Title

On Reducing Routing Overhead and Redundancy in Mobile Ad Hoc Networks

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On Reducing Routing Overhead and Redundancy in Mobile Ad Hoc Networks

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Abstract— **The majority of the routing protocols designed to date for mobile ad hoc networks (MANET) rely on flooding of route requests for the establishment of routes on demand. A novel approach called CBORCA (Cut-Based On-demand Routing with Coordinate Awareness) is introduced. CBORCA improves the efficiency with which route requests are disseminated by partitioning the designated route forwarders in distinct quadrants and by selecting at most one "pivot" within each quadrant. Each new pivot is required to pass a distance test before joining the pivot set. Message complexity at each hop is shown to be $O(C) \asymp O(1)$. Experimental results using simulations demonstrate that the performance of CBORCA achieves better results than ORCA (On-demand Routing with Coordinate Awareness) in packet-delivery ratio, signaling overhead, and end-to-end delay.**

I. INTRODUCTION

Mobile ad hoc networks (MANET) have a great potential to provide much needed communication on the move in military and commercial applications. A MANET is self-configuring and is independent of access points (AP); mobile nodes communicate each other directly without requiring centralized management. A MANET node can move at different speeds and with no knowledge of the location of other nodes. Before data can be transmitted between nodes, each source is required to establish a valid route to its destination, and this functionality is supported by the routing protocol running in the MANET.

Many MANET routing protocols have been developed to date, which vary in terms of the mechanisms used to discover and maintain routes to destinations and the way in which they attempt to reduce signaling overhead. Because of the negative effects of multiple access interference [1]–[3], a key design goal of any MANET routing protocol is to limit the amount of signaling overhead incurred in finding and maintaining routes to destinations.

ORCA (On-demand Routing with Coordinate Awareness) [4] implements on-demand routing in MANETs and requires at most six relay nodes to forward a route request (RREQ) sent by a given MANET node, independently of the size or density of the network. This is a dramatic reduction in signaling overhead compared to other MANET routing protocols.

This paper describes CBORCA (Cut-Based On-demand Routing with Coordinate Awareness), which improves the efficiency with which ORCA disseminates route requests.

Section II summarizes prior work on MANET routing protocols related to CBORCA. Section III presents the design of CBORCA, which operates by partitioning the designated route forwarders in distinct quadrants and by selecting at most one "pivot" within each quadrant. Each new pivot is required to pass a distance test before joining the pivot set. The message complexity at each hop is analyzed and shown to be $O(1)$.

Section IV compares the performance of CBORCA against the performance of location aided routing (LAR) [5], AODV [6], and ORCA. The results from the simulation experiments used to study the performance of CBORCA show that CBORCA achieves better results than ORCA (On-demand Routing with Coordinate Awareness) and the other protocols in terms of packet-delivery ratio, signaling overhead, and end-to-end delay.

II. RELATED WORK

Many routing protocols have been proposed to date for MANETs, and the vast majority of them can be characterized as proactive or on-demand methods. Well-known examples of on-demand routing in MANETs are AODV [6] and DSR [7]. In an on-demand routing protocol, a node with traffic to be sent to a destination for which it has no route needs to send a route request (RREQ) to find such a route.

The basic approach for the dissemination of RREQs is intelligent flooding, which consumes considerable bandwidth. Location-Aided Routing (LAR) [5] reduces the signaling overhead incurred in the flooding of RREQs by taking advantage of previously known locations of the destinations. RREQs are directed towards the expected location of the destinations. The limitation of LAR is that the expected geographical information tends to be lost in networks with high mobility, which induces much longer end-to-end delays.

Dircast [8] was developed to attain much lower routing overhead. The operation of Dircast is such that a node selects at most four relay nodes to forward a RREQ by computing the shortest distances from neighbors to boundary vertices of the network terrain, given that each node knows its own geographical coordinates and the geometry of the terrain. The disadvantage of Dircast is that, in certain scenarios, some peer relay nodes are also neighbors. When they are too close each other, their flooding of RREQ packet may lead to a larger overlapping area which is unnecessary. For other nodes, which are far away from them, may stay idle without being properly used to forward RREQ.

ORCA [4] was developed to address the limitations of LAR and Dircast. ORCA uses geographical coordinates to attain efficient route signaling while ensuring full coverage of all MANET nodes by a RREQ. A node using ORCA selects at most six forwarders at each hop. ORCA computes the Euclidean distances between its one-hop neighbors and the four polars. The neighbors with the shortest distances are elected as relay nodes. Besides this, supplemental relay nodes are added to fully cover all nodes in the neighborhood. The remaining limitation in ORCA is that it selects more relay nodes than actually needed. The work presented in this paper improves the selection process used in ORCA by chopping the unused relay nodes from the preselected relay set $R(u)$ by ORCA.

III. CBORCA PROTOCOL DESIGN

The problem addressed in CBORCA can be formulated as follows:
Given: a preselected relay set $R(u)$ of node u.
Find: $P(u)$ such that $|P(u)| = min(|R(u)|)$.

$P(u)$ denotes the pivot set of node u, which is a refined subset of $R(u)$. Each member of $P(u)$ handles the dissemination of RREQ to neighbors and iterates the selection process of new pivots for next hop. For future reference, the following assumptions are made and Table I summarizes the nomenclature used to describe CBORCA.

- Each node has a unique node identifier
- Each node has a unique geographical location
- Each node has the same transmission range r
- Each node is equipped with GPS [9]
- Nodes share a single half duplex channel

TABLE I
CBORCA NOTATION

u	a node
r	Transmission range
(x_u, y_u)	Coordinates of u
$d(u_1, u_2)$	Distance between u_1 and u_2
$R(u)$	Set of one-hop relay nodes of u
$P(u)$	Set of 1-hop pivots of u
$\|P(u)\|$	The cardinality of $P(u)$

For the purpose of well cutting the redundant route requests (RREQ), CBORCA simply builds a set of refined pivots as relay nodes instead of selecting of at most six neighbors as next hop forwarders at each hop implemented by ORCA. For instance, Figure 1 shows the preselected relay set $R(u) = \{u_1, u_2, u_3, u_4, u_5, u_6\}$ of node u in ORCA, given any node having its own geographical coordinates. Furthermore, the source does not know the geographical coordinates of the destination. The weakness of taking $R(u)$ is that six relay nodes are more than needed in most networks. Our proposed refinement in CBORCA choses only one pivot in each quadrant to relay a RREQ, so that totally four relay nodes at each hop alleviate control overhead in routing process. This pivot selection process is iterated by the next hop, until either a route to the intended destination is found or source needs to restart new routing. The mechanism is that the neighbor is elected as a new pivot only if it has the greater distances to all other pivots than transmission range r, otherwise the neighbor is eliminated, which efficiently improves the bandwidth for data transmission.

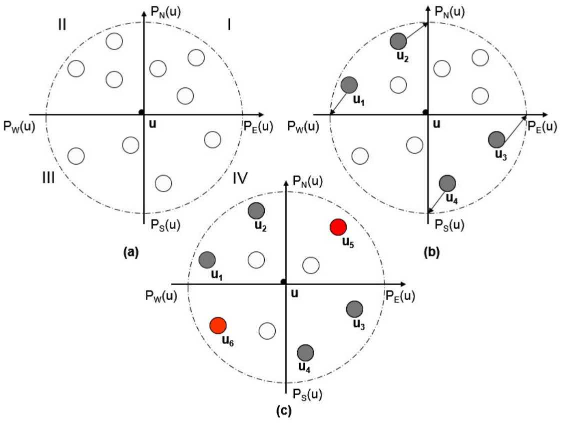

Fig. 1. $R(u) = \{u_1, u_2, u_3, u_4, u_5, u_6\}$

A. CBORCA Mechanism

The basic idea of CBORCA is to drop the redundant relay nodes from $R(u)$ and build a new refined pivot set to broadcast RREQ, so that the major advantage behind this approach is to limit the number of routing messages, thereby reducing the network overhead. We propose an efficient method that can accomplish the RREQ dissemination while ensuring less control signaling.

Every node broadcasts local Hello messages periodically to establish its connectivity with neighbors. If a node has not received Hello message from neighbors within TIMEOUT period, then the link between the node and the neighbor might be broken due to a variety of reasons. Hello messages contain its node identifier and 2D geographical coordinates. Over time, each node gets the geographical locations of its one-hop neighbors.

When a source u has data to send to an intended destination for which it does not have a valid route, it proceeds with a route discovery process similar to most on-demand routing protocols. Node u broadcasts a RREQ to its neighbors in order to establish a valid route to the destination. As in prior on-demand routing protocols, the RREQ specifies the source, the intended destination, and a sequence number used to prevent replicas of the RREQ to be transmitted. For ORCA, the RREQ specifies the aforementioned fields and also embeds the nominated relay set $R(u)$ for broadcasting the RREQ for next hop. For CBORCA, the RREQ contains the same contents as ORCA. The only difference between ORCA and CBORCA is that CBORCA chops the redundant relay nodes operated by ORCA, to generate a new set of pivots, which are eligible to relay the RREQ to its successors, until destination or the node knowing destination is reached. The same mechanisms used in prior on-demand routing protocols for the processing of RREQ apply to CBORCA. Any node receiving the RREQ may send a route reply (RREP) if it has a valid route to the destination.

To well design the protocol, we define the uniqueness of pivots in each quadrant. At most one pivot in each quadrant is selected by its predecessor, acting as the only relay node to forward RREQ in the quadrant where the pivot is located, shown in Figure 5. Furthermore, the distances of peer pivots are required to be greater than transmission range r. For instance, before a new pivot joins $P(u)$, it must pass the distance test, which has the distances greater than r to all existing members of $P(u)$.

The selection of pivots follows the following steps:

Let $R'(u) = R(u), P(u) = \emptyset$

1) If $\exists v \in R'(u)$, then $\begin{cases} P(u) = P(u) \cup \{v\} \\ R'(u) = R'(u) - \{v\} \end{cases}$

2) If $\begin{cases} \exists v_i \in R'(u), \exists u_j \in P(u) \\ d(v_i, u_j) > r \end{cases}$ for $\forall j, 1 \leq j \leq |P(u)|$, then $\begin{cases} P(u) = P(u) \cup \{v_i\} \\ R'(u) = R'(u) - \{v_i\} \end{cases}$

Else if $\begin{cases} \exists v_i \in R'(u), \exists u_k \in P(u) \\ d(v_i, u_k) < r \end{cases}$ then $R'(u) = R'(u) - \{v_i\}$

3) Iterates Step (2) $\forall i, 1 \leq i \leq |R'(u)|$, until $R'(u) = \emptyset$

If a node detects a link break for the next hop of an active route, or it receives a RERR from a neighbor for one or more active routes, it initiates processing for a RERR message. If destination or the node having active route to destination is traversed, it responds to RREQ by unicasting RREP to the next hop in reverse path toward to source until source is reached. Once a valid route is established, data transmission will be initiated and proceeded.

B. Example

Let us take an example to implement the selection process of pivot set $P(u)$.

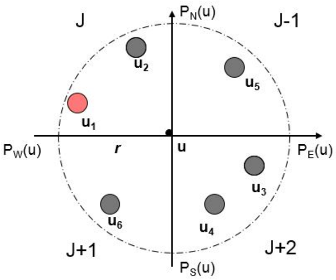

Fig. 2. $P(u) = \{u_1\}$

Given $R(u) = \{u_1, u_2, u_3, u_4, u_5, u_6\}$, let $R'(u) = R(u)$, $P(u) = \emptyset$,

1) Select arbitrarily $u_1 \in R'(u)$: $\begin{cases} P(u) = \{u_1\} \\ R'(u) = \{u_2, u_3, u_4, u_5, u_6\} \end{cases}$

2) Compute $d(u_2, u_1) = \sqrt{(x_{u_2} - x_{u_1})^2 + (y_{u_2} - y_{u_1})^2} < r$, thus u_2 is eliminated: $\begin{cases} P(u) = \{u_1\} \\ R'(u) = \{u_3, u_4, u_5, , u_6\} \end{cases}$

3) Iterates step 2), shown in Figure $3, 4, 5$:

Compute $d(u_6, u_1) > r$, thus $\begin{cases} P(u) = \{u_1, u_6\} \\ R'(u) = \{u_3, u_4, u_5\} \end{cases}$

Compute $\begin{cases} d(u_5, u_1) > r \\ d(u_5, u_6) > r \end{cases}$, thus $\begin{cases} P(u) = \{u_1, u_6, u_5\} \\ R'(u) = \{u_3, u_4\} \end{cases}$

Compute $\begin{cases} d(u_4, u_1) > r \\ d(u_4, u_6) > r \\ d(u_4, u_5) > r \end{cases}$,

thus $\begin{cases} P(u) = \{u_1, u_6, u_5, u_4\} \\ R'(u) = \{u_3\} \end{cases}$

Compute $d(u_3, u_4) < r$ and $u_4 \in P(u)$, so u_3 is eliminated, $R'(u) = \emptyset$. The selected pivot set is: $P(u) = \{u_1, u_6, u_5, u_4\}$.

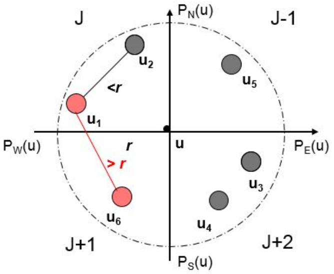

Fig. 3. $P(u) = \{u_1, u_6\}$

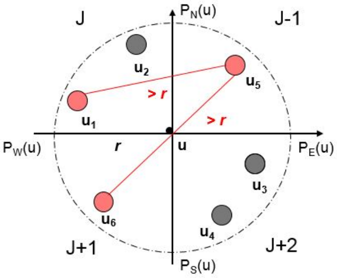

Fig. 4. $P(u) = \{u_1, u_6, u_5\}$

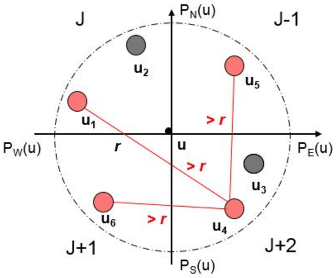

Fig. 5. $P(u) = \{u_1, u_6, u_5, u_4\}$

The pseudo code for the selection of pivots is presented below.

Algorithm III.1: SELECT PIVOTS OF NODE(u)

```
$R'(u) \leftarrow R(u)$
$P(u) \leftarrow \{\emptyset\}$
SELECTP($u$)
procedure SELECTP($u$)
  $k \leftarrow random(|R'(u)|)$
  $P(u) \leftarrow P(u) + \{v_k\}$
  $R'(u) \leftarrow R'(u) - \{v_k\}$
  for $i \leftarrow 1$ to $|R'(u)|$
    do
      for $j \leftarrow 1$ to $|P(u)|$
        do
          if $d(v_i, u_j) < r$
            then
              $R'(u) \leftarrow R'(u) - \{v_i\}$
              $j \leftarrow |P(u)| - 1$
              $break$
      if $j = |P(u)|$
        then
          $P(u) \leftarrow P(u) + \{v_i\}$
          $R'(u) \leftarrow R'(u) - \{v_i\}$

output ($P(u)$)
```

C. Message Complexity

We analyze how message complexity of CBORCA scheme is asymptotic to $O(1)$, using the nomenclature in Table I.

Given an undirected graph $G = (N, E)$, where N is the set of network nodes and E is the set of edges. The plane is divided into four quadrants by the reference axis in a Cartesian coordinate system, denoted by j in Figure 2.

Based on CBORCA definition, the maximum number of pivots in any one quadrant is at most one. It is straightforward to prove that:

$$|P(u)| = \sum_{j=1}^{4} |P^j(u)| \leq 4$$

$$O(|P(u)|) = O(C) \asymp O(1)$$

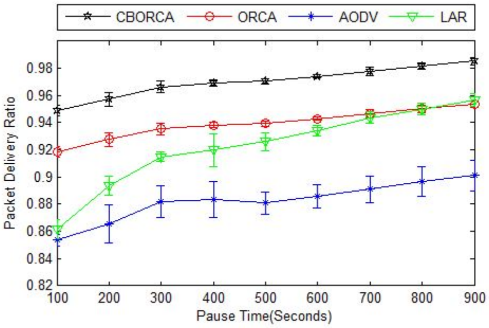

Fig. 6. Packet Delivery Ratio (200 nodes 200 flows)

IV. PERFORMANCE EVALUATION

We conducted discrete-event simulations in Qualnet [10] to compare CBORCA with AODV, LAR, and ORCA.

The experiments run for nine random seeds. In the simulations, the terrain size is set to be a rectangular-shaped area of 1200x300 m^2 and 1500x400 m^2 for total nodes as 200 and 250 respectively. The nodes move with the speed randomly chosen between 1m/s and 20m/s according to the random waypoint (RWP) mobility model. The simulation time is 900 seconds. The pause time in the X-axis represents the duration of all moving nodes temporarily stop the movement and maintain static for different number of seconds, varying from 100 seconds to 900 seconds by increments of 100 seconds for each test. When pause time increases, the networks tends to be more static and less moving.

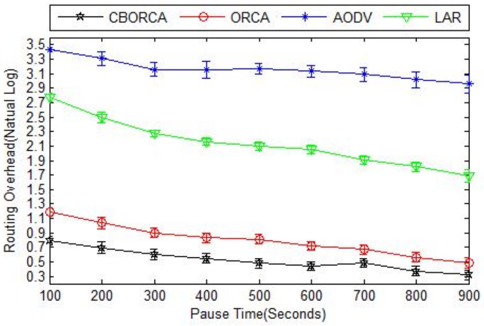

Fig. 7. Routing Overhead (200 nodes 200 flows)

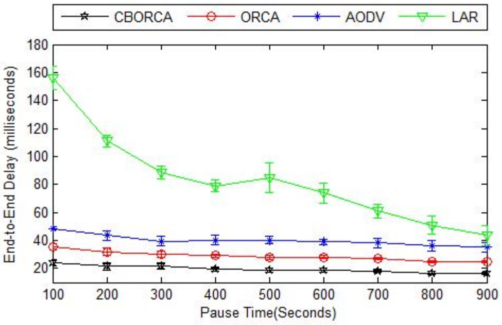

Fig. 8. End-to-End Delay (200 nodes 200 flows)

Data transmissions are generated by constant bit rate (CBR) sources, and the flow durations are exponentially distributed with a mean value of 100 seconds. The number of flows is equal to 30 and 40 percent of the total number of nodes. Four data packets of 512 bytes are generated each second. We use the two-ray signal propagation model, which is common for open-space scenarios. At the physical layer, we use the IEEE 802.11 protocol operating with a data transmission rate of 2Mbps and transmission range of $250m$. At the MAC layer, we use the IEEE 802.11 DCF protocol. Finally, at the transport layer, we use the UDP protocol. The collected data show the 95% confidence interval of the mean value.

Three performance metrics are measured in our paper. *Packet Delivery Ratio* is the ratio of the total number of received data packets by all destination sides to the total number of the transmitted packets by all source sides. *Routing Overhead* is the ratio of the total number of routing messages to good received data packets, which implies the average network routing load per good data packet. *End-to-End Delay* is the average latency including routing, data transmission and retransmission per good received data packet. As shown in Figure 6 and Figure 9, CBORCA attains better data packets transmission rate than ORCA, AODV and LAR as pause times increase. This result proves that more data bandwidth is saved with CBORCA after the removal of redundant relay nodes. LAR transmits data faster, because LAR tracks the estimated zone of destinations. When pause time is 900 seconds, the network tends to be static, and LAR processes routing more efficiently.

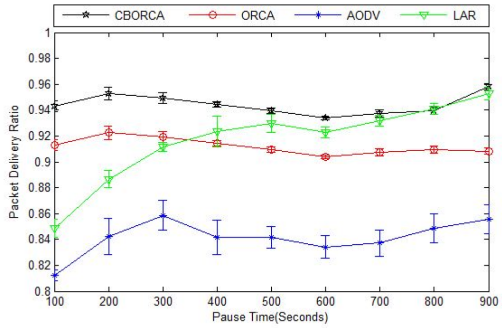

Fig. 9. Packet Delivery Ratio (250 nodes 100 flows)

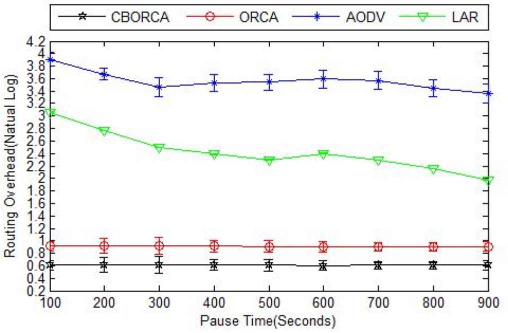

Fig. 10. Routing Overhead (250 nodes 100 flows)

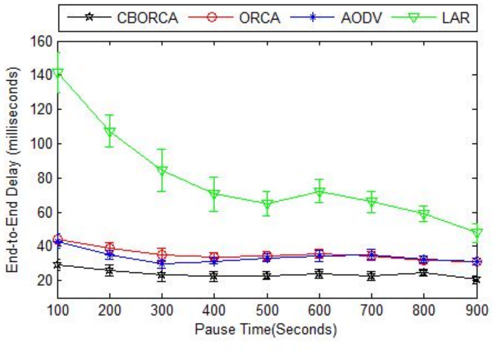

Fig. 11. End-to-End Delay (250 nodes 100 flows)

As shown in Figure 7 and Figure 10, CBORCA is very stable in both scenarios and provides the lowest routing overhead. AODV shows the worst performance because AODV must incur more efforts in locating the intended destinations. ORCA performs better than AODV but worse than CBORCA because ORCA elects at most six relay nodes at each hop and still makes use of redundant relay nodes than practically demanded. Therefore, CBORCA achieves a minimal number of pivots to forward RREQs.

As shown in Figures 8 and 11, CBORCA attains the shortest end-to-end delays in both scenarios than other protocols because all peer pivots are chosen from the distinct quadrants which extend routing discovery to the greater area through the network, compared to ORCA. Beyond that, the lower routing overhead of CBORCA results in better bandwidth for data transmission, so that leads to the shorter queuing delay.

V. ACKNOWLEDGMENTS

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VI. CONCLUSION

This paper presents CBORCA, a refinement algorithm of an existing routing protocol ORCA. The refinement eliminates redundant relay nodes while maintaining higher data packet delivery rate and lower routing overhead . CBORCA take the preselected relay set $R(u)$ used ORCA, which has been proved efficiently covering all nodes in the connected network, and chops the redundant relay nodes by a distance test. As a result, routing overhead is further reduced and data transmission is granted more bandwidth. Simulation results show that CBORCA outperforms ORCA, AODV, and LAR in terms of packet delivery ratio and routing overhead.

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