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Using Geographical Coordinates To Attain Efficient Route Signaling in Ad Hoc Networks

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***Abstract*— Flooding of route requests or link states is a necessity in many routing protocols for mobile ad hoc networks (MANET), and several mechanisms have been devised to make flooding more efficient; however, all flooding approaches to date are such that the number of neighbors each node must use to relay a flooded packet grows as the node density increases. A new method, called ORCA (On-demand Routing with Coordinates Awareness) is introduced for the dissemination of route requests in MANETs. The selection of relaying nodes at each node in ORCA is done by computing the shortest Euclidean Distance from all neighbors of the node to four polar points located in the transmission range of the node. We prove that ORCA guarantees the coverage of all nodes in a connected MANET, and that the number of relays for each node is at most six. ORCA is compared with representative routing protocols, namely AODV, OLSR, LAR, and THP. The simulation results in networks of 200 and 250 nodes show that ORCA incurs the smallest routing load while attaining average delays and packet delivery ratios that are comparable to or better than those obtained with the other four routing protocols.**

I. Introduction

Proactive routing protocols (e.g., OLSR) require that all network nodes receive signaling packets with updates to the state of links of distances to destinations, so that correct routes to destinations can be established at each node. On the other hand, on-demand routing protocols (e.g., AODV, DSR) require that route requests reach all nodes in the network, so that it can be ensured that either the destination or a relay with a route to it answers a given route request. Consequently, flooding or network-wide dissemination of signaling packets constitutes an integral component of many routing protocols designed for mobile ad hoc networks (MANET), and it could be argued that any solution to the routing problem in MANETs requires some signaling packets to traverse the entire network, even if this involves changing the content of the signaling packets on a hop by hop basis.

Section II summarizes the prior work aimed at making the flooding or network-wide dissemination of route signaling packets more efficient. What is most interesting about this prior work is that the number of neighbors forwarding the signaling packets transmitted by a given node increases as the size of the node neighborhood increases. Hence, the number of neighbors that must relay signaling packets for any given node is $O(|\mathcal{N}(j)|)$ where $|\mathcal{N}(j)|$ is the cardinality of the set of neighbors of a node j.

We introduce ORCA (On-demand Routing with Coordinate Awareness), the first approach to routing for MANETs in which the number of neighbors needed to disseminate signaling packets for any given node has complexity $O(1)$ with respect to the density of the network. Section III presents the design of ORCA. ORCA assumes that each node knows its own geographical coordinates, and each node communicates its identifier and geographical coordinates to its neighbors periodically, and hence learns the geographical locations of all its own neighbors. A node determines its polar relay neighbors, which are those neighbors that are closest to the four polar points (North, South, East, West) within the transmission range of the node. The node also adds secondary relay neighbors as needed, such that its four polar quadrants are covered. When a node relays a route request, it asks its relay neighbors to forward the route request if they do not have a route to the intended destination.

Section IV shows that ORCA requires at most six neighbors of a node to forward a signaling packet intended to reach all network nodes. To the best of our knowledge, ORCA is the first approach that attains a forwarding complexity of $O(1)$ with respect to the number of neighbors of a node for complete coverage of the network. Section V presents the results of simulation experiments based on MANETs of 200 and 250 nodes used to compare ORCA with AODV, OLSR, LAR, and

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THP. The results of the simulations show that ORCA incurs the smallest routing load among all protocols while attaining average delays and packet delivery ratios that are comparable to or better than those obtained with the other four routing protocols. Section VI presents our conclusions.

II. Related Work

Many approaches have been proposed and implemented to reduce routing overhead in wireless networks. The prior work includes hierarchical routing, substituting flooding of signaling packets with depth-first search mechanisms, targeting the dissemination of signaling packets based on known prior locations of destinations, and reducing the number of nodes that must ensure that signaling packets reach all nodes.

Many hierarchical routing approaches have been proposed in the past (e.g., [1–4]). With hierarchical routing, groups of destinations are aggregated into clusters or other structures in a way that the number of entities for which routing-table entries must be maintained is reduced. However, the use of routing hierarchies still requires the dissemination of signaling packets within clusters or areas and across clusters of areas for those entities for which routing-table entries are maintained . As such, it is an orthogonal topic to the reduction of signaling packets for a given set of destinations. Furthermore, additional signaling is needed to update the affiliation of nodes to clusters or zones when nodes move away from their home clusters or clusters are partitioned into two or more components due to mobility.

There have been only a few attempts to solve the problems incurred with flooding by using depth first search (DFS) instead of breadth first search (BFS) or flooding. These approaches have focused on the use of *random walks* [5], [6] in which a route request starts at the source and travels along a single path found by consecutive random next-hop choices in search for the destination. The limitation of this prior work is that the communication complexity incurred in reaching destinations when packets have to traverse random walks may be comparable to that of flooding, but with much longer delays.

Approaches based on DFS and BFS that have improved over random walks in the past use geo-location information for the routing of packets. Starting with the first proposals on geographical routing (e.g., Greedy Perimeter Stateless Routing (GPSR) [7]), they have assumed that the sources know the geographical coordinates of the destinations, or at least regions where the destinations may be located. Cartesian Routing [8] uses latitude and longitude address to determine the position of route relative to that of the destination. GeoGRID is an extension of GRID [9] in which a forwarding zone is composed of multiple two-dimensional logical grids. Two types of GeoGRID are proposed; a flooding-based GeoGRID restricts the gateway nodes within forwarding zone to forward the geocast packets, and a ticket-based GeoGRID restricts the gateways nodes to be only those holding tickets evenly distributed by the source to rebroadcast the geocast packets. GeoTORA [10] is an extension of TORA that floods geocast packets to a geocast group. In Distance Routing Effect Algorithm for Mobility (DREAM) [11], each node periodically broadcasts location information about its own position to maintains routing tables and uses this information to transmit data packets.

Many approaches have been proposed that take advantage of knowledge regarding the geographical locations of destinations to make route signaling more efficient. Location-Aided Routing (LAR) [12] and GeoCast [13] are two examples of this approach. In particular, in LAR, after a source finds the geo-location of a destination by means of the flooding of a route request without any sense of direction, the source or relays are able to direct subsequent route requests towards the previously known location of the destination. Location-Based Multicast (LBM) protocol [14] reduces flooding by using an extension of LAR; a node can forward a packet to a forwarding zone, or to the nodes within a distance to the center of a geocast region. It is important to note that, as the density of the network increases (i.e., the average number of nodes in the neighborhood of any one node), the number of nodes that must relay signaling information with or without a sense of direction increases.

Several approaches have been proposed and implemented attempting to reduce the number of nodes that need to relay signaling packets in a network while still ensuring that all network nodes are able to receive such packets. These approaches (e.g., [15–18]) use different algorithms that in essence establish connected dominating sets dynamically. OLSR [19] is arguably the best known example of this approach. The strength of these schemes is that they succeed in reducing the number of nodes that must relay signaling packets in a MANET. However, the number of relays that must forward a signaling packet transmitted by a given node grows with the density of the network.

The main observation that can be derived from this

TABLE I

NOTATION

u	Node u
r	Transmission radius
i	Direction Set, $i \in \{E, S, W, N\}$
j	Quadrant Set, $j \in \{I, II, III, IV\}$
(x_u, y_u)	Coordinates of u
$d(u_1, u_2)$	Distance between nodes u_1 and u_2
$P_i(u)$	Polar point of u, $i \in \{N, E, S, W\}$
r_i, r_+	$r_i \in \{r_E, r_S, r_W, r_N\}, r_+ \in \{r^+, r^{++}\}$
$C(u)$	Coverage Set of u
$\mathcal{N}_k^j(u)$	k-hop Neighbor Set of u in quadrant j
$\mathcal{N}_k(u)$	$\mathcal{N}_k^I(u) \cup \mathcal{N}_k^{II}(u) \cup \mathcal{N}_k^{III}(u) \cup \mathcal{N}_k^{IV}(u)$
$n^k(u)$	Node identifier of kth neighbor in a list of neighbors at node u lexicographically ordered
$\|\mathcal{N}_k(u)\|$	The cardinality of set $\mathcal{N}_k(u)$
$R_k^j(u)$	k-hop Relay Set of u in quadrant j
$R_k(u)$	The set of relays k hops away from node u
$\|R_k(u)\|$	The cardinality of set $R_k(u)$

brief summary of prior work is that in *all* these prior schemes the number of nodes that must relay signaling packets must increase as the density of the network increases.

III. ORCA

The operation of ORCA makes the following assumptions: (a) all nodes have the same transmission range r, (b) nodes are half duplex and share a single broadcast channel, (c) the MANET in which ORCA operates is connected, (d) each node knows its own geographical location and has a unique node identifier, and (e) no two nodes have the exact same geographical location. Table I summarizes the nomenclature we use in the description of ORCA.

The goal of ORCA is to attain full coverage of all nodes in the MANET while requiring only a constant number of neighbors to forward a signaling packet transmitted by any one node, independently of the total number of one-hop neighbors that the node may have. ORCA consists of two main components, the selection of relays by each node, and the propagation of signaling packets by such relays.

A. Selecting Relay Nodes

Each node u transmits a HELLO message to all its neighbors periodically stating its own identifier and geographical coordinates. As a result of HELLO transmissions among nodes, a node learns the identifiers and geographical coordinates of all its one-hop neighbors, the set of which we denote by $\mathcal{N}(u)$. Based on its own location and transmission radius, a given node defines four polar positions for the four main directions on the plane (i.e., *North, East, South* and *West*). Node u selects a subset of its one-hop neighbors as relays of its signaling packets based on this information.

Although the geographical location information available at nodes through such systems as GPS may not be very granular, this does not impede the correct operation of ORCA. ORCA uses the geographical coordinates of its neighbors solely to select which subset of them should serve as relays, not to determine any sense of direction for signaling packets. Hence, given that the transmission ranges of nodes are typically much larger than the errors that such systems as GPS may induce in the actual location of nodes, ORCA is likely to select the right number of neighbors as relay, even if the geographical coordinates of some of them may not reflect their exact location.

First, node u computes its set of polar points $\{P_N(u), P_E(u), P_S(u), P_W(u)\}$. The coordinates of each polar point is given by the coordinates of node u and the length of its transmission radius r. Given the coordinates (x_u, y_u), the coordinates of a given polar point $P_i(u)$, where $i \in \{N, E, S, W\}$, equal $P_i(u) = (x_u, y_u) + e_i$ where $e_N = (0, r)$, $e_E = (r, 0)$, $e_S = (0, -r)$, and $e_W = (-r, 0)$. Fig. 1 helps explain the computation of relays in ORCA; Fig. 1(a) shows the polar points for node u.

For each polar point $P_i(u)$ with $i \in \{N, E, S, W\}$, node u selects a polar relay node, denoted by r_i with $i \in \{N, E, S, W\}$, from its neighbor set $\mathcal{N}(u)$. A neighbor

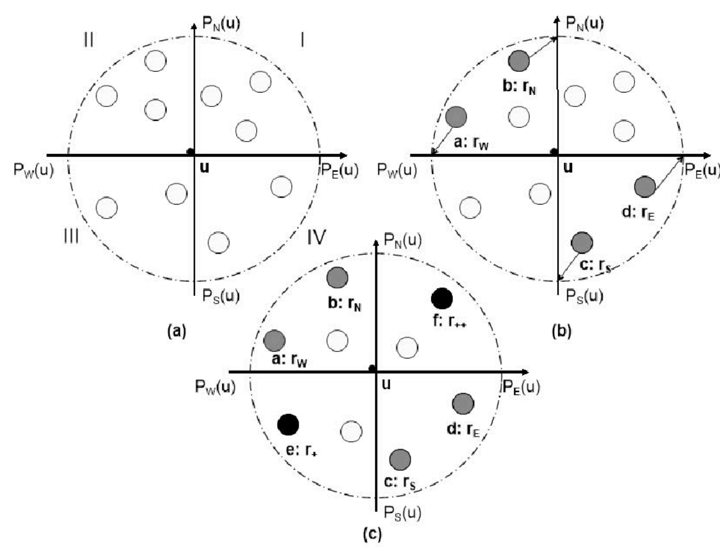

Fig. 1. Relay selection in ORCA

node v of node u becomes a polar relay node for node u if it has the smallest distance to the polar point and the smallest node identifier among those neighbors with the smallest distances to the same polar point. This can be stated as node v satisfying the following equations:

$$d(v, P_i(u)) = D_{P_i(u)} = \min_{n \in \mathcal{N}(u)} \{d(n, P_i(u))\} \qquad (1)$$

$$v = \min_{n \in \mathcal{N}(u)} \{n \mid d(n, P_i(u)) = D_{P_i(u)}\} \qquad (2)$$

In the example shown in Fig.1, nodes a, b, c, and d are the nodes closest to the polar points and hence become the polar relay nodes for node u, as shown in Fig. 1(b). However, it is important to point out that, depending on the topology of the MANET at a given time, the same node may become a polar relay node for up to two polar points, and that some polar points may not have any polar relay nodes.

Once node u selects its polar relay nodes, it selects additional relays to ensure that all the neighbors of its one-hop neighbors are covered by the transmissions of its own relays. Let $R_1(u)$ denote the set of relays selected by node u, which initially contains only the polar relay nodes. A neighbor $n \in \mathcal{N}(u)$ is added to $R_1(u)$ if the following condition is satisfied:

$$\forall v \in R_1(u), d(n, v) > r \qquad (3)$$

Node u repeats this procedure until no neighbor can satisfy Eq. 3. Fig. 1(c) illustrates the selection of two additional relays by node u, with nodes e and f becoming relays r_+ and r_{++}, respectively.

The pseudocode of the simple relay-selection procedure in ORCA that we have just described is presented below using the nomenclature stated in Table I. The algorithm consists of two procedures, the first one selects polar relay nodes, and the second one selects additional relays as needed.

It is clear that no more than two relay nodes can exist in any one quadrant of the plane for a given node u, because that would require more than one node being closest to a polar point. Furthermore, if nodes exist in a given quadrant with no polar relay node, at most one additional relay can be added to the relay set of node u, because of the restrictions imposed on the selection of polar relay nodes. Hence, it is intuitive that ORCA should require at most six relays per node, independently of the number of neighbors of a node. Section IV provides a formal proof of this.

Algorithm : COMPUTE RELAY SET AT NODE(u)

$R_1(u) \leftarrow \{\emptyset\}$
SELECTRELAYNODE(u)
ADDRELAYNODE(u)

procedure SELECRELAYNODE(u)
  $MIN = \infty$
  for $i \leftarrow 1$ **to** 4
  do
    for $k \leftarrow 1$ **to** $|\mathcal{N}(u)|$
    do
      if $n^k(u) \notin R_1(u)$
      then
        if $d(P_i, n^k(u)) < MIN$
          then $MIN \leftarrow d(P_i, n^k(u))$; $m \leftarrow n^k(u)$
        if $d(P_i, n^k(u)) = MIN$
          then **if** $n^k(u) < m$
            then $m \leftarrow n^k(u)$
    $R_1(u) \leftarrow R_1(u) + \{m\}$

procedure ADDRELAYNODE(u)
  for $k \leftarrow 1$ **to** $|\mathcal{N}(u)|$
  do
    $c \leftarrow 0$
    for $j \leftarrow 1$ **to** $|R_1(u)|$
    do
      for each $n \in R_1^j(u)$
      do
        if $d(n^k(u), R_1^j(u)) > r$
        then $c \leftarrow c + 1$
        else $break$
    if $c = |R_1(u)|$
      then $R_1(u) \leftarrow R_1(u) + \{n^k(u)\}$

output $(R_1(u))$

B. Propagation of Signaling Packets by Relay Nodes

ORCA requires the list of relays to be included in the header of a signaling packet that is to be flooded in the network. Given that the number of relays is at most six, this is not a significant overhead. All nodes in the one hop neighborhood of a node u receive the broadcast signaling packet, and the nodes that are not listed in the relay list of the packet header process the packet but but do not forward it; only the nodes in the relay list forward the packet using their own relays, which they compute using the ORCA relay selection procedure.

When a source s 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 s broadcasts a route request (RREQ) to establish a valid route by flooding the RREQ throughout the network in order to find the destination or a node with a valid route to the destination. As in prior on-demand routing protocols, AODV in particular, the RREQ specifies the source, the intended destination, and a sequence number used to prevent replicas of the RREQ to be transmitted. The only difference in ORCA is that the RREQ also specifies the list of relays for the packet. The same mechanisms used in AODV and prior on-demand routing protocols for the processing of RREQs apply to ORCA. Any node receiving the RREQ may send a route reply (RREP) if it has a valid route to the destination; however, only the nodes listed in the relay list of the RREQ can propagate the RREQ.

The handling of RREPs in ORCA is the same as in AODV and similar on-demand routing protocols, and the same applies to the processing of route errors (RERR) sent by a node n to the source s of a data packet when n is asked to forward a data packet for which it has lost its valid route.

IV. ORCA Correctness

For ORCA to work correctly, it must ensure that a flooded signaling packet covers all network nodes in the absence of packet losses due to multiple access interference, and it must require a maximum number of relays per node that is constant and fixed independently of how many one-hop neighbors a node may have.

The following theorems demonstrate that ORCA is correct using the nomenclature stated in Table I. We address the full coverage of a connected undirected graph $G = (N, E)$, where N is the set of network nodes and E is the set of edges, by stating that any k-hop neighbors of source s are reachable from s for an arbitrary number of hops k. The plane is divided into four quadrants by the reference axis in a Cartesian coordinate system, denoted by j in Table I, at most two relays can be selected in each quadrant.

Theorem 1: Given any nodes $s \in G$ and $u \in G$, if $u \in \mathcal{N}_2(s)$ then $u \in C(s)$.

Proof: All one-hop neighbors of node s are covered because they are within the transmission range of s. The rest of the proof proceeds by contradiction.

Assume that there is a node $u' \in \mathcal{N}_2(s)$ for which $u' \notin C(s)$ is true, then $\forall v \in (\mathcal{N}_1(s), \mathcal{N}_1(u'))$, $v \notin R_1(s)$. This implies that there is a node $v' \in \mathcal{N}_1(v)$ for which $v' \in R_1(s)$. Thus, v' uses the same process as node s to select its relay set $R_1(v')$. Based on the shifting offset from s to v', either v is selected or the node closer to u' is selected to be r_i. Then $u' \in C(s)$, which contradicts the original assumption. Therefore, $\forall v \in (\mathcal{N}_1(S), u \in C(s)$. ■

Theorem 2: Given any nodes $s \in G$ and $u \in G$, if $u \in \mathcal{N}_k(s)$ then $u \in C(s)$.

Proof: The proof is by induction. For the basis case, we have $k = 1$ and $k = 2$, and it follows from Theorem 1 that $\forall u \in \mathcal{N}_1(s)$, $u \in C(s)$, and $\forall v \in \mathcal{N}_2(s), v \in C(s)$.

Assume that $\forall u \in \mathcal{N}_{k-1}(s)$, $u \in C(s)$ is true. It needs to be shown that $\forall u' \in \mathcal{N}_k(s)$, $u' \in C(s)$.

Because G is connected, there must exist shortest physical paths from node s to node u', and hence there must exist a set of nodes $V = \{v \mid v \in \mathcal{N}_{k-1}(s), v \in \mathcal{N}_1(u')\}$. Given this set of nodes, either at least one node $w \in V$ is also in $R_{k-1}(s)$ (i.e., is a relay of signaling packets from u) or no node in S is in $R_{k-1}(s)$.

If at least one node $w \in V$ is also in $R_{k-1}(s)$, then it follows that $u' \in C(s)$, because node u' is in transmission range of node w and hence it must receive signaling packets from s.

On the other hand, if no node in V is in $R_{k-1}(s)$, it must still be true from the inductive hypothesis that all nodes in V are also in $C(s)$. Hence, there must exist at least one node y such that $y \in R_{k-2}(s)$ and $y \in \mathcal{N}_2(u')$ (or conversely $u' \in \mathcal{N}_2(y)$). However, this is a contradiction to the assumption that no node in V can be in $R_{k-1}(s)$, because $u' \in \mathcal{N}_2(y)$ and Theorem 1 dictates that, if $y \in R_{k-2}(s)$ then any node $p \in \mathcal{N}_2(y)$ is also in $C(s)$. Accordingly, it is impossible so that is true. ■

Lemma 1: Given any node $u \in G$, node u can have at most two polar relay nodes in any one quadrant.

Proof: Without loss of generality, assume that the quadrants of node u are ordered as I, II, III, IV as shown in Fig. 1(a), and that a selected relay node whose location is on any of the polar axis delimiting quadrants is considered to be part of the quadrant with the smallest identifier.

According to Eqs. (1) and (2) at most one node can be selected as a polar relay node for a given polar point. Hence, from our prior assumption, given that each quadrant is delimited by two polar axis, at most two polar relay nodes can be found in any quadrant. ■

Lemma 2: Given any node $u \in G$, node u cannot have two adjacent quadrants with two polar relay nodes each.

Proof: The result follows from Lemma 1 and the fact that at most one polar relay node is selected for each polar point. ■

Lemma 3: Given any node $u \in G$, node u cannot have any additional relay node in a quadrant for which it has any polar relay nodes.

Proof: The proof is by contradiction. Assume that node u has a polar relay node r_i in quadrant j, and that node u then selects an additional relay node v in the same quadrant. The maximum distance from any node in one of the quadrants of node u is with node u and equals r, and any two nodes other than u in the same quadrant of node u have a distance between them equal smaller than r. Accordingly, $d(v, r_i) < r$. However, this result is a contradiction, because according to the algorithm used in ORCA to select relay nodes, the distance from node v to r_i must be larger than r. ∎

Lemma 4: Given any node $u \in G$, node u can have at most two relay nodes in a quadrant.

Proof: The result follows directly from Lemmas 1 and 3. ∎

Lemma 5: Given any node $u \in G$, if $|R_1^j(u)| = 2$, then $|R_1^{j-1}(u)| \leq 1$ and $|R_1^{j+1}(u)| \leq 1$.

Proof: Let $|R_1^j(u)| = 2$. From Lemmas 1 and 3, it follows that the two relay nodes selected by node u for quadrant j must be polar relay nodes. Given this result and Lemma 2, it must be true that node u cannot have two polar relay nodes in quadrants $j-1$ and $j+1$. From this result and Lemma 3 it follows that the Lemma is true. ∎

Theorem 3: For any node $u \in G$, $|R_1(u)| \leq 6$.

Proof: From Lemma 4, the maximum number of relays in any one quadrant is 2. Without loss of generality, assume that $|R_1^j(u)| = 2$, then from Lemma 5, it must be true that $|R_1^{j-1}(u)| \leq 1$ and $|R_1^{j+1}(u)| \leq 1$, and from Lemma 4 we have $|R_1^{j+2}(u)| \leq 2$. Thus we have $|R_1(u)| = \sum_{j=I}^{IV} |R_1^j(u)| \leq 6$ ∎

Given the result in Theorem 3, we have that $O(|R(S)|) = O(c) \asymp O(1)$.

V. Performance Comparison

A. Scenarios and Metrics

We conducted discrete-event simulations using the Qualnet Simulator [20]. In the scenarios we used, 200 and 250 nodes were deployed randomly in a rectangular-shaped area of 1200x300 m^2 and 1500x400 m^2, respectively, to have similar densities. Nodes move with speeds randomly chosen between 1m/s and 20m/s, according to the random way-point (RWP) mobility model. The simulation time is 900 seconds, and pause time varies from 100 seconds to 900 seconds, by increment of 100 seconds. Nine seeds were used for each simulation run. Data transmission is constant bit rate (CBR), and the duration of data flows is exponentially distributed with the mean value of 100 seconds. Different percentages of flows to total number of nodes were used from 40% to 100%. A data packet is of size 512 bytes. The two-ray signal propagation model is used, 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 2M bit/s. The radio range is $250m$. 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 shows that guarantee 95% confidence interval of the mean value.

Three performance metrics were used to compare the performance of routing protocols. *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 Load* is the ratio of the total number of routing messages(RREQ, RREP and RRER) to good received data packets, which implies the average network routing load per good data packet. *Average Delay* is the average latency including routing delay, data transmission period and retransmission period per good received data packet.

We simulated five routing protocols, ORCA, AODV, LAR, OLSR and THP.

B. Performance Results

Figure 2 and Figure 3 show the packet delivery ratios attained by the five protocols we compare. ORCA attains the highest or second highest packet delivery ratio in both scenarios. This performance is the result of the bandwidth savings attained in ORCA from reducing the overhead incurred in flooding signaling packets. The fact that ORCA attains high packet delivery ratios is an indication that it covers all network nodes when RREQs are sent to find routes to destinations. LAR attains better packet delivery ratios than ORCA at low mobility, and is worse than ORCA when node mobility is high. This performance of LAR is the result of its use of previously-known geographical coordinates of destinations to direct the propagation of RREQs; hence, if node mobility is low, directing RREQs is effective, but as nodes move more and more, the location information used in LAR becomes out of date more quickly. THP attains much lower packet delivery ratios than ORCA and LAR, and the reasons for this performance appear to be that too few relays are used in THP to forward RREQs, and the two-hop information exchanged among nodes becomes outdated with node mobility, which leads to unsuccessful RREQ attempts. OLSR shows the worst packet delivery ratios, because of the large amount of signaling packets it requires. AODV performs better than OLSR in this regard, but is worse than ORCA and LAR, which is a consequence of the larger amount of signaling traffic it

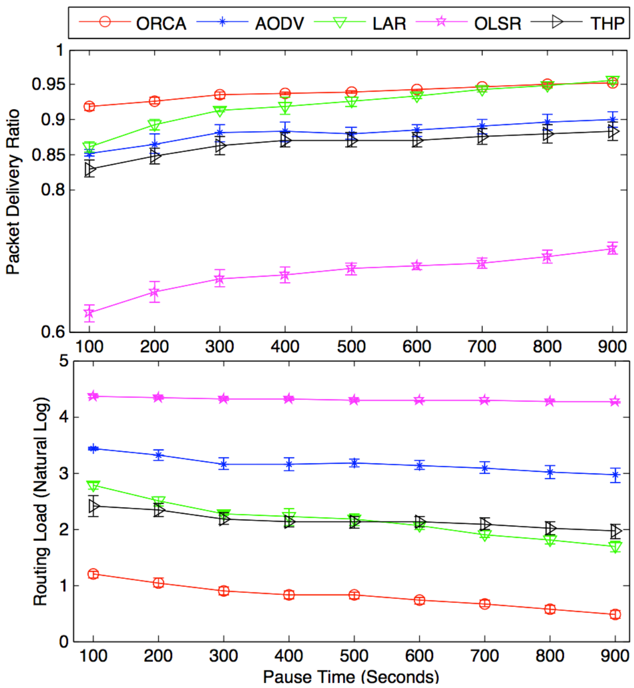

Fig. 2. PDR & Routing Load (200 nodes 200 flows)

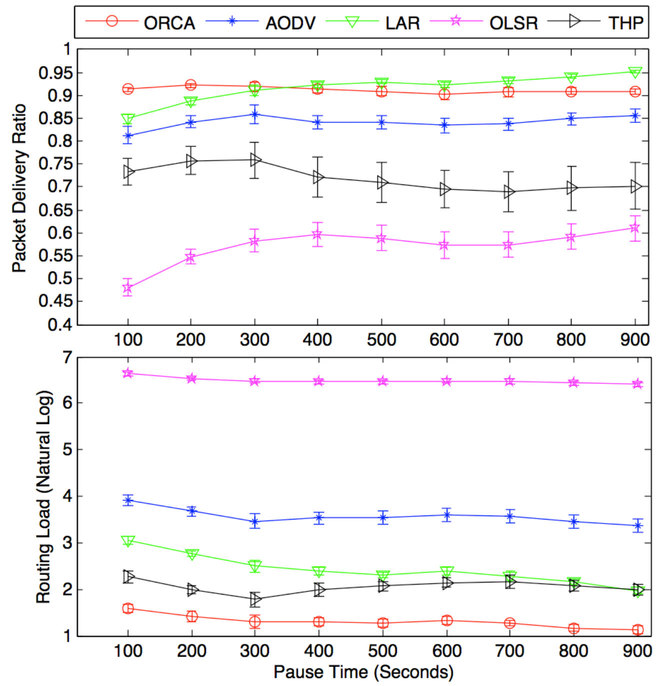

Fig. 3. PDR & Routing Load (250 nodes 100 flows)

incurs.

Figure 2 and Figure 3 also show the routing load incurred by each routing protocol we simulated. OLSR requires the most control overhead in both scenarios, due to routinely flooding topological information through multipoint relays. AODV consumes the second largest load, which is the result of flooding RREQs when new routes need to be established or broken routes need to be re-established. THP incurs a smaller overhead than OLSR and AODV thanks to its use of fewer relays of signaling packets than those used in AODV. In all cases, ORCA incurs the smallest signaling overhead, which results from its use of a constant number of relay nodes per node, independently of how many neighbors a node has.

Figure 4 and Figure 5 show the average delays experienced by packets delivered using each of the five routing protocols. ORCA attains the smallest delays for 200 nodes, and is as good as THP and AODV for 250 nodes. However, it is important to note that both THP and AODV deliver much fewer packets than ORCA does. OLSR incurs higher delays than ORCA, THP and AODV due to its higher signaling overhead, which leaves less bandwidth for data traffic. LAR performs poorly at high mobility, because the previously-known location information it uses to direct RREQs becomes obsolete.

VI. Conclusion

This paper introduced ORCA, a novel approach for reducing the amount of broadcast signaling traffic in MANETs. ORCA is the first routing protocol in which a signaling packet is forwarded by a maximum constant number of relay neighbors per node, independently of the number of neighbors that the node has.

Under the assumption that wireless transmission ranges for all nodes consists of circles of radius r, we proved that the relaying of a given signaling packet in ORCA covers all network nodes in the absence on multiple access interference, and that at most six relays per node are needed to flood a signaling packet independently of the neighborhood size.

Simulation results were presented with the comparison of the performance of ORCA and four other routing protocols, namely OLSR, AODV, THP and LAR, which are representatives of routing approaches for on-demand and proactive routing. OLSR uses multipoint relays to reduce its signaling overhead, THP defines subsets of one-hop neighbors that cover all two-hop neighbors to serve as relays, and LAR uses previously-known locations of destinations to direct route requests when routes to those destinations are broken. The simulation results show that ORCA performs better than the other four protocols overall, and that its selection of relay nodes

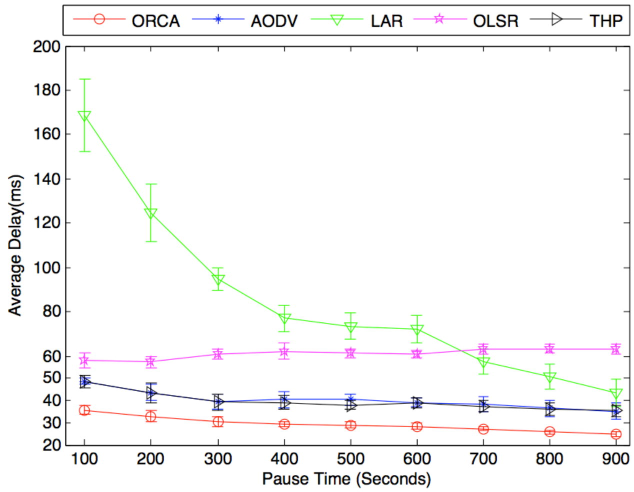

Fig. 4. Average Delay (200 nodes 200 flows)

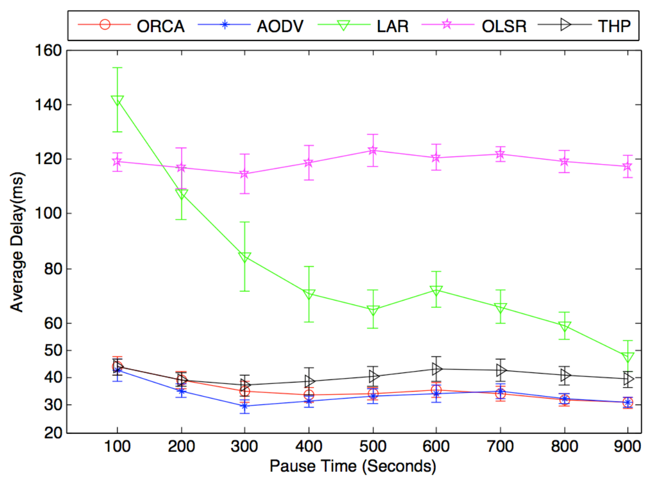

Fig. 5. Average Delay (250 nodes 100 flows)

is such that all network nodes tend to be reached by flooded signaling packets.

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