other algorithms are lower.

However, using community based mobility model as shown in Fig. 1(b) the performance of both algorithms shows different trends. Although ECS and counter-based schemes portray similar trend, their SRB performance was higher than in Fig. 1(a). However, the performances degrade as network density exceeds 60 nodes. On the hand flooding and fix probability also shows similar trend but achieved almost the same SRB performance as in Fig. 1(a). In respective of the mobility model used, our scheme has superior SRB performance than the other schemes.

2) Reachability

Fig. 2 shows the reachability achieves by the different schemes using the two mobility models. Flooding has the best performance in terms of reachability, reaching about 100% of the nodes for 40 nodes to 100 nodes. The performance of efficient counter-based scheme shows that the reachability is about 52% in sparse networks and above 95% in any other network density. In sparse network, ECS has low reachability compare to counter-based schemes because of the low connectivity in the network. In general the trend shows that reachability increases as density increases for random waypoint mobility model.

However, for community based mobility model the trend is different. Although both schemes achieve better reachability than in Fig. 2(a) for nodes 20 but they achieve the same 100% reachabilty for node 40 and 60. Moreover, for node 80 and 100 the reachability of all the schemes falls which might be connected with the high contention and collision in the networks.

3) End to End Delay

The results in Fig. 3 show the effects of network density on end-to-end delay of broadcast packets for both the models. When node density increases, more broadcast packets fail to reach all the nodes due to high probability of packet collision and channel contention cause by excessive redundant retransmission of broadcast packets. Therefore the waiting time of packets in the interface queues increases. As shown in Fig. 3, ECS exhibit lower latency than the other three schemes. Thus, the total number of packet transmitted in the channel has a significant impact on the end-to-end delay. In both cases ECS has lower end-to-end delay. However, end-to-end delay performance is quite better for community based model implementation than in random waypoint model which can be due to node distribution problem. However, as clearly shown in Fig. 3, the two mobility model gives different results for the same algorithm or schemes.

4) Number of Retransmitting Nodes

In Fig. 4 we present the effect of density on number of retransmission node for both mobility models which is a complementary metric to saved rebroadcast. The Figure depicts that number of retransmitting nodes increases with increasing density. However, unlike saved rebroadcast the less the number of retransmitting nodes the better for the algorithm in terms of performance because few nodes rebroadcast and therefore higher saved rebroadcast and less collision and contention in the network.

Fig. 4(a) shows the number retransmitting nodes required by each scheme as node density increase using random waypoint model. The figure illustrates that each scheme except flooding is scalable in terms of higher node density in fixed network area. The ECS has the least number of rebroadcasts which indicate its performance superiority. On the other hand Fig. 4(b) depicts the number of retransmitting nodes performance of the schemes using community based model. Like the previous figure (i.e. Fig. 4(a)), ECS performs better than the other schemes with least number of rebroadcasts. However, all the schemes achieved better performance with community based model. In fact, for higher node density (100 nodes) the number of retransmitting nodes achieved by ECS is almost double when using random waypoint model. Nevertheless, our scheme has the least number of retransmitting nodes regardless of the mobility model used.

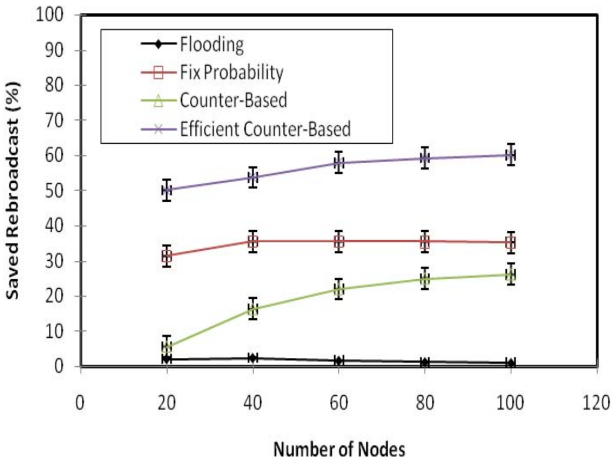

Fig. 1(a). Saved rebroadcast against network density for random waypoint mobility model using 10 packets/second traffic rates.

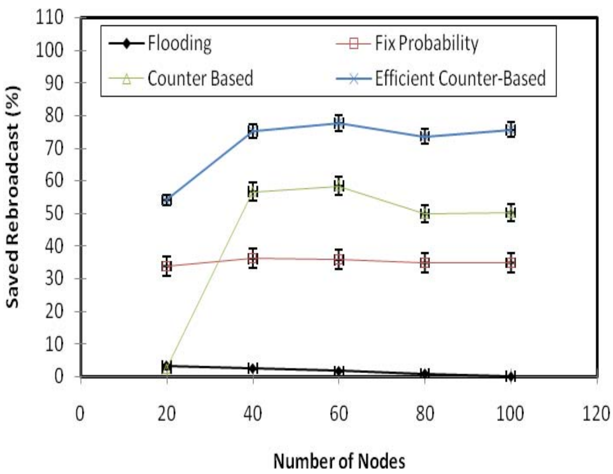

Fig. 1(b). Saved rebroadcast against network density for community based mobility model using 10 packets/second traffic rates.

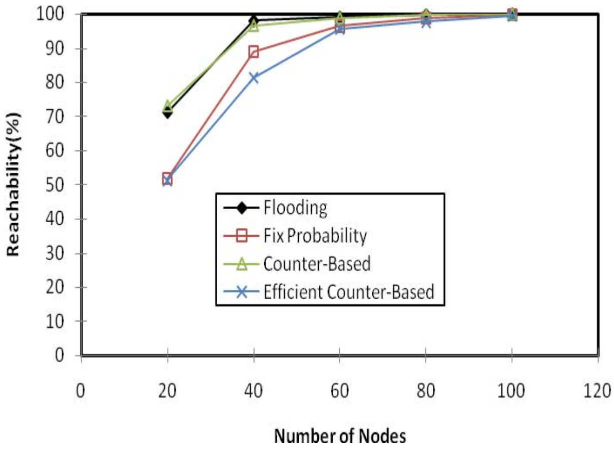

Fig. 2(a). Reachability against network density for random waypoint mobility model using 10 packets/second traffic rates.

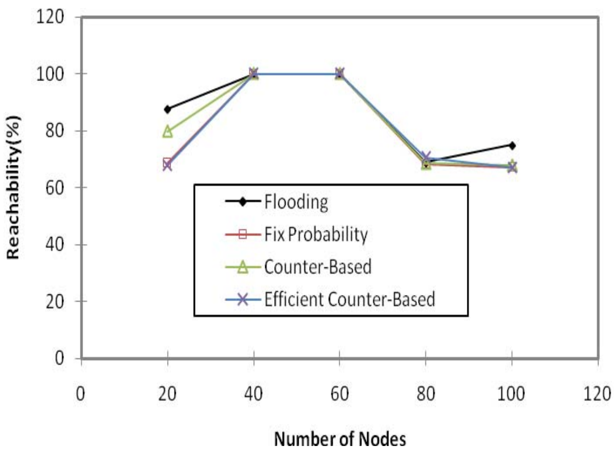

Fig. 2(b). Reachability against network density for community based mobility model using 10 packets/second traffic rates.

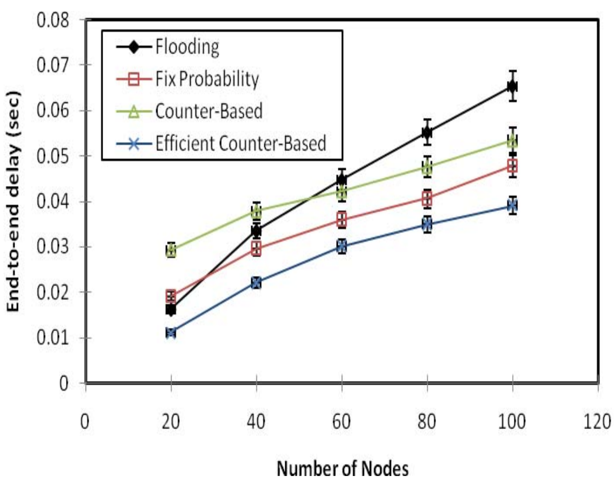

Fig. 3(a). End to end delay against network density for random waypoint mobility model using 10 packets/second traffic rates.

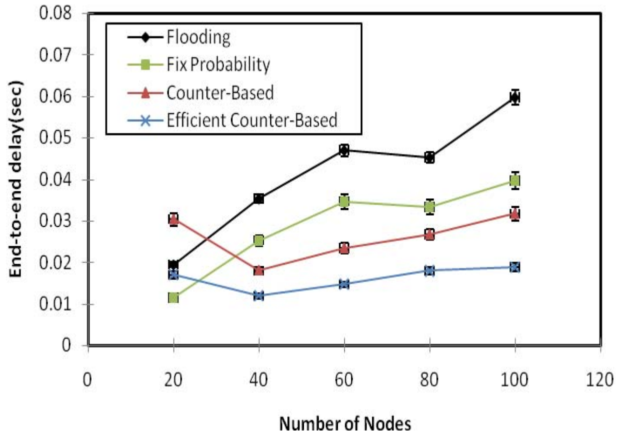

Fig. 3(b). End to end delay against network density for community based mobility model using 10 packets/second traffic rates.

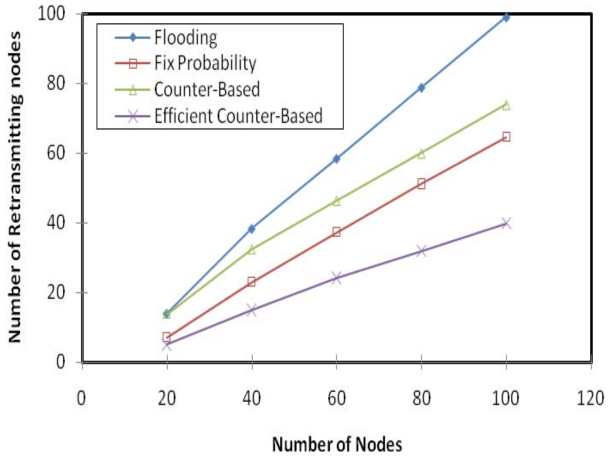

Fig. 4(a). Number of retransmitting nodes against network density for random waypoint mobility model using 10 packets/second traffic rates.

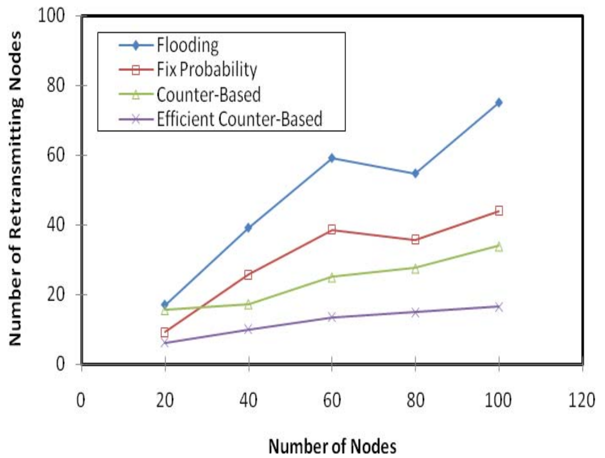

Fig. 4(b). Number of retransmitting nodes against network density for community based mobility model using 10 packets/second traffic rates.

VI. CONCLUSIONS

This paper has presented a performance evaluation of an efficient counter-based broadcast scheme for MANETs that mitigate the broadcast storm problem associated with flooding using a realistic mobility model called community based mobility model and compared it against the widely used mobility model (random waypoint mobility model). Simulation results reveals that our scheme achieved better performance in terms saved rebroadcast, end-to-end delay without sacrificing reachability in both medium to high density networks irrespective of which mobility model is used. Likewise, results have reveal that using unrealistic movement pattern in performance evaluation might not necessarily give a true picture of the actual performance of the scheme in terms of saved-rebroadcast, reachability and end to end delay as the two mobility models give different results in terms of all the performance metric under consideration.

As a continuation of this work, we intend to explore further the evaluation our scheme using other realistic mobility models and also look at effect of these models on the performance our scheme when used for route discovery process in AODV routing protocol.

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