Pro-AODV (Proactive AODV): Simple Modifications to AODV for Proactively Minimizing Congestion in VANETs

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***Abstract*—Vehicular Ad Hoc Networks (VANET) are key to realizing Intelligent Transportation Systems (ITS). Although VANETs belong to the class of Mobile Ad Hoc Networks (MANET), and there are numerous routing protocols for MANETs, none of these protocols are applicable for VANETs. In particular, VANETs are highly dynamic due to high speed mobility of vehicles and traditional routing algorithms for MANETs cannot deal with such dynamicity of network nodes. Several comparative studies have suggested AODV (Ad hoc On-Demand Distance Vector), a well known MANET protocol that is adaptive to dynamic changes in network and makes efficient utilization of network resources, to be the best candidate for dealing with VANETs. However, verbatim adoption of AODV is not an efficient routing solution for VANETs. Recent works therefore proposed various modifications and/or additions to AODV to make it suitable for VANETs. It is particularly important to control congestion in VANETs by efficiently dealing with the AODV "Route Request" (RREQ) packets. In this paper, we propose Pro-AODV (Proactive AODV), a protocol that uses information from the AODV routing table to minimize congestion in VANETs, yet sustains other performance metrics at acceptable levels. The novelty and elegance in Pro-AODV comes from the fact that it does not require the execution of any additional logic, it is sufficient to know only the size of the routing table at each node.**

Keywords—VANET; AODV; congestion; routing protocol; routing table

I. Introduction

The future of Intelligent Transportation Systems (ITS) depends crucially on Vehicular Ad Hoc Networks (VANET) [1]. In these networks vehicles communicate with each other and possibly with roadside infrastructure to provide a long list of applications varying from transit safety to driver assistance and Internet access. This new technology has attracted great attention from ITS designers, governments and private research agencies, standardization bodies, car manufacturers, and university research laboratories world-wide. VANETs are special cases of Mobile Ad Hoc Networks (MANETs). However, the high speed mobility of vehicles in VANETs results in a rapidly and dynamically changing network topology that MANET routing protocols cannot handle without deterioration in performance.

Our focus in this paper is to tackle the problem of minimizing congestion in VANETs. To this end, we adopt and modify a well-known MANET routing protocol called "Ad hoc On-Demand Distance Vector routing (AODV)" [2] and propose a novel probabilistic scheme to minimize rebroadcasting of control packets in the network. We note that there are two classes of routing protocols for VANETs, namely topology-based and geographic-location based [3]. Since geographic-location based protocols rely on additional equipment and services (i.e., GPS device and a server) that may not be equally accessible everywhere and also uses sophisticated algorithmic computations [3], we chose in this paper to maximize our gains from the topology-based protocols. We would also like to mention that our focus here was to improve the state of the art for the more general purpose scenarios where broadcasting is unavoidable, rather than application specific scenarios where unicast or multicast might work [4,5]. Under this setup (i.e., topology based broadcasting), AODV is known to be more advantageous for VANETs than the other protocols, namely OLSR, DSDV, and DSR [6], and hence is the subject of focus in many studies including our present attempt. AODV is intrinsically capable to deal with dynamic changes in network topology – an important aspect that makes AODV attractive for VANETs. However, AODV critically relies on broadcasting RREQ packets to set up communication paths. This characteristic of AODV is particularly problematic for VANETs. Communication paths are highly unstable in VANETs and the round of RREQ broadcasting will supposedly occur much more frequently than in MANETs. Thus, straight forward adoption of AODV for VANETs is likely to cause congestion in the network.

Our key observation is that conventional AODV follows a very trivial congestion control mechanism. Our simulations also reveal that a VANET becomes congested if it is allowed to perform the default (as in MANETs) level of RREQ packet broadcast. Our main concern in this paper is to reduce the congestion of a VANET by controlling RREQ broadcasts. To this end, we propose a simple solution that utilizes the information available in a node's routing table. The essence of our solution is, if the number of routing table entries is below some threshold then we will allow the corresponding node to broadcast, otherwise the node will broadcast the RREQ packet with some *a priori* probability. All information required by our proposed solution are easily available in the AODV routing table at each node. Thus no extra overhead is incurred. Our proposed solution is able to increase the performance of traditional AODV and as well as can also be implemented in VANET.

The rest of this paper is organized as follows. Section II is an overview of the AODV protocol. In Section III, we discuss the other related works that deal with AODV for VANETs. In Section IV, we present our results. Finally, Section V is a conclusion and discussion about future works.

II. Overview of AODV

A. Communication scheme

AODV is a method of routing messages between mobile computers. It allows these mobile computers, or nodes, to pass messages through their neighbors to nodes with which they cannot directly communicate. Figure 1 shows a set up of five nodes on a wireless network. The circles illustrate the range of communication for each node. Because of the limited range, each node can only communicate with the nodes next to it. If node X can communicate with node Y directly, then node Y is considered to be a neighbor of node X. A node keeps track of its neighbors by listening for a HELLO message that each node broadcasts at set intervals.

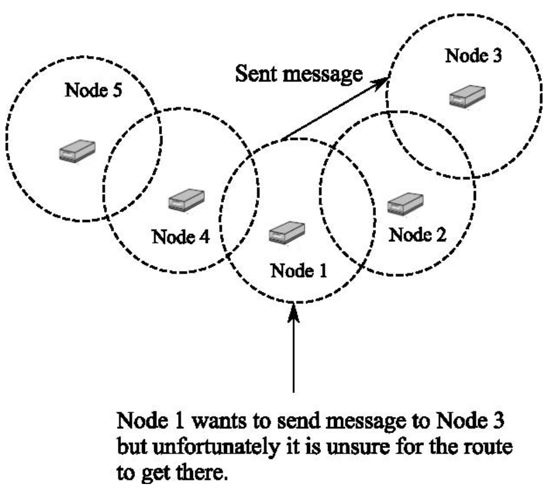

Fig. 1. An illustration of AODV.

When one node needs to send a message to another node that is not its neighbor, it broadcasts a Route Request (RREQ) message. The RREQ message contains several key bits of information: the source, the destination, the lifespan of the message and a Sequence Number which serves as a unique ID.

In the example, as shown in Figure 2, Node 1 wishes to send a message to Node 3. The neighbors of Node 1 are Nodes 2 and 4. Since Node 1 cannot directly communicate with Node 3, Node 1 sends out a RREQ. The RREQ is heard by Node 4 and Node 2.

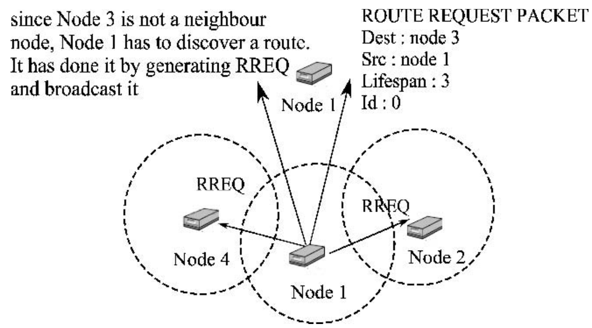

Fig. 2. Sending Route Request (RREQ).

When Node 1's neighbors receive the RREQ message, they can either reply with a Route Reply (RREP) message or rebroadcast the RREQ message to their own set of neighbors. They reply with a RREP message if they are the destination or they know a route to the destination. The message keeps getting rebroadcast until its lifespan is up. If Node 1 does not receive a reply in a set amount of time, it will rebroadcast the request except this time the RREQ message will have a longer lifespan and a new ID number. All of the Nodes use the Sequence Number in the RREQ to insure that they do not rebroadcast a RREQ. In Figure 3, Node 2 has a route to Node 3 and replies to the RREQ by sending out a RREP. Node 4 on the other-hand does not have a route to Node 3 so it rebroadcasts the RREQ.

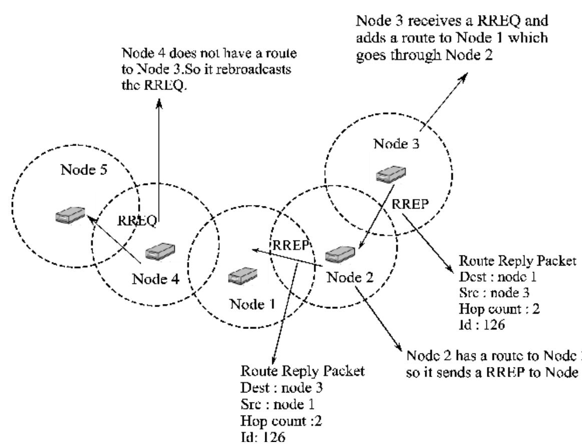

Fig. 3. Sending Route Reply (RREP).

B. Routing table entries

AODV is a routing protocol, and it deals with route table management. Route table information must be kept even for short-lived routes. AODV uses the following fields with each route table entry: (i) Destination IP Address, (ii) Destination Sequence Number, (iii) Valid Destination Sequence Number flag, (iv) Other state and routing flags (e.g., valid, invalid, repairable, being repaired, etc.), (v) Network Interface, (vi) Hop

Count, (vii) Next Hop, (viii) List of Precursors, and (ix) Lifetime.

C. Generating route requests

A node disseminates a RREQ when it determines that it needs a route to a destination and does not have one available. This can happen: (i) if the destination is previously unknown to the node, or (ii) if a previously valid route to the destination expires or is marked as invalid.

III. Related Works

We review here the current literature that modify AODV to optimize its use in VANETs. We note that all the deterministic algorithms proposed to date uses more memory, more computational power, and more information (e.g., about the network topology) than our protocol [7-10]. The probabilistic algorithms, although they come close to ours in spirit, require more memory and global information about the network [11]. We would like to note that, probabilistic approaches to minimizing congestion is not new in the case of MANETs. However, the same protocols cannot be applied for VANETs since the MANET protocols exploit the typically stable topology of MANETs and can afford to infer on global network structure [12] or insert random delays [13,14]. Such assumptions fall apart in VANETs and therefore we deliberately avoid any comparison of our work with the probabilistic protocols proposed for MANETs.

In the paper [7] the authors proposed a routing protocol IAODV (Improved AODV) that ensures giving timely and accurate information to drivers in V2V (vehicle to vehicle) communication compared to AODV protocols in city scenarios of vehicular ad hoc networks. The proposed IAODV protocol is defined as limited source routing up to two hops with backup route between source node and destination node.

AODV and other on-demand routing protocols find their destinations based on the process of flooding a request to neighbors searching for their destinations. In [8], the authors showed that neighbors of nodes are detected based on the neighbor discovery method, which periodically broadcasts HELLO messages to detect available neighbors at time. Generating routing packets and neighbor discovery messages produce high overhead in AODV. In order to overcome such issues, a novel scheme in Ad hoc networks based on Intelligent-AODV (I-AODV) is proposed. This scheme functions to exploit neighbor discovery and reduce the overhead of neighbor discovery processes. I-AODV was integrated with a new process to recognize neighbors while the HELLO timer is not called.

To improve AODV routing protocol in VANET, the authors in [9] make a two-step optimization in route discovery and route selection process to improve the route stability and decrease overhead. The speed information and direction information of vehicle are included for optimization. In the first step, only parts of nodes are selected to forward Route Request (RREQ) packet, and these nodes are chosen because of their stable links with others. At the same time, control overhead is decreased because not all neighbor nodes are used to forward RREQ messages. In the second step, the most stable route will be used for packet transmission when the source node obtains multiple routes to destination node. By the two step optimization, the route selected for transmitting packets is more stable and overhead is decreased.

The paper [10] proposes and evaluates V-AODV, a version of AODV especially created for VANETs. V-AODV is designed to run with a complex cross layered metric based on both delay from node to node and Bit Error Rate (BER) coming from the physical layer.

The paper that comes closest to our work is by Khalaf *et al.* [11], where they proposed a route discovery algorithm called Smart Probabilistic Broad-casting (SPB) that utilizes probabilistic broadcast methods to propagate the RREQ packets in AODV. They used average of node count of the network for adjusting the dynamic value of the probability. However, in this solution each node needs to know the whole network topology to determine its density condition.

We summarize in Table I a comparison between Pro-AODV and the other existing protocols, which highlights the novelty of Pro-AODV.

TABLE I. Comparison between Protocols

Protocol	Additional Requirements beyond core AODV		
	Memory	***Computation***	***Information***
Improved AODV	Yes	Yes	No
Intelligent AODV	Yes	Yes	No
Two-step optimized AODV	Yes	Yes	Yes
V-AODV	No	Yes	Yes
SPB	Yes	Yes	Yes
Pro-AODV	No	Yes (nominal)	No

IV. Results

A. The Pro-AODV Scheme

In Pro-AODV we propose that each node will check the number of entries in its routing table before broadcasting an RREQ packet. If the number of entries in the routing table of node v is N_v, then v will drop the message with a certain probability p if $N_v > \theta$, otherwise v will broadcast the message. The details of computing p is described below.

Suppose nodes u and v are neighbors in a network. Upon receiving a RREQ message, node v computes the probability p using two parameters q and S as $p = min(q \times S, 1)$, where q is the probability that node v shares a neighbor with node u and S is a scaling factor depending on N_v.

Each node u in the network has a communication disc, i.e., the circular area whose radius (also known as the communication radius of u) is equal to the distance up to which u's radio signal is functional. We assume that each node in the network has the same communication radius, r (see Figure 4). For the nodes u and v, we can use the area A overlapping between their communication discs (the grey region in Figure 4) to estimate q as $q = A/_{\pi r^2}$, where we have assumed that neighbors of each node are uniformly distributed within its communication disc. Applying basic geometric arguments, we can deduce that $A = 2\alpha r^2 - \frac{1}{2} d\sqrt{4r^2 - d^2}$, where d is the distance between u and v, and 2α is the angle created at v by the arc between the two intersection points (i.e., x and y) of the two communication discs. In order to simplify the computation of q, we take a conservative step to ignore the exact value of d and assume that $d = r$, in which case A becomes: $\frac{2}{3}\pi r^2 - \frac{\sqrt{3}}{2} r^2$, and hence $q \approx 0.39$. However, as one may appreciate, if positioning information is available the we can also use the exact value of d in this computation and obtain a more accurate estimate of q.

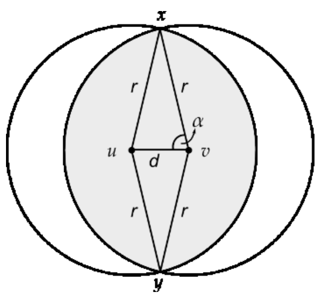

Fig. 4. Computation of the probability p that a node v will drop an RREQ packet received from its neighbor u (see Text for details).

Since q denotes the probability that the two nodes share a neighbor, and is always a constant, we use a scaling factor S to reflect the intuition that if v has more neighbors overall, then v shares more neighbors with u and can expect that some other common neighbor between u and v will rebroadcast this message. In this case v can safely deny to rebroadcast the packet with a probability $> q = 0.39$. Similarly, if v has fewer neighbors overall, then v shares less neighbors with u and it is not safe to assume that some other common neighbor between u and v will rebroadcast this message. In this case the probability that v denies to rebroadcast the packet should be $< q = 0.39$. We use a scaling factor S decided using a sigmoidal function to achieve the above change in q and compute the ultimate probability $p = min(q \times S, 1)$ that v will not rebroadcast the message. In particular, we use $S = \frac{1.5}{1+\exp(-(N_v - \theta))}$, and we chose $\theta = 5$. This means, when v has fewer than 5 neighbors, it will rebroadcast the message with almost certainty, but as its number of neighbors increase, v will start dropping the message.

B. *Probabilistic analysis of Pro-AODV*

We first demonstrate how a threshold-based scheme to forward RREQ packets is useful in ad hoc networks. We are conservative below in considering that every node uses the same probabilistic parameter p to represent the probability that it will broadcast a RREQ packet. To keep the analysis simple, we assume that there are N number of paths between a source and a destination node, and that there are k nodes in each path. Thus that probability that a RREQ packet reaches from the source to the destination along a specific path is given by: $q = p^k$. Hence, the probability P that a RREQ packet will reach from the source to the destination is given by:

$$Nq - \binom{N}{2} q^2 + \binom{N}{3} q^3 - \cdots$$
$$= 1 - (1-q)^N$$
$$= 1 - (1-p^k)^N$$

As shown in Figure 5, for typical values of N and k, this probability P is high and approaches the empirically observed optimal values of packet delivery ratio [15]. However, the N number of paths between the source and the destination need not be independent. In the case of extreme overlap between paths, the probabilistic scheme becomes extremely fragile and $P = p^k$. However, neither the optimal topology of N independent paths nor the worst-case topology of a single path will persist; and the network performance metrics will be intermediate, yet very promising, as we show below.

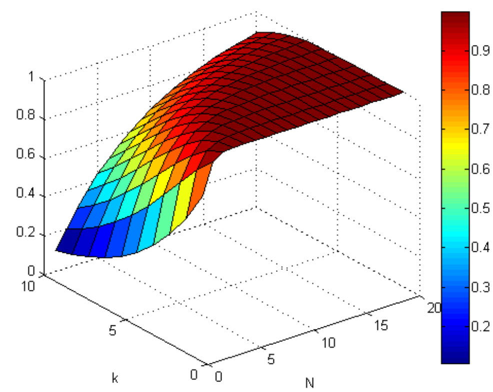

Fig. 5. Probability of successful RREQ transmission (Z-axis) for typical values of N (X-axis) and k (Y-axis). The plot was created with a conservative value of 0.8 for p.

C. *Experimental setup*

In this paper, we evaluated the efficacy of our proposed method through ns-2 simulation [16]. Here, we focused on four different performance metrics. This metrics are average end-to-end delay, control overhead, delivery and drop ratio. We created different scenarios varying the number of nodes. For all the scenarios, we used a fixed coverage area of 1000 X 500 m^2. Besides, we used the realistic Two-Ray Ground reflection model [17] as the radio propagation model. In our simulation each node consisted of a drop-tail priority queue having a maximum 40 packets under the transmission. The nodes utilized Ad hoc On-Demand Distant Vector (AODV) as the network layer protocol for our simulation. Besides, we enabled flows having constant bit data rate over the nodes. Additionally, we used EnergyModel as the energy model. Here, the initial energy level and other energy values are set according to [18]. We performed 30 independent simulation runs and take average over them for achieving near-stable results. Now, we present these results over different scenarios. The name and values of other simulation parameters are summarized in Table II.

TABLE II. SIMULATION PARAMETERS

Parameter	Value	Parameter	Value
Simulation time	200 sec	Coverage area	1000 X 500 m^2
Traffic source	CBR	Mobility model	Random waypoint
Propagation model	Two-ray ground	Energy model	EnergyModel
		Packet Ratio	150 Mpps
Packet size	512 bytes	Pause time	2s
Initial energy	100J	Speed	40 m/s
Transmission range	250 m	Radio bandwidth	54 Mbps
Transmission power	3132 e-3 W	Reception power	3528 e-3 W
Idle power	712 e-6 W	Sleep power	144 e-9W

D. Average delay

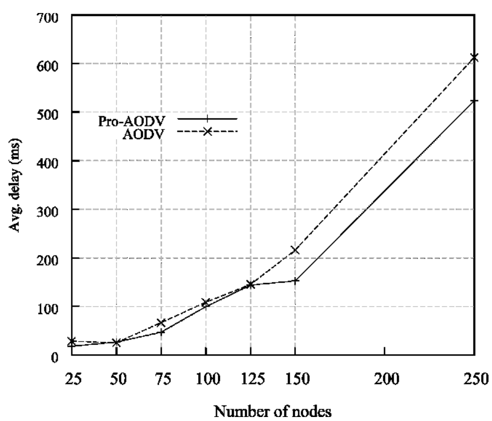

Fig. 6. Average delay vs. number of nodes in Pro-AODV.

Figure 6 illustrates the impact of varying the network size on average end-to-end delay, i.e., the time needed to deliver data from source to destination [19]. Here, the average delay increases with an increase in the number of nodes. Since our proposed Pro-AODV minimizes congestion proactively the average delay reduces compared to traditional AODV. As shown in Figure 6, our proposed solution is remarkably good in bigger network (i.e. when the numbers of nodes are greater than 125).

E. Control overhead

Figure 7 demonstrates the impact of control overhead for the variation in network size. In order to establish a route, traditional AODV deploys 4 types of control messages such as RREQ, RREP, RERR and HELLO messages. During congestion usage of such control messages eventually results more congestion. Therefore, our main concern is to reduce the control messages specifically RREQ control message for congestion control. Since Pro-AODV allows a node to drop RREQ control message with a specific probability p, the overall control overhead reduces to a great extent compared to traditional AODV (Figure 7).

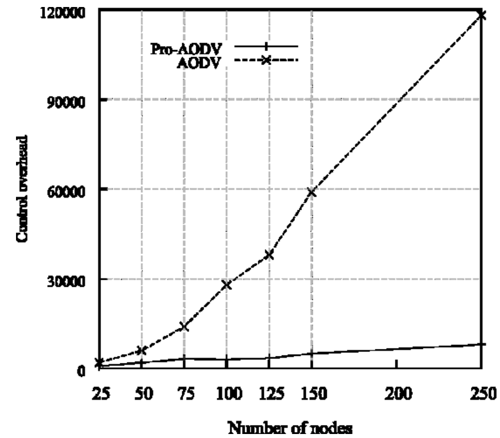

Fig. 7. Control overhead vs. number of nodes in Pro-AODV.

F. Delivery and Drop Ratio

Figures 8 and 9 show the impact of delivery ratio and drop ratio with the variation in network size. Delivery ratio [15] is the ratio between the number of data packets delivered to the destination and the number of packets sent to the destination.

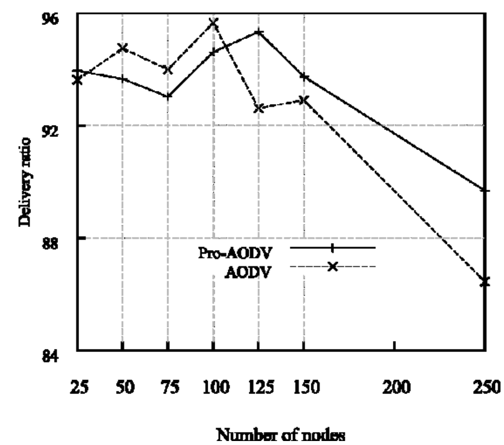

Fig. 8. Delivery ratio vs. number of nodes in Pro-AODV.

In Figure 8 the delivery ratio decreases with an increase in the number of nodes for both traditional AODV and Pro-AODV. However, Figure 8 reveals the overall superiority of the proposed method with respect to AODV.

Drop ratio means the ratio of packets dropped in the network, which is measured as the ratio between the number of packets lost and the number of packets sent [15]. The lower the value of drop ratio, the better is the performance of the protocol. Figure 9 demonstrates the impact of drop ratio with the variation in the network size. Our proposed Pro-AODV exhibits better drop ratio for large number of nodes.

To summarize, our protocol shows improvement in different performances metrics such as average end-to-end delay, control overhead, delivery and drop ratio. Our algorithm can find routes to the destinations avoiding congestion in big networks which contributes toward higher delivery and lower drop ratio of Pro-AODV.

V. Conclusion and Future Works

Our work highlights the general application of simple yet effective ideas in complicated network routing scenarios. VANETs have challenged traditional MANETs in several ways. To date, the response to these challenges have largely been by designing additional algorithmic steps. However, given that VANET topologies change faster than that in the traditional settings, it is legitimate to ask *why should we perform such computation that cannot help us?*

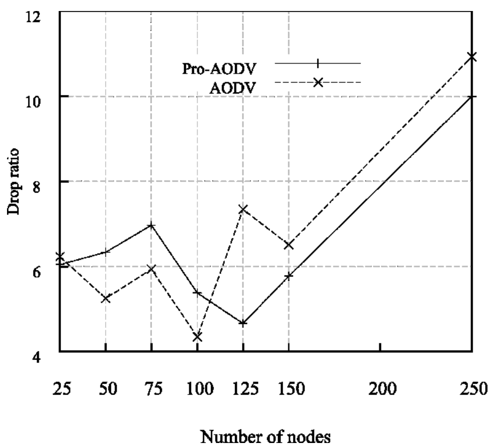

Fig. 9. Drop ratio vs. number of nodes in Pro-AODV.

We demonstrated that by simply utilizing the information available in every node's routing table, one may effectively achieve congestion control in VANETs. The simplicity and effectiveness of our approach makes it worth to discuss several additional mechanisms along the same line. Implementation and comparison of these mechanisms will be subject of our future works.

First, we can make our model parameters adaptive so that each node adapts to suitable parameter values with time. The following scheme can facilitate such adaptation. In general, we can consider schemes that make minimal use of additional memory, as opposed to using additional computing time, in VANET nodes. A node may keep the status of its last *N* responses to RREQ broadcast requests and use this status to decide its response to the next request. Such schemes may avoid the current low sensitivity of Pro-AODV for small-sized networks.

Additionally, the number of routing table entries may be used as the parameter of some probability distribution, say an exponential distribution, to decide the probability with which the node will broadcast a packet.

Finally, when a node decides to broadcast an RREQ request, it may choose to send the request to only a subset of the nodes listed in its routing table. Any of the aforementioned schemes will reduce network congestion, yet presumably will perform better in other metrics.

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