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RAODV: An Entropy-based Congestion Control for the AODV Routing Protocol

Xiaojie Liu, Ulrich Speidel, and Wanqing Tu

Abstract*—In networks, congestion causes packet loss and transmission delays. This paper presents a modified AODV routing protocol to detect and relieve congestion: R-AODV. We add an early congestion detection and avoidance mechanism to the route discovery process to achieve this purpose. In most previous congestion detection schemes, the affected node itself detects whether it is congested or not. The early detection and avoidance algorithm in this paper employs entropy estimation to determine the congestion status of a node's neighbours and establish a less congested route by avoiding the congested nodes. Moreover, R-AODV presents a multipath routing mechanism to support a backup route for the sender nodes. Finally, R-AODV provides a local replacement mechanism for route maintenance to improve the network performance.

***Key words*—R-AODV, congestion, congestion detection and avoidance, congestion status, multipath routes**

I. INTRODUCTION

Ad hoc networks are multi-hop wireless networks. They are composed of wireless nodes, and do not depend on any pre-existing fixed infrastructure. In ad hoc networks, wireless nodes participate in routing and act as routers to forward data for communicating nodes that are outside each other's transmission range. Hence, ad hoc networks can support both peer-to-peer and peer-to-remote communications. Moreover, mobile wireless nodes may frequently join or leave the network, so the ad hoc network topology may change dynamically [1].

Based on these characteristics, ad hoc networks face more challenges than fixed networks or networks with pre-existing structures. One important challenge is network congestion. It is caused by contention for the same finite resource: channel capacity. When congestion occurs, it leads to a higher rate of packet loss, more retransmissions, potentially a slower transmission rate, and reduced goodput and service quality [2]. This further causes connection interruption.

One method to resolve congestion is by applying an ideal routing protocol to find proper routes and efficiently control and relieve any congestion events [3]. This paper focuses on modifying the AODV (Ad hoc On-demand Distance Vector Routing) protocol to achieve this purpose.

Unlike AODV establishes the route based on the shortest hops without taking congestion into account, R-AODV employs a fast congestion detection and avoidance mechanism to avoid potential congestion on a route. R-AODV determines each node's congestion status via entropy estimation by its uncongested neighbour nodes.

Compared to the original single route mechanism of AODV, R-AODV uses a dual-route mechanism to provide a backup route for the communication nodes. So a source node in R-AODV does not need to wait until a new route is found before it can retransmit data if the primary route between source and destination becomes invalid. This improves AODV in terms of fast congestion recovery. Unlike other multipath extensions of AODV, R-AODV does not need to find multiple unnecessary routes for all active nodes. This can conserve the finite network capacity and avoid unnecessary delay.

For route maintenance, AODV has a local repair algorithm to find a new route connecting from the upstream node to the destination node. R-AODV instead first only tries to find a usable uncongested node to replace the problem node or to help to distribute the load of the congested node instead of finding a short new route.

The rest of this paper is structured as follows: Section 2 discusses the previous contributions on the AODV routing protocol modifications; Section 3 introduces the AODV routing protocol as well as its drawbacks for the operation of ad hoc networks; Section 4 presents the mechanism of the proposed modified AODV, R-AODV. This is followed by our conclusion.

II. RELATED WORK

In ad hoc networks, one of the most challenging problems is how to control congestion. Routing protocols are applied to establish an optimal path and offer connectivity link between two communication nodes. Many studies have contributed

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X. Liu is with the Computer Science Department, University of Auckland, Auckland, New Zealand (e-mail: xliu785@aucklanduni.ac.nz).

U. Speidel is with the Computer Science Department, University of Auckland, Auckland, New Zealand (e-mail: ulrich@cs.auckland.ac.nz).

W. Tu is with the Computer Science Department, University of Auckland, Auckland, New Zealand (e-mail: w.tu@auckland.ac.nz).

improved congestion mechanisms on the top of the AODV routing protocol to improve ad hoc network performance.

Kumaran and Sankaranarayanan [4] proposed an early congestion detection and adaptive routing (EDAPR) protocol. EDAPR has a non-congested neighbours list (NHN). It uses this list to find a route from the source node to the destination node. Nodes along the primary route calculate their queue status combined with an optimization of random early detection (RED) to detect any network congestion in advance. Apart from applying the early congestion detection mechanism, EDAPR also finds an alternate non-congested path in order to improve the performance of the network.

The AOMDV (Ad hoc On-demand Multipath Distance Vector) routing protocol is an extension of AODV. It attempts to find loop-free and link-disjoint multiple paths from the source to the destination. Quite a few studies have been presented to further enhance AOMDV. A typical one is the QLB-AOMDV (QoS and Load Balancing-AOMDV) proposed by Tekaya et al. [5]. In order to balance traffic load better with QoS requirements, QLB-AOMDV chooses the less congested routes by computing a metric of nodes' buffer sizes until it reaches the destination. If there is more than one single route, the network traffic is distributed across different active routes. On the other hand, QLB-AOMDV uses network delay and throughput to achieve the QoS requirement in the route discovery process. Each node estimates its link quality with its one-hop neighbours.

Bawa and Banerjee [6] proposed a load balancing mechanism based on AOMDV to deal with the congestion problem. They consider the queue size of each node to monitor the congestion, and choose the best route with the minimum congestion as the primary route and others as the backup routes.

Ali et al. [7] proposed the CAMRLB protocol (Congestion Adaptive Multipath Routing Protocol for Load Balancing) to balance the network load once congestion occurs. This protocol is based on the SMORT protocol (Scalable Multipath On-demand Routing protocol), a multiple route extension of AODV. Compared with AODV, SMORT allows nodes to accept multiple copies of the route request packet in order to obtain multiple routes. However, when the route reply packet is unicast from the destination to the source node, the intermediate nodes just forward the first route reply packet and discard all other additional replies. In CAMRLB, when the average load on the current route is beyond the traffic load threshold or the remaining battery energy or the available bandwidth are below their correspondingly defined thresholds, traffic is distributed across the multiple routes to relieve the congested primary route.

Kaur and Pandey [8] presented a modified AODV (M-AODV) protocol. They considered the metrics of network delay, energy consumption and network lifetime in order to decrease the likelihood of congestion. Among these metrics, the network delay is used to avoid the congested route. M-AODV selects its route based on the network delay in its route request mechanism. After the destination receives the route request packet, it chooses the intended route with the highest path lifetime in its route reply mechanism.

Sharma and Bhadauria [9] introduced a congestion control mechanism by using mobile agents in AODV. They use mobile agents to collect the congestion status of nodes and update the nodes' routing tables with the agents' movement through the whole network. The mobile agent defines the congestion status of a node via computing the combined metrics of both queue length and channel contention when it visits each node.

III. AODV

Routing protocols can be divided into two types: proactive (table-driven) routing protocols and reactive (on-demand) routing protocols [10].

In proactive routing protocols, each node maintains a routing table which contains all routing information. Nodes exchange the routing information with each other and update the routing table when the network topology changes. So when a route is needed, the route may already exist in the routing table.

In reactive (on-demand) routing protocols, a route is set up when it is needed. Nodes do not need to keep all the route information in their routing tables. Only the active nodes keep the routing information. Active nodes are nodes involve in the active communication. Compared to proactive routing protocols, reactive routing protocols have lower overhead, but suffer from higher delay.

The AODV routing protocol is a reactive routing protocol. It performs two processes: route discovery and route maintenance [11].

A. Route Discovery

When the source node wants to send date to the destination node and there is no valid route from the source node to the destination node, the source node will broadcast an RREQ (Route Request) message. The RREQ message carries a source sequence number and a broadcast id. Any neighbour node which receives the RREQ will record the address of the sending node of the RREQ and set up a reverse path to the source. If the neighbour is not the destination node or the neighbour does not have a route to the destination, this neighbour continues to broadcast the RREQ to its own neighbours. Otherwise, the neighbour will return an RREP (Route Reply) message to the source node.

When the RREP message is unicast back by the destination node and intermediate nodes to the source node via the reverse path, a forward path will be set up in these nodes. Nodes will update their routing table entries: the required route has been found.

B. Route Maintenance Process

Each active node updates its local connectivity via periodically broadcasting and receiving "Hello" message. AODV floods RERR (Route Error) message to notify nodes until reach the source node of the failure route. If the destination is close to the problem node, the upstream node of the problem node will choose a local repair process to find another path to the destination. Otherwise the source node will reinitiate the route discovery process when it receives the RERR message.

The whole process of AODV is shown below in Fig.1.

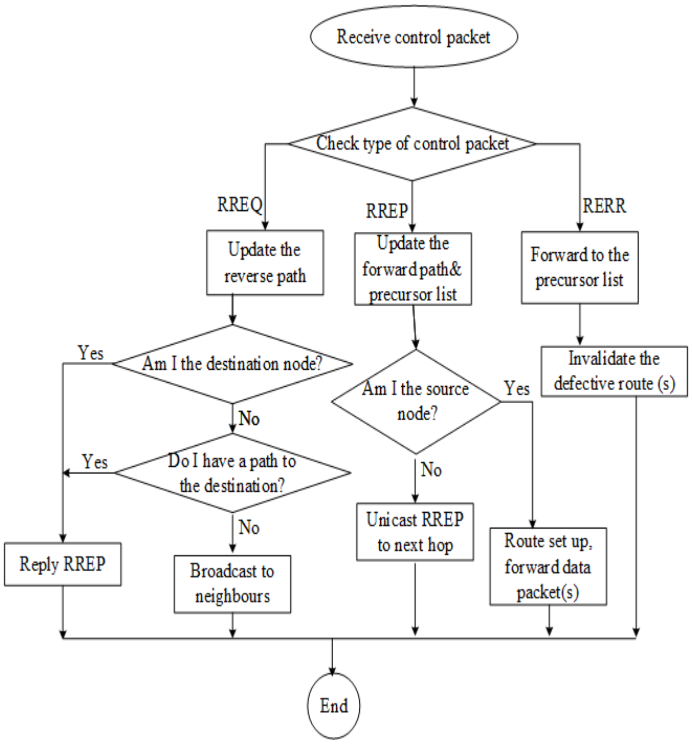

Fig. 1. The entire AODV process: If the control packet is an RREQ, the node updates the reverse path to the source. If the node has a path to the destination or is the destination, it responds with an RREP packet. Otherwise, the node continues to broadcast RREQ packets. If the control packet is an RREP packet, the node updates the forward path as well as its precursor list (where the node stores its neighbours). The route will be set up from the source node to the destination node as the RREP is forwarded to the source node. If the control packet is an RERR (Route Error) packet, the RERR packet will be forwarded to notify other nodes of the failure.

C. *Drawbacks of AODV*

AODV is mainly designed for and used in ad hoc networks. But it still has some disadvantages which motivate our adaptation to better serve ad hoc networks.

1) *Long delay*

In ad hoc networks, mobile nodes may frequently join in or move out of the networks. Moreover, nodes in networks that act as routers to forward packets can cause serious network congestion. When the active route is congested, AODV suffers from a long delay until it can successfully retransmit data.

2) *Congestion control mechanism*

AODV has a simple congestion control mechanism, which is to multiply the next waiting time for an RREP by 2. But based on the characteristics of ad hoc networks, an effective congestion control method is required to smooth the congestion.

IV. AODV MODIFICATION-RAODV

Based on the characteristics of the AODV routing protocol, this paper proposes an extension of AODV, the R-AODV routing protocol. R-AODV is designed to relieve and resolve the congestion problem and shorten the delay that the original AODV needed when the congestion occurs. As far as the processes of the AODV routing protocol are concerned, we modify AODV in the following two phases: route discovery process and route maintenance process.

A. *Route Discovery Process*

Based on the original route discovery process of AODV, we add a congestion early detection and avoidance mechanism in R-AODV. Unlike the AODV just finds the shortest hops of route, by the congestion early detection and avoidance mechanism, once detecting potential congestion nodes, R-AODV re-routes the transmissions via establish an efficient path with less potential congestion to reduce the future recover delay if congestion occurs.

In the congestion early detection and avoidance mechanism, we achieve this purpose via the following two aspects: the node management mechanism and an RREQ broadcasting modification.

1) *Node management mechanism*

R-AODV's node management mechanism first classifies the intermediate nodes into three categories: idle nodes, busy nodes and congested nodes. In this mechanism, we use entropy to classify the congestion status for nodes [12].

The process of the entropy-based congestion detection is: We use a neighbour node which is uncongested to collect the sequence number of TCP packets sent to or via the node under congestion monitoring. The neighbour node concatenates the differences of collected sequence numbers into strings using a sliding window. We then analysed the strings with entropy. Repeating sequence numbers introduce new difference values, which increases the information content of the string. So in a smooth network, the differences represent low entropy [12].

Secondly, R-AODV adds neighbour node management in node management mechanism. Neighbour status is defined and updates through periodically broadcasting Hello messages.

2) *RREQ broadcasting modification*

Unlike AODV's RREQ broadcasting, R-AODV defines a "direction zone". The "direction zone" is the broadcasting direction of the RREQ message. The direction zone is an area within which intermediate nodes will receive the RREQ message and broadcast the RREQ to their neighbours. The zone is considered as the side of a source node which points into the direction of the destination. In this case, the neighbors on the other side do not need to broadcast and receive the RREQ. In this way, R-AODV intends to save the network from overload and relieve the congestion situation of hot intermediate nodes.

In the congestion early detection and avoidance mechanism, idle nodes are chosen with priority for the required route. This is shown in Fig. 2:

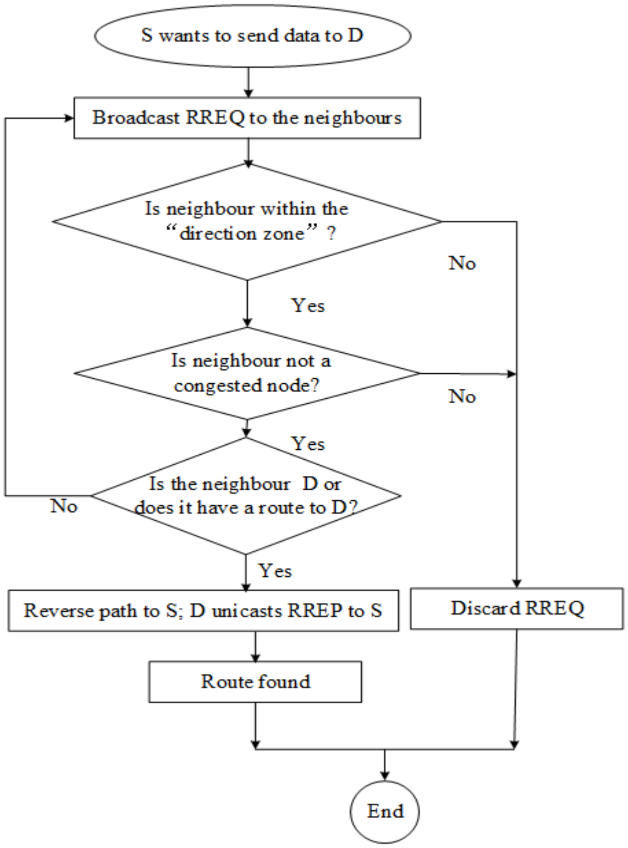

Fig. 2. The route discovery process of R-AODV: When node S wants to find a route to node D, it will first broadcast a RREQ message to its neighbours within the "direction zone". If a neighbour is uncongested and has a valid route to the destination node D or this uncongested neighbour is node D, R-AODV sets the reverse path to node S. Node D then unicasts a RREP packet to node S. The route from node S to node D has been found.

B. *Route Maintenance Process*

In ad hoc networks, link breakage mainly occurs due to mobility or congestion of the intermediate nodes which function as routers. Methods to fix the broken route: locally repairing the current remainder of the route from the problem node to the destination node or find another new proper route from the source to the destination. But these methods can cause high network overload and long delay, further reducing the performance of the network.

In this phase, we modify the AODV routing protocol under the following two aspects: backup route mechanism and local repair modification mechanism.

1) *Backup route mechanism*

In order to improve the network performance, R-AODV has a backup mechanism in the route discovery process. When a route is needed, R-AODV sets up two totally different routes: a primary route and a bypass route. If the primary route develops a problem, the backup/bypass route is used instead.

There is a simple example to explain this mechanism, as shown in Fig.3. If an intermediate node in the primary route is congested, S sends data to D via the bypass route S-> a-> b-> c-> D.

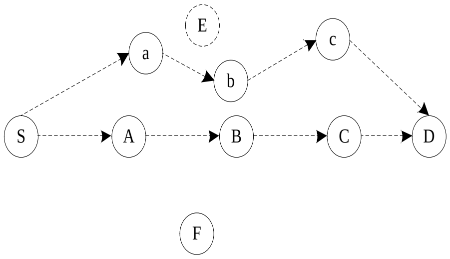

Fig. 3. Two totally different routes are found: Source node S wants to communicate with the target node D. The black arrow shows the primary route from node S to node D is: S-> A->B -> C-> D. The dashed black arrow shows the bypass route from node S to node D is: S-> a-> b-> c-> D.

2) *Local repair modification mechanism*

If there is no other backup route and the node at which the problem occurred (congested or moved from its original position) is within the "reachable zoo" (scheduled in advance) of the destination node, then R-AODV will initiate the local repair modification mechanism. There are two steps in the local repair modification mechanism.

Step 1: R-AODV will first find another suitable node to replace the problem node (or help to release the overload if the problem node is congested).

When the upstream node of the problem node (which is also a neighbour of the problem node) could not receive the Hello message from the problem node within the schedule time, then the upstream node will flood a "Help" message to its neighbours. The destination node in the "Help" message is the downstream node of the problem node. So if the neighbour of the upstream node's neighbour is the downstream node and this neighbour is a uncongested node, then this neighbour will reply with a "Yes" message to both the upstream node and the downstream node. This concludes the successful replacement of the problem node and the routing table will be updated. The process is as shown in Fig.4.

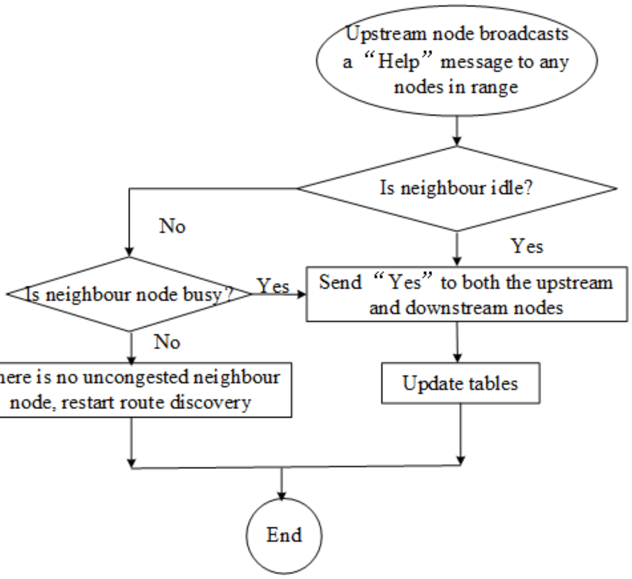

Fig. 4. Local repair mechanism: If there is a neighbour node is able to reply "Yes" to both upstream node and downstream node, then this neighbour node is added into the route to replace the problem node.

Step 2: If there is no suitable node to replace the congested node, then R-AODV will repair the error route locally in the same way as AODV. Otherwise, R-AODV will reinitiate the route discovery process for the source node.

R-AODV remains the original simple multiply-by-2 congestion mechanism of AODV.

C. *Simple Example of the Discovery Process of R-AODV*

Fig.5 is a simple example to show the route discovery process of R-AODV.

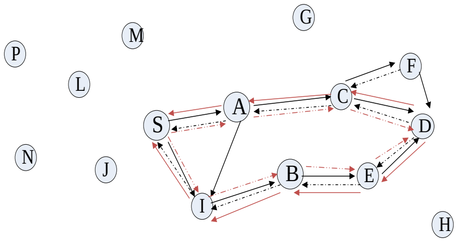

Fig.5. The discovery process of R-AODV: Source node S wants to send data to node D. The black solid arrows show the RREQ broadcasting from node S, until an RREQ reaches node D. The dashed black arrows shows the reverse path during the process of RREQ broadcasting. The solid red arrows are the path of the RREP unicast from node D to node S. The dashed red arrows show the forward path. The primary route from S to node D is S-> A-> C-> D, while the bypass route is S-> I-> B-> E-> D.

Unlike other multipath extensions of AODV, there are just two paths: the primary path and the bypass path. The primary path is first chosen to transmit data which is composed of the least congested nodes with the least delay.

In the R-AODV routing protocol, the RREQ message broadcasts are made in the direction of the side facing the destination node (direction zone). Also, the receiving neighbour node only rebroadcasts RREQ to its neighbours if it is not congested.

The destination node will not discard an RREQ message from S until it receives this RREQ message twice. As a result, R-AODV will set up two totally different proper routes.

V. CONCLUSION AND FUTURE WORK

In networks, congestion not only degrades network performance but also wastes the finite network capacity. Due to the dramatic topology changes and lack of pre-existing fixed infrastructure supports, congestion presents a more serious challenge in ad hoc networks than in wired networks. This paper proposed R-AODV, an extension of AODV, to efficiently control ad hoc network congestion based on entropy calculation.

The route discovery process of R-AODV employs the fast congestion detection and avoidance mechanism to establish a primary route and a backup (bypass) route between the source and destination nodes. These two routes are composed of nodes with low congestion possibility. As for the route maintenance process, instead of searching a new route as other related studies do, R-AODV replaces a congested node with a suitable uncongested node to forward the traffic to the downstream node of this congested node.

In general, R-AODV should perform better in a dense ad hoc network as it relies on the availability of uncongested neighbouring node to support the transmission recovery from congestions. With the R-AODV algorithm, we are currently studying how to accurately define the congestion threshold (used for identifying a node's congested status) by carrying out a set of experimental studies with different parameter settings. The previous contributions, which only roughly defined the congestion threshold, considered the queue size and the available capacity [4-7]. However, R-AODV uses entropy instead. It has the potential to detect congestion in a more timely fashion: It requires fewer resources than other network metrics, such as retransmission rates, as one does not need to keep track of multiple connections [12].

The present paper describes work in progress. We are currently working on the first test simulations in order to confirm that the proposed extended AODV protocol actually works as intended. We are also evaluating the performance of R-AODV against other related solutions via different simulation experiments in ns3. We will compare R-AODV with related studies with respect to the performance metrics of goodput, transmission rate and entropy. Our simulation observations will be reported in a future paper.

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