Threshold and RAD Analysis of Adjusted Counter-Based Broadcast in MANETs

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Abstract: The broadcasting protocol can dramatically affect the performance of Mobile Ad Hoc Networks (MANETs). Proper use of a counter-based scheme can reduce the number of rebroadcasts and hence reduce the chance of contention and collision among neighbouring nodes. While most previous studies have used a fixed counter-based threshold value irrespective of node/network status, this research argues that one-hop neighbourhood information could be used to dynamically estimate more suitable threshold and RAD values of the traditional counter based at a given node. This is done based on locally available information and without requiring any assistance of distance measurements or exact location determination devices. This study inspects the new algorithm under the variability of three main aspects: node mobility, network density and traffic load. Our simulation results show that the new dynamic scheme provides good performance levels regarding Saved ReBroadcast (SRB) and REachability (RE) compared to the existing solutions.

Keywords- MANETs, broadcasting, flooding, counter-based.

I. INTRODUCTION

A MANET (Mobile Ad hoc NETwork) is an autonomous system consisting of a set of mobile hosts that are free to move without the need for a wired backbone or fixed base station. Broadcasting is the process by which one node sends a packet to all other nodes in the network. Broadcasting may be used for discovering neighbours, collecting global information, naming, addressing, and sometimes helping in multicasting [1]. In a MANET in particular, due to node mobility, broadcasting is expected to be performed more recurrently. For example, broadcast services could be used for paging a particular host, sending an alarm signal, and finding a route to a particular host [2]. Moreover, Ad hoc On-Demand Distance Vector Routing (AODV)[3], Dynamic Source Routing (DSR)[4], Zone Routing Protocol (ZRP)[5], and Location Aided Routing (LAR)[6] are some examples of routing protocols that rely on broadcasting for route discovery.

Blind flooding is the basic approach to broadcasting where every node in the network forwards the received packet exactly once. Blind flooding is simple and guarantees high reachability, but at the expense of inefficient utilisation of system resources such as channel bandwidth and battery power of mobile nodes. The approach is associated with high redundant transmissions that can cause high channel contention and packet collisions in the network. This phenomenon of blind flooding is referred to in the literature as broadcast storm problem [2].

Several methods have been proposed to alleviate the broadcast storm problem associated with blind flooding [7,8,9,10,11]. These methods can be put into two categories. The first category of broadcast schemes is referred to as non-deterministic broadcast schemes. These schemes mitigate the network congestion levels by reducing the number of retransmitting nodes. This is achieved by inhibiting some intermediate nodes from forwarding the received broadcast packets using some local topological characteristic. Examples of the non-deterministic broadcast schemes include counter-based, area-based, distance-based, and probability-based schemes [2].

The second category of broadcast schemes predetermines a set of forwarding nodes based on global topological information of the network. These schemes are referred to as deterministic broadcast schemes. Examples of deterministic broadcast schemes include pruning [7], multipoint relaying [8], node-forwarding [9], neighbour elimination [10], and clustering [11]. In general the nodes using non-deterministic broadcast schemes make instantaneous local decisions about whether to broadcast a packet or not using information derived only from overheard broadcast packets. Consequently non-deterministic schemes incur a small communication overhead and can adapt to changing environments when compared to deterministic schemes [12].

In this study we propose a new efficient counter-based broadcast scheme that aims at reducing the broadcast storm problem without degrading the reachability. Our new broadcast scheme dynamically adjusts the counter threshold at a forwarding node based on its local topological characteristics. Our simulation results reveal that the proposed scheme can achieve better performance in terms of saved rebroadcast while providing comparable reachability when compared against the traditional
counter-based scheme and the blind flooding based broadcast.

The rest of this paper is organised as follows. Section 2 will be on the related work of the counter-based rebroadcast. Section 3 outlines our proposed adjusted-counter-based scheme. Section 4 presents the simulation results of the proposed algorithm. Finally, section 5 is our future directions and conclusion.

II. RELATED WORK

Counter-based broadcasting was initially proposed in [13] as a mechanism to reduce redundant rebroadcast packets and alleviate problems associated with blind flooding. The basic idea of the counter-based scheme is based on the inverse relation between the expected additional coverage (EAC) and number of duplicate broadcast packets received [2,13]. A node is prevented from retransmitting a received broadcast packet when the EAC of the node’s rebroadcast is low [14].

The idea of EAC is depicted by an example in Figure 1. The hollow shaped nodes are source nodes that initiate the broadcast transmission, and the solid black nodes are nodes we use to clarify our idea, we refer to them as (black-a, black-b). Apparently, black-a neighbourhood density is higher than that of black-b. Thus, the number of duplicate broadcast messages that would be received by black-a is higher as well. Moreover, it is likely that the nodes within the transmission range of black-a would already have been reached by other forwarding nodes. Therefore, the EAC of black-a is lower than the EAC of black-b.

Figure 1: Example of Expected Additional Coverage

The counter-based broadcasting scheme works as follows: when receiving a packet for the first time a counter \( c \) is initiated to keep track of the number of duplicate packets received and a random assessment delay (RAD) timer is also initiated.

The RAD is a jitter randomly chosen between 0 and \( T_{\text{max}} \) seconds, where \( T_{\text{max}} \) is the maximum time delay. This delay is necessary for two reasons. First, it allows nodes adequate time to receive redundant packets and assess whether to rebroadcast. Second, the randomized scheduling prevents collisions [15]. As soon as the RAD timer expires the counter \( c \) is compared against a fixed threshold value \( C \); broadcast is inhibited if \( c \geq C \).

An adaptive counter-based scheme was proposed in [1]. The authors have suggested extending the traditional fixed counter threshold scheme to incorporate the number of neighbours at a node. Specifically, the decision to forward the broadcast packet is determined by the function \( C(n) \) where \( n \) is the number of neighbours of the forwarding node. However, they have stated that the function \( C(n) \) is undefined [1].

**ACBase Broadcast Algorithm**

Pre: \( \text{avg} \) is average number of neighbors.

\( g \) broadcast packet \( m \) at node \( X \) was heard.

Post: rebroadcast the packet or drop it, according to the algorithm

1. Get the Broadcast ID
2. Get degree \( n \) of node \( X \)
3. If \( n < \text{avg} \) then
   Sparse network
   \( C = C_1 \)
   \( T_{\text{max}} = x/\text{RF2} \)
4. Else
   Dense network
   \( C = C_2 \)
   \( T_{\text{max}} = x/\text{RF1} \)
5. End if
6. Set RAD
7. \( c = 1 \)
8. While \( \text{(RAD)} \) Do
   If (same packet heard)
   Increment \( c \)
9. End while
10. If \( c > C \)
    drop packet
    exit algorithm
11. End If
12. Submit the packet for transmission

**End ACBase Broadcast Algorithm**

Other variants of the counter-based broadcast scheme include color-based [16] scheme and the distance-aware counter-based scheme [17]. The main idea of the first scheme is to assign colours to the broadcast packets. Using \( \eta \) different colours \( C_1, C_2, \ldots, C_{\eta} \) each forwarding node selects a colour which it writes to the colour-field of the broadcast packet. All nodes which hear the packet rebroadcast it unless they have heard all \( \eta \).
colours by the time a random timer expires. The question could be asked: what if \( \eta = 3 \) and a node received \( 2\eta \) messages having the colours \{C1, C2\} only? According to color-based broadcasting, this node will still rebroadcast the message although it received a high number of messages, six. Additionally, the proposed color-based broadcasting scheme suffers from the same drawback that the fixed counter-based suffers from: it scores high reachability only when used with homogeneous density networks; when the network is sparse \( \eta = 3 \), and when dense \( \eta = 2 \). Moreover, the authors stated that by increasing \( \eta \) reachability increases. However, they also claimed that there is no such threshold value that can provide full-reachability for any arbitrary connected network. The distance-aware counter-based broadcast is based on the counter-based algorithm proposed by Ni et al [2]. Additionally, this algorithm introduces the concept of distance into the counter-based broadcast scheme by giving nodes closer to the node transmission range border a higher rebroadcast probability since they create better EAC.

III. ADJUSTED COUNTER-BASED BROADCAST

Existing counter-based broadcasting schemes use a fixed threshold value to alleviate the shortcomings of pure flooding; however, we have the following remarks on counter-based broadcast schemes with existing fixed threshold value. First, the topology of MANETs is often random and dynamic with varying degree of node density in various regions of the network. Therefore, fixed counter threshold approach suffers from unfair distribution of C since every node is assigned the same value of C regardless of its local topological characteristics. Second, there exist a trade-off between reachability and saved rebroadcast. While using small threshold values provides significant broadcast savings, unfortunately, the reachability will degrade sharply in a sparse network. Increasing the value of C will improve the reachability, but, once again, the amount of saving will be sacrificed [1]. Third, according to my knowledge, there is no proposed method that dynamically and autonomously changes the counter threshold value.

Accordingly, sparse networks need a higher chance to rebroadcast than dense networks. This could be achieved by one of two ways or a combination of them. First, altering the threshold value C to adapt to network density where a small threshold value C2 is used for dense networks (high n) and a large threshold value C1 for sparse networks (low n). Second, altering the RAD where a small RAD values are used for dense network areas (high n) and a large RAD values for sparse network areas (low n). Moreover, for convenience a scaling Random Factor (RF) is introduced, as shown in Equation 1 where x is a random number between zero and one. Tmax values are designated according to the values of the random number x and the random scaling factor RF. For example if \( x = 0.5 \) then \( T_{\text{max}} \) values would be: 0.5, 0.05 and 0.005 for RFs 1, 10, 100 respectively.

\[
T_{\text{max}} = \frac{x}{RF}
\]  

(1)

The adjusted counter-based broadcast algorithm, works as follows: when receiving a broadcast packet for the first time a node sets the RAD, which is randomly chosen between 0 and 1 second and initiates the counter to one. Following, the node checks the number of neighbours n against the average number of neighbours avg; if \( n < \text{avg} \) then the network is considered sparse and C1 is selected as the threshold value and RF is set to RF1, otherwise the threshold value is set to C2 and RF is set to RF2. Additionally, the values C1 and C2 are selected in a way that considers the expected additional coverage EAC. That is, C1 (sparse network threshold) should be in a way larger than C2 (dense network threshold) in order for the node to have a higher chance to rebroadcast in a sparse area whilst the EAC of the sparse network is higher than that of the dense network as we mentioned with an example previously in section 2. The same principle applies to RAD, that is, a longer RAD interval is selected for more sparse areas. After selecting the threshold value and during the RAD, the counter is incremented by one for each redundant packet received. When the RAD expires the counter is checked against the threshold value, if the counter is less than or equal to the threshold, the packet is rebroadcast. Otherwise, it is simply dropped.

While blind flooding ensures that every node in the network receives the broadcast packet (i.e. high reachability) at the cost of high communication overhead (i.e. low save rebroadcast), our proposed scheme aims at significantly reducing the communication overhead while still achieving comparable reachability when compared to blind flooding. To achieve this, our broadcast approach utilizes neighbourhood information, i.e. number of neighbours in particular to select the best counter threshold. The number of surrounding neighbours (n) a node has is known by periodic exchange of HELLO packets among neighbouring nodes.

IV. PERFORMANCE ANALYSIS

We evaluate the performance of our proposed algorithm using the ns-2 network simulator [18]. Ns-2 is a discrete event simulator targeted at networking research for both wired and wireless networks. Moreover, ns2 has been used by most researchers for performance evaluation in MANETs research [15,16,17]. The present study investigates the performance impact of system parameters.
on the proposed algorithm; notably node mobility and network density. Node density is calculated according to Equation 2, where \( n \) is the total number of nodes, \( A \) is the total network area.

\[
\text{node\_density} = \frac{n}{A} \quad \text{(2)}
\]

Moreover, a node is considered in a sparse area if its neighbour count is less than the average number of neighbours of the whole network and is considered dense if more. The average number of neighbours is calculated according to [19] in Equation 3, where \( r \) is the transmission range of the nodes.

\[
\text{avg\_neighbors} = (n - 1) \frac{\pi \times r^2}{A} \quad \text{(3)}
\]

In addition, we have investigated the effects of threshold values on the performance of the proposed algorithm. For system parameter under investigation, the counter-threshold values \((C1, C2)\) are \((2,3), (2,4), (3,4)\) comparing our scheme to the fixed counter-based threshold value of 2 [15]. The RF \((RF1, RF2)\) values are varied over the range \((100, 10), (100, 1)\) and \((10, 1)\) [14]. The results for blind flooding have been added for the sake of completeness.

**A. Simulation parameters**

shows some of the essential simulation parameters that have been used in the evaluation of our protocols.

**B. Performance Measures**

Below is the performance metrics used to evaluate the performance of the proposed broadcast approach:

- Reachability (RE), defined as \( r/e \), where \( r \) is the number of hosts receiving the broadcast packet and \( e \) is the number of mobile hosts that are reachable, directly or indirectly, from the source host.

- Saved Rebroadcast (SRB), defined as \((r - t)/r\), where \( r \) is the number of hosts receiving the broadcast packet, and \( t \) is the number of hosts that actually transmitted the packet.

- Average latency (Delay), which is the interval from the time the broadcast was initiated to the time the last host finished its rebroadcasting.

**C. Threshold Results Discussion**

To analyze the impact of different threshold values on the performance of our proposed Adjusted Counter Based approach (ACBase), we have divided the study into three parts: first the study of node mobility, then node density and finally traffic load.

**- Mobility and threshold value study**

We investigate the effects of mobility on the performance of the proposed algorithms by varying the maximum nodal speed over a range of 1, 5, 10, 15, and 20 m/sec. The number of nodes deployed over the area of 1500m x 500m had been fixed at 50. Ten nodes were randomly selected to initiate the broadcast process. Each node sends 2 packets/sec. Packet size of 256 bytes has been used. Figure 3 depicts the SRB verses maximum nodal speed. As it is shown in the figure, ACBase can achieve high SRB when compared against Cbase and blind flooding.

![Figure 3. SRB vs. node mobility for 50 nodes](image-url)

For example, the SRB of ACBase with threshold pairs 2 and 3, namely, ACBase: \(T(2x3)\) is around 16% and that of Cbase is around 6% at low mobility of 1m/sec. At
medium to high mobility (i.e. from 10m/sec), the SRB of ACBase is around 15% and that of Chase is 6%. In addition, ACBase SRB decreases with the increase of the threshold values. For instance, ACBase: T(2x3) SRB is 5% higher than the ACBase T(3x4) SRB.

Figure 4 shows reachability versus mobility. All the algorithms present similar trends of reachability for all node speeds. The reachability for all the algorithms is around 84% except for the flooding which was 75%.

Figure 5. Delay vs. node mobility for 50 nodes

Figure 5 investigates the effects of mobility and variable threshold values on average latency (delay for short) of the protocols. The figure shows that the ACBase approach is out performed by both counter-based scheme and blind flooding for low mobility scenarios. But the delay for all the protocols remains fairly the same across medium to high mobility.

- Density and threshold value study.

This section evaluates the effects of node density and threshold values on the performance of the proposed protocol, ACBase. The study of density is imitated by fixing all network parameters and varying number of nodes. The number of nodes is increased over a fixed area of 1500m x 500m. The number of nodes has been varied from 25 to 200 in steps of 25 nodes with each node moving at a speed between 0 and 5 m/sec. To reduce the effects of traffic load, one node was randomly selected to initiate the broadcast process at a sending rate of 2 packets/sec.

Figure 6 presents SRB versus network density. The SRB of ACBase increases with increasing number of nodes. However, the SRB of Chase and blind flooding remains almost flat with increasing node density. This is due to the fact that the Chase scheme uses a fixed counter value for all network regions. However, a node using ACBase uses low threshold values when in sparse regions and high when in dense regions of the network, which aids for more packet savings. At low density of 25 nodes, the ACBase and the Chase scheme achieve similar SRB of around 10%. But at high density of 200 nodes, ACBase achieves superior performance in terms of SRB reaching about 50% while Chase SRB has a linear flat relationship to the number of nodes which is 10% along all nodes numbers.

Figure 7. Reachability vs. number of nodes

Figure 7 shows the effects of network density on reachability. All the algorithms present similar trends of reachability with increasing number of nodes. The reachability increases almost linearly from low to medium number of nodes and reaching 100% at high node numbers. The poor reachability at low number of nodes is due to poor connectivity suffered by sparse networks.
In Figure 8, we present results of the effects of density and threshold values on average latency. ACBase: T(2x3) achieves comparable performance in terms of delay with Cbase and blind flooding across high network densities.

- Traffic load and threshold value study.

Studying network behaviour under variable traffic load, 50 nodes was considered. Moreover, number of sending nodes employed was varying between 1 and 10 in steps of 5 sending nodes with each node moving at a speed between 0 and 5 m/sec. Given that each of the sending nodes has the chance to send 2 packets/sec, the total network load would be: 2, 10, and 20 packets/sec.

Figure 9 shows the SRB of ACBase increases with increasing traffic load. At low traffic load of 1 sending node of 2 packets/sec ACBase T(2x3), SRB was about 34% and the Cbase T(2) SRB was about 9%. That proves the superiority of ACBase over Cbase SRB under low traffic load. However, the ACBase SRB is higher with lower threshold values, for example ACBase T(2x3) is saving more than ACBase T(2x4) and ACBase T(3x4) by 5%. Moreover, SRB in general is worsening when increasing number of sending nodes until it reaches 10 sending nodes where the network saturation point starts.

Figure 10 investigates the effects of traffic load and threshold values on reachability. The performance was quite comparable with reachability degrading as the traffic load increases, that is due to higher collisions and contentions that affect reachability.

D. RAD Results Discussion

This section studies the impact of different RAD, random delay factor, interval combinations on the performance of our proposed (ACBase) algorithm. We have divided out the study into three parts: first the study of node mobility, then density and finally traffic load.

- Mobility and RAD study

We investigate the effects of mobility on the performance of the proposed algorithm by varying the maximum nodal speed over a range of 1, 5, 10, 15, and 20 m/sec. The number of nodes deployed over the area of 1500m x 500m had been fixed at 50. Ten nodes were randomly selected to initiate the broadcast process. Each node sends 2 packets/sec. A packet size of 256 bytes has been used.

Figure 11 shows the effect of traffic load and threshold values on average latency that was affected negatively with higher traffic loads.
Figure 12 depicts the SRB versus maximum nodal speed. As is shown in the figure ACBase can achieve high SRB when compared against the Cbase and blind flooding when the mobility of nodes is increased from low to medium mobility. For example, the ACBase RF(100,1) SRB is around 30% and that of Cbase is around 6% at low mobility of 1m/sec. At medium to high mobility (i.e. from 10m/sec), the SRB of ACBase is around 25% and that of Cbase is still 6%. In addition, apparently the ACBase SRB values decreases with increasing waiting time random factor (RF). For instance, the SRB of ACBase RF(100,1) is about 10% higher that that of ACBase RF(100,10).

Figure 13 shows reachability versus mobility. The figure shows that the ACBase algorithm outperformed the Cbase algorithm at all nodal speeds.

Figure 14 investigates the effects of mobility and RAD on the average latency of the protocols. The figure shows that the ACBase approach is out performed by both Cbase scheme and blind flooding for all mobility scenarios. Though the average latency for all the protocols remains fairly constant across all mobility speeds. The figure also reveals that the average latency incurred by ACBase is worsened when the RFs decreases from RF(100,10) to RF(100,1).

- Density and RAD study

This section evaluates the effects of node density and RAD on the performance of the proposed protocol. The study of density is imitated by fixing all network parameters and varying number of nodes which is increased over a fixed area of 1500m x 500m. The number of nodes has been varied from 25 to 200 in steps of 25 nodes with each node moving at a speed between 0 and 5 m/sec. To reduce effects of traffic load, one node was randomly selected to initiate the broadcast process at a sending rate of 2 packets/sec.

Figure 15 presents SRB versus number of nodes. The SRB of ACBase increases with increasing number of nodes. However, the SRB of Cbase and blind flooding remains almost flat with increasing number of nodes. This due to the fact that the Cbase scheme uses a fixed counter value and a fixed random factor for all network regions. However, a node using ACBase sets the RAD values high within dense regions and low in sparse regions of the network. When number of nodes in the network is small (25 nodes), the ACBase RF (100, 1) and the Cbase scheme achieve similar SRB of around 10%. However, with high number of nodes (200 nodes), the ACBase RF(100, 1) achieves superior SRB reaching about 60% while Cbase SRB has a linear relationship to the number of nodes which is 10% along all nodes numbers.
Figure 16 shows the effects of variable number of nodes on reachability. All the algorithms present similar trends of reachability with increasing number of nodes. The reachability increases almost linearly from low to medium network density and reaching 100% at high network density. The poor reachability at low network density is due to poor connectivity suffered by sparse networks.

Figure 17 we present results of the effect of variable number of nodes and RF on average latency. ACBase RF(100, 10) achieves comparable performance in terms of delay with the counter-based and blind flooding across all network densities. However, the delay incurred by ACBase RF(100, 1) is much higher, due to the factor of having a considerably higher waiting time.

- Traffic load and RAD study

To study network behaviour under variable traffic load, a size of 50 nodes was considered. Furthermore, the number of sending nodes employed was 1, 5, and 10 nodes with each sending node having the chance to send 2 packets/sec. Eventually, the total network load would be: 2, 10, 20 packets/sec.

Figure 18 shows an average performance of 27%, 35% and 7% scored by ACBase:RF(100,10), ACBase:RF(100,1) and Cbase respectively. That shows a noticeable gain for ACBase over Cbase. Moreover, SRB in general is worse when increasing number of sending nodes until it reaches 10 sending nodes as stated in the section IV-C.

With respect to reachability, Figure 19, the performance was quite comparable with a slight gain for ACBase against Cbase. However, reachability degrades as the traffic load increases, that is due to higher collisions and contentions that worsen reachability.
The same is to say with regards to average latency Figure 20 that is higher traffic load affects all schemes negatively. Though ACBase:RF(100,10) had slightly performed better than Cbase scheme.

V. CONCLUSION

We have analysed the performance of the proposed Adjusted Counter-Based (ACBase) broadcasting scheme in MANETs. We analysed our algorithm under three different variations: mobility, network density and traffic load. Moreover, the effect of alternative combinations of threshold and RAD values on SRB, Reachability and delay was investigated. ACBase broadcasting scheme scored a large gain in SRB compared to the fixed counter-based with a similar reachability and a slight loss in delay. In particular, ACBase: T(2x3) RF(100,10) out performed Cbase scheme under tow variations of mobility, and node density. As a continuation to this work, we plan to implement a MANET routing protocol that utilizes the new ACBase scheme de.

REFERENCES
