Probabilistic Counter-Based Route Discovery for Mobile Ad Hoc Networks

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ABSTRACT

Conventional on-demand route discovery for ad hoc routing protocols extensively use simple flooding, which could potentially lead to high channel contention, causing redundant retransmissions and thus excessive packet collisions in the network. This phenomenon has been shown to greatly increase the network communication overhead and end to end delay. This paper proposes a new probabilistic counter-based method that can significantly reduce the number of RREQ packets transmitted during route discovery operation. Our simulation results reveal that equipping AODV routing protocol with the proposed probabilistic counter-based route discovery method can result in significant performance improvements in terms of routing overhead, MAC collisions and end-to-end delay while still achieving a good throughput.

Categories and Subject Descriptors

C.2.2 [**Computer-Communication Networks**]: Network Protocols – routing protocols

General Terms

Measurement, Performance.

Keywords

Broadcast storm, flooding, MANETs, reactive routing, route discovery, simulation.

1. INTRODUCTION

Mobile ad hoc networks (MANETs) have received considerable research attention over last few decades because of their ease of deployment without the need of any fixed infrastructure. 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].

One of the fundamental challenges in the design of MANETs in a multi-hop environment is the design of dynamic routing protocol that can efficiently establish routes to deliver data packets between mobile nodes with minimum communication overhead while ensuring high throughput and low end-to-end delay.

Several routing protocols have been suggested for MANETs over the past few years [2-5]. In general, these routing protocols can be divided into two categories [6]: proactive and reactive (or on-demand). Proactive routing protocols, such as DSDV [7] and OLSR [8], attempt to maintain consistent and up-to-date routing information from each node to every other node in the network. In the on-demand routing protocols, such as AODV [9] and DSR [10], routes are discovered only when they are needed. Each node maintains a route for a source-destination pair without the use of periodic routing table exchanges or full network topological view. Additionally, there are hybrid protocols that combine the features of both proactive and on-demand protocols. In such protocols, each node maintains routing information about its zone using proactive routing, but uses on-demand routing outside the zone [3]. The periodic routing information updates and updates due to broken links that are inherent in proactive routing protocols can lead to a large routing control overhead in high mobility environments. Hence, these protocols suffer from excessive routing control overhead and therefore are not scalable for MANETs due its limited bandwidth and highly dynamic topologies.

In traditional on-demand routing protocols [2, 7, 10, 11], a node that needs to discover a route to a particular destination, broadcasts a Route Request control packet (RREQ) to its immediate neighbours. Each mobile node blindly rebroadcast the received RREQ packet until a route is established. This method of route discovery is referred to as blind flooding. Since every mobile node is required to rebroadcast the received RREQ packet once. This can potentially lead to excessive redundant retransmissions and hence causing considerable collisions of packets in a contention-based channel, especially in dense networks. Such a phenomenon induces what is known as broadcast storm problem, which has been shown to greatly increase network communication overhead and end-to-end delay [12, 13]. To lessen the deleterious impact of flooding, a number of broadcasting techniques have been suggested in [12, 14, 15].

This paper proposes a new hybrid route discovery approach, called probabilistic counter-based route discovery (or PCBR for short) which combine the advantages of fixed probability and counter-based broadcast schemes to address the broadcast storm

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problem associated with existing on-demand routing protocols. We evaluate the new route discovery method using AODV as it is one of the early routing protocols proposed in the literature that has been widely investigated and analyzed [9]. Our results reveal that equipping AODV with PCBR route discovery method help to reduce the overall routing overhead while achieving improved throughput and delivery latency when compare against counter-based (CB), gossip-based (FP) and the traditional AODV, especially in dense networks under high load. Although, this scheme has been evaluated earlier in [15] and further enhanced in [16]. However, both schemes mainly focus on 'pure' broadcast scenario.

The rest of the paper is organized as follows. Section 2 presents related work on some route discovery methods. Section 3 provides a brief overview of on-demand route discovery process in AODV. Section 4 presents the new route discovery method, PCBR. Section 5 conducts a performance evaluation of the new route discovery method. Finally, concluding remarks are presented in Section 6.

2. RELATED WORK

Traditional on-demand routing protocols [2, 9, 11] produce a large amount of routing control traffic by blindly flooding the entire network with RREQ packets during route discovery. The routing overhead associated with the dissemination of routing control packets such as RREQ packets can be quite huge, especially when the network topology frequently changes. Recently, the issue of reducing the routing overhead associated with route discovery and maintenance in on-demand routing protocols has attracted increasing attention.

Probabilistic routing approaches have been proposed to help control the dissemination of the routing controls packets. Zhang and Agrawal [17] have described a probabilistic method for on-demand route discovery, where the probability to forward an RREQ packet is determine by the number of duplicate RREQ packets received at a node. However, using the number of duplicate packets received at a node to determine the local characteristics of the forward node is not appropriate. This is because some of the broadcast packets may be lost due to collisions. In [18], the authors have proposed a probabilistic route discovery approach which utilizes the characteristics of both probabilistic and connected dominating set (CDS) based methods. Unfortunately, to determine the minimum CDS that optimises the forward nodes set has been shown to be NP-complete [19, 20]. The authors in [21] have suggested an on demand route discovery method that combines the functionality of probabilistic broadcasting and the area covered by the broadcast signal. The area covered by the broadcast signal is estimated by a GPS receiver or the signal strength at the receiving node. A node with the strongest received signal is assumed to be located close to sender and therefore will not cover additional area, as such it is assigned a lower forwarding probability. On other hand, a node is assigned a high forwarding probability when the received signal is relatively low. However, the use of received signal strength will require the design of a network layer protocol to depend on the physical layer.

Hass et al. [22] have proposed a gossip-based ad hoc route discovery approach. The authors have used a predefined probability value to decide whether or not to forward a broadcast packet. Some optimizations such as two-threshold scheme (i.e. use higher probability value for nodes with fewer neighbours) are introduced to prevent broadcast packets from quickly dying out and/or prevent nodes from transmitting excessive packets. In this approach, the number of neighbours is used to determine the forwarding probability. However, the forwarding probability at a node is predetermined by its predecessor irrespective of the local density of its predecessor. In addition, the use of only one or two forwarding probability values at nodes in a network with wide range neighbour densities is unfair of distribution of the forwarding probabilities.

3. ON-DEMAND ROUTE DISCOVERY MECHANISM IN AODV

On-demand routing protocols [9, 11] construct a path to a given destination only when it is required. Thus, they do not maintain topological information about the whole network. Since the focus of our study is on the route discovery part of the protocol, we present a brief overview of the route discovery process in AODV in the remainder of this section.

When a source node **S** needs a route to some destination **D**, it broadcasts a RREQ packet to its immediate neighbours. Each neighbouring node rebroadcasts the received RREQ packet only once if it has no valid route to the destination. Each intermediate node that forwards the RREQ packet creates a reverse route pointing towards the source node **S**.

When the intended destination node **D** or an intermediate node with a valid route to the destination receives the RREQ packet, it replies by sending a route reply (RREP) packet. The RREP packet is unicast towards the source node **S** along the reverse path set-up by the forwarded RREQ packet. Each intermediate node that participates in forwarding the RREP packet creates a forward route pointing towards the destination **D**. The state created in each intermediate node along the path from **S** to **D** is a hop-by-hop state in which each node remembers only the next hop to destination nodes and not the entire route, as in DSR [11].

4. PROBABILISTIC COUNTER-BASED ROUTE DISCOVERY (PCBR)

In this study, we propose a hybrid route discovery algorithm which combine the features of fixed probability and counter-based approaches. Like in counter-based approach, we maintain a counter at each node for every received broadcast packet. Whenever a copy of the packet is received the counter is increase by 1. A high counter values implies that the node's number of neighbours is high while a low counter value relates to a small number of neighbours. Thus, we use packet counter as density estimates as against using "Hello" packets to gather neighbour information which induces more communication overhead.

As in fixed probability approach, we use a rebroadcast probability p for forwarding the packet based on the counter value at the current node. This minimises the number of redundant retransmission in the network. Moreover, the value of packet counter does not necessarily correspond to the exact number of neighbours from the current node, since some of its neighbours may have suppressed their rebroadcasts according to their local rebroadcast probability. This allows a node in sparse region (i.e. with low counter value) to forward a packet with a probability *p,* while nodes in dense region (i.e. high counter value) are inhibited from forwarding the packets.

Combining the features of the above two approaches, we adopt a simple hybrid algorithm as follows: A node upon reception of a previously unseen RREQ packet initiates a counter *c* that will record the number of times a node receives the same packet and a random assessment delay timer (RAD, which is randomly chosen between 0 and T_{max} seconds). Such a counter is maintained by each node for each broadcast packet. During waiting for the RAD timer to expire, the counter is incremented for each duplicate packet received. After the RAD expiration, if *c* exceeds a predefined threshold *C*, we inhibit the node from this RREQ packet rebroadcast. Otherwise, if *c* is less than or equal to the predefined threshold, *C,* the packet is rebroadcast with a probability *p* as against automatically rebroadcasting the RREQ packet in counter-based scheme. This indicates that the node is in dense region and no additional coverage can be achieved by forwarding the packet. The outline of the algorithm is presented in Figure 1.

```
Upon receiving a broadcast packet at a node $X$
  - If it is not in the node's received packet list
      o Set the packet counter $c$ to 1
      o Set the RAD
      o Add the broadcast packet ID to the received packet list and wait for RAD to expire.
      o If $c \leq C$ (threshold value)
          ▪ Rebroadcast the packet with a probability $p$.
          ▪ Exit
      o Else
          ▪ Remove the packet ID from the received packet list
  - Else
      o If $c \leq C$ (threshold value)
          ▪ Increase the packet counter by 1 and wait for RAD to expire.
      o Else
          ▪ Remove the packet ID from the received packet list.
  - Exit.
```

Figure 1. An outline of Probabilistic Counter-Based Route Discovery (PCBR)

The most important factor in our algorithm is the choice of counter threshold value and the forwarding probability. In this work, we choose a rebroadcast probability of *0.5* based on the work in [14] which clearly shows its performance superiority in pure broadcasting scenario over other probabilistic schemes. Due to space constraint interested readers can refer to paper for more details. Our scheme also assumed a counter threshold-value of 3, as it has been shown in [12] that a threshold-value of 3 or 4 can save many rebroadcasts in a dense network while achieving a reachability ratio comparable to flooding. As our scheme require a node to keep track of redundant packets received over a short time interval (i.e. RAD[1]) in order to make rebroadcast decision. The T_{max} value used in this study is the counter-based scheme default [12]. This delay in transmission allows nodes sufficient time to receive redundant packet and makes rebroadcast decision.

5. PERFORMANCE ANALYSIS

We have evaluated the performance of the new probabilistic route discovery method using ns-2 [23] packet level simulator (v.2.29). We have implemented the route discovery methods by modifying the current AODV implementation in ns-2. We have compared our PCBR-AODV against counter-based method (CB-AODV), gossip-based (FP-AODV) and traditional AODV. 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. The Distributed Coordination Function (DCF) of the IEEE 802.11 protocol is used as the MAC layer protocol. The mobility model is based on the random waypoint model [24] in a field of 1000m x 1000m. 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 1.

Table 1. Simulation Parameters

Simulation Parameter	*Value*
Simulator	NS-2 (v.2.29)
Transmission range	100 meters
Bandwidth	2 Mbps
Interface queue length	50
Packet size	512 byte
Traffic type	CBR
Packet rate	4 packets/sec
Topology size	1000 x1000 m^2
Number of nodes	20, 40, …, 200
Simulation time	900 sec
Counter threshold (C)	3
Maximum speed	5 m/s
No. of traffic flows	1, 5, 10, 15, … 35
RAD T_{max}	0.01 sec

Each data point represents an average of 30 different randomly generated mobility starting distribution with 95% confidence interval. We have evaluated the algorithms using the following performance metrics:

Routing Overhead: the total number of RREQ packets transmitted during the simulation time. For packets sent over multiple hops, each transmission over one hop is counted as one transmission;

End-to-end delay (or average delay): is the average time difference between when a data packet is sent by the source node and when it is successfully received by the destination node.

Throughput: is defined total number of data packets received (bytes) at destinations in one second.

Average Number of Collisions: The total number of packets dropped resulting from the collisions at the MAC layer.

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[1] Is randomly chosen from a uniform distribution between 0 and T_{max} seconds, where T_{max} is the highest possible delay interval.

5.1 Performance Results

The simulation scenario is designed specifically to assess the impact of network density on the performance of the protocols. The impact of network density is assessed by deploying 20 – 200 nodes over a fixed square topology area of 1000m x 1000m using 5m/s node speed and 10 identical source-destination connections.

5.1.1 Routing Overhead

Figure 2 shows the performance of the four routing protocols in term of routing overhead over varying network density. As shown from the figure, the routing overhead generated by each of the routing protocols increases almost linearly as the network density increases. The results in the figure reveal that for a given network density, the routing overhead generated by PCBR-AODV is lower compared with the other protocols. The figure demonstrates that PCBR-AODV can significantly mitigate the routing overhead incurred during the route discovery process, especially in dense networks. The superior performance of PCBR-AODV could be due to the reduction of the number of redundant retransmissions.

5.1.2 Collision Rate

The results in Figure 3 depict the effects of network density on the performance of the algorithms in terms of average number of MAC collisions per unit simulation time. Since data and control packets share the same physical channel, the collision probability is high when the dissemination of RREQ packet is not appropriately controlled. The figure reveals that when the network density is increased, the collision rate for each of the four routing protocols is increased. Compared against traditional AODV, PCBR-AODV protocol incurs lower average packet collision rate by achieving about 65% reduction of packet collision rate when the number of nodes deployed is 200.

5.1.3 Throughput

Figure 4 depicts the achieved throughput of all four protocols against network density. The throughput for each of the routing protocols is lower when the network density is set low (i.e. 20 nodes). This is due to poor network connectivity associated with sparse network. The figure shows that, although PCBR-AODV can significantly reduce the routing control overhead and packet collisions as demonstrated in Figure 2 and 3, it can still achieve comparable performance levels in terms of throughput when compared with the other schemes for various network densities.

5.1.4 End-to-End Delay

The results in Fig. 5 illustrate the performance of the four protocols in terms of end-to-end delay performance under varying network density. When network density increases, more RREQ packets fail to reach the destinations due to high probability of packet collisions and channel contention caused by excessive redundant retransmissions of route request packets. Therefore, the waiting time of data packets in the interface queues increases. The figure also reveals that in the case of sparse network (i.e. 20 nodes) where the network is poorly connected the end-to-end delay in all the protocol is higher with PCBR-AODV being affected most. However, the reduction of routing overhead translates to better end-to-end delay in dense networks. Thus, as number of nodes increases, the better the delay performance achieved by PCBR-AODV.

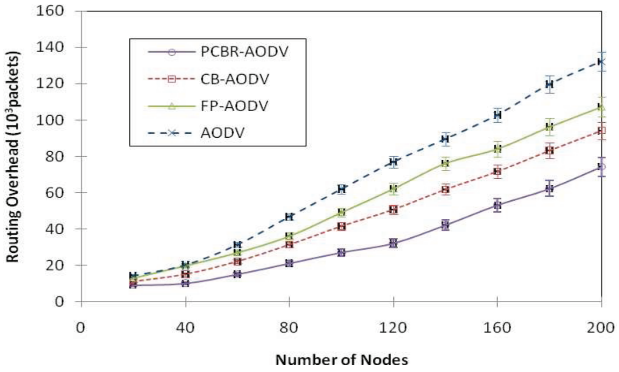

Figure 2. Impact of network density on routing overhead using 5 m/sec node speed and 10 source-destination connections each generating 4 packets/sec traffic loads

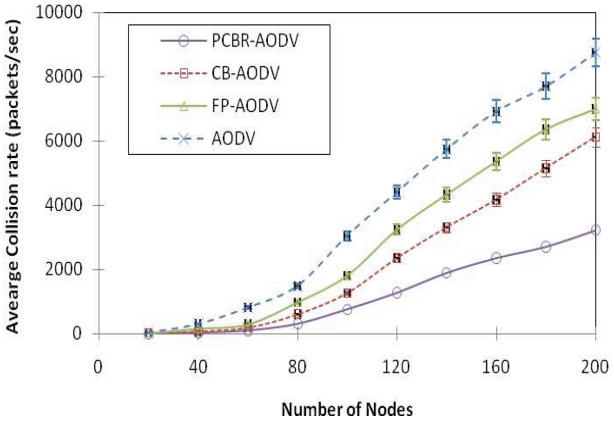

Figure 3. Impact of network density on average collision rate using 5 m/sec node speed and 10 source-destination connections each generating 4 packets/sec traffic loads

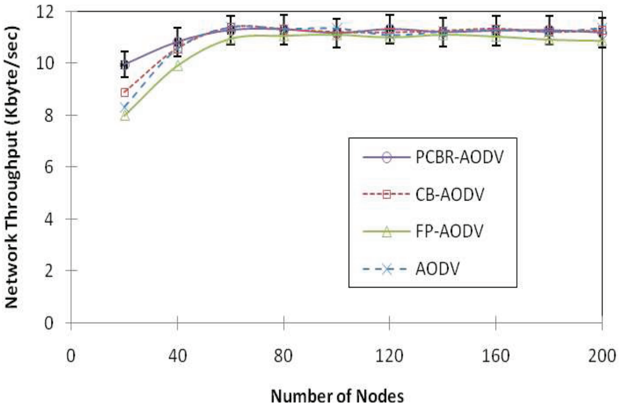

Figure 4. Impact of network density on throughput using 5 m/sec node speed and 10 source-destination connections each generating 4 packets/sec traffic loads.

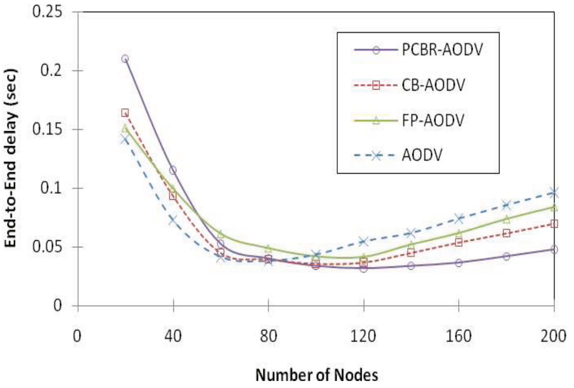

Figure 5. Impact of network density on end-to-end delay using 5 m/sec node speed and 10 source-destination connections each generating 4 packets/sec traffic loads.

6. CONCLUSIONS

This paper has proposed a new probabilistic route discovery method for routing in MANETs, referred to as Probabilistic Counter-based Route discovery (PCBR), which combine the features of counter-based and gossip-based approaches. The paper has evaluated the performance of PCBR using AODV as the base routing protocol, which traditionally uses the blind flooding. Compared against CB-AODV, FP-AODV and AODV, results obtained from the extensive Ns-2 simulations have revealed that our PCBR-AODV generates a much lower routing overhead, especially in dense networks, thus significantly reducing the number of MAC collisions with comparable throughput performance.

As a continuation of this research in the future, it is interesting to further explore the effect of traffic load, mobility and topology size on the performance of the PCBR-AODV route discovery. We also plan to explore the performance of our scheme in other reactive and proactive routing protocols such as DYMO and OLSR.

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