Overhead Analysis of Query Localization Optimization and Routing

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ABSTRACT

Query localization is an improved extension of on-demand routing protocols for ad hoc networks. It makes use of prior routing histories to localize the query flood to a limited region of a network. However, the lifetime of the found route by two existing query localization approaches tends to be much shorter than that of network-wide flooding. In this paper we address this shortcoming and provide an improved solution through analyzing the routing overhead incurred by network-wide flooding. The analytical results clearly show the superiority by adopting query localization in routing. We also perform experimental simulation in NS-2 simulator to validate our theoretic analysis and to evaluate the performance of the proposed solution.

Categories and Subject Descriptors

C.2.2 [**Network Protocol**]: Routing Protocols

General Terms

Theory, Performance, Algorithms, Design.

Keywords

Analysis of routing overhead, ad hoc networks, on-demand routing protocols, flooding, query localization optimization.

1. INTRODUCTION

Ad hoc networks are self-configuring and self-organizing wireless networks, which operate without any fixed infrastructure. Ad hoc networks have many potential applications from civil to military domains including battlefield communications, disaster relief and rescue operations, environmental monitoring, security surveillance, etc.

The frequent topology changes of an ad hoc network result in route invalidation. On-demand routing protocols are the table-driven routing protocols with the advantage of much lower routing overheads. Classic on-demand routing protocols include DSR [1] and AODV [2], etc. Most on-demand routing protocols simply discover routes by network-wide flooding. However, this naïve flooding approach consumes much of the limited bandwidth imposed in such networks. A new technique, referred to query localization [3] has since been proposed, which utilizes the previous routing information to localize the query flooding to a limited region of the networks. The simulation results in [3] demonstrated that this strategy can reduce the routing overhead significantly in addition to reducing the network congestion. Consequently it will also improve the end-to-end delay performance of packet deliveries in a heavy traffic scenario. However, the life time of found routes through query localization in [3] is much shorter than that of global flooding. The proposed approaches intend to select the links in the prior broken path for new routes, while these links are the most vulnerable and most likely to break down again in the near future.

In this paper, we first address this shortcoming by redefining the region. We then analyze the routing overheads of global flooding and provide an optimization solution to it. We finally perform experimental simulations to validate our theoretic analysis and evaluate the performance of the proposed solution.

The rest of the paper is organized as follows. Section 2 briefly introduces the concept of query localization. Section 3 addresses the shortcomings of the two existing approaches and describes our optimization policy. Section 4 analyzes the routing overheads of network-wide flooding and the proposed solution. Section 5 is the simulation experiments. And Section 6 will conclude the paper.

2. QUERY LOCALIZATION

The proposed query localization [3] is based on the notion of spatial locality, that is, “a mobile node cannot move too far too soon”, which means that it is very likely to find a new routing path through the neighborhood of the earlier broken path. It utilizes prior routing histories to estimate a region and retains the query in the region.

Let P_{old} denote the set of nodes in the previous broken path, two query localization approaches are proposed in [3]. One is the path locality. The protocol maintains a set of nodes P_{old}, which includes all the nodes in the last valid route between a pair of nodes. In the process of route discovery, the query flooding is propagated by only such nodes for which the accumulated path P in the query packet contains at most k nodes not in P_{old}. A node counter is used as part of the query, which is initialized to be zero. With the route request packet propagates, if it passes through a node not in P_{old}, the counter will increment by one, the route request packet will be dropped if the counter is larger than k. Another is the node Locality. The mechanism of node locality is similar to path locality. The only difference lies in, when the route request packet passes through a node in P_{old}, the counter is reset to zero; otherwise, the counter increments itself by one. Once again, the route request packet will be dropped off when the counter is larger than k.

Simulation experiments demonstrate the superiority of query localization in the reduction of routing overheads, and it indirectly

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contributes to lower end-to-end delay of data packets for reducing network congestion and multiple-access interference, the reduction is more prominent when the network workload is heavy.

3. OPTIMIZATION OF QUERY LOCALIZATION

In this section, we address the shortcoming of [3] and show how to rectify it. The proposed approaches in [3] prefer to include the nodes in P_{old} when performing a new route finding. Therefore the links (nodes) in a prior broken path are preferred. Unfortunately, these links are likely to be broken down again if chosen. Our experimental simulation results demonstrate that the life time of the routes chosen by the methods in [3] is much shorter than that of network-wide flooding on average. Particularly, it becomes much worsen in either one of the following three cases: (i) The distance between a source node and a destination node is far way from each other. In this situation, data packets must be relayed by many intermediate nodes, the existing approaches prefer to existing links than the new ones which may have shorter distance. Furthermore, a longer routing path is more vulnerable than a shorter one. (ii) Node mobility is high. There are frequent routing breakings when nodes move so quickly, so that the average valid route time is much shorter. (iii) In a sparse network, there are few choices in terms of route discovery, and this tendency is more prominent and more adverse.

Our definition of locality is subsumed in node locality. We do not allow a route request packet to pass through more than 1 hop away from P_{old}. Also, we notify the neighborhood nodes of the route information for the destination node periodically so that the neighbors know they are near an active transmission, and they have their routes to the destination. Figure 1 illustrates our idea. Assuming that the path *S->A->B->D* is a broken path and *B->D* is the broken link, nodes in the areas of big circles are allowed to forward RREQ (Route Request) packets, the nodes in P_{old} are not particularly selected.

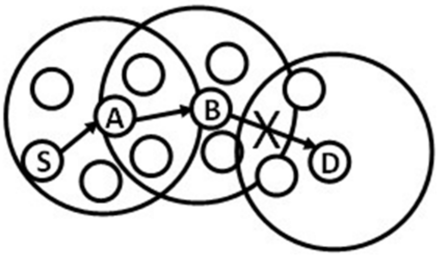


Figure 1. Query Localization Optimization, where each small circle represents a mobile node while each big circle represents the transmission region of the mobile node.

In comparison with the existing approaches, the proposed one has exhibited the following advantages.

Query localization can be applied to the distance vector protocols. Paper [3] modified DSR by incorporating query localization, while paper [4] includes query localization into AODV and refers to this extension as AODV-QL. Note that AODV is a distance vector routing protocol, which means each node has no knowledge about the prior broken path. It can also be used to hold down unnecessary forwarding of RREQ packets and leads to the following benefits.

To suppress RREQ packets from propagating backward to the source node, the local repair technique can be adopted [2], in which the intermediate nodes will also initiate the procedure of route discovery. For example, in Figure 1, when the link *B->D* is broken, because the destination node is closer to it than that of the source node, node B will repair the broken route by initiating a route discovery. In this situation, there is no need for the RREQ packet propagating in the whole coverage areas of the big circles. In our scheme, a RREQ packet carries the sender's last valid hop count for the destination, neighboring nodes can suppress the backward propagating by comparing the sender's last valid hop count against its own one.

Nodes with quick mobility hold down forwarding of RREQ packets. Despite that these nodes were near to an active transmission area now, they may already move out from the area at next routing discovery moment, the forwarding by these nodes does not help in the route discovery. What follows is to add a restriction in forwarding. Let *h_src* denote the sender's last valid hop count for the destination and *h_cur* denote the last valid hop count of the current node. Assume that *h_forward* is the number of hops that the RREQ packet has been forwarded, the constraint is that: *h_cur* + *h_forward* ≤ *h_src +1*, then a smaller and more precise propagating area of RREQ packets is obtained. The proposed scheme also provides alternative routes for the primary route [5], when the primary route fails, alternative routes can be used to replace and repair the broken links.

We name the coverage area by the big circles as *the Basic Request Zone*. It is possible to fail to find a new route from the Basic Request Zone. To avoid that, we take the following actions. The RREQ packet for the first time is only propagated within the Basic Request Zone. If this route request fails, for the second and third time, the RREQ packet will not only leave the Basic Request Zone but also pass through the nodes within 1 and 3 hops from the Zone. To achieve that, a counter variable associated with each RREQ packets is needed. If none of the first three route requests succeeds, flooding will follow.

We incorporate the above optimization strategy into the implementation of AODV and refer to this extension as AODV-QL-O.

4. ANALYSIS OF ROUTING OVERHEAD

Assume that network nodes are uniformly distributed with transmission range R and network density of ρ. In many on-demand routing protocols, the dominating routing overhead is made by the RREQ packets. The rest is to analyze the route overhead contributed by RREQ packets in [3] with flooding and query localization optimization.

4.1 Routing Overhead of Flooding

In the scheme of flooding, each node forwards a specific RREQ packet at most once, and duplicated RREQ packets will be dropped off. Let d be the distance between a source node and a destination. Then, a RREQ packet will be flooded from the source node to the destination node; the coverage area of the packet will be a circle of radius no less than d, which is illustrated by Figure 2. The lower bound on the overhead of routing thus is

$$N_l = \rho\pi d^2 - 1. \tag{1}$$

As the destination will not rebroadcast the RREQ packet, the right hand side of Eq. (1) is reduced by one. In the worst case, the RREQ packet will be flooded within the entire network.

So the routing overhead of network-wide flooding is $\Omega(d^2)$.

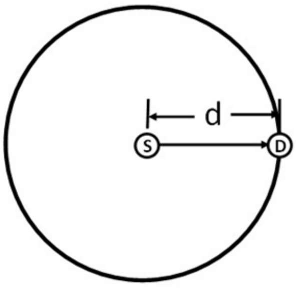


Figure 2. Flooding of RREQ packets within the network.

4.2 Routing Overhead of Query Localization Optimization

4.2.1 Problem Statement

Assuming that there are h+1 points: A_0, $A_1, \dots, A_h$. Let r_i be the length of segment $A_{i-1}A_i$, $(0 \le r_i \le R)$, where R is the transmission range of node which is a non-negative constant, *i=1, 2, ..., h*. We further assume that the line distance of $A_0\,A_h$ is *d*; for each A_i, a circle with the center at A_i and radius *R* is formed. For simplicity, we also use A_i to represent the circle centered at it, *i=1,2, ...,h*. One such an example is shown in Figure 3. Let *S* be the union of the coverage areas by the *h* circles. In the following we aim to find the minimum and maximum values of *S* when both *h* and *d* are fixed.

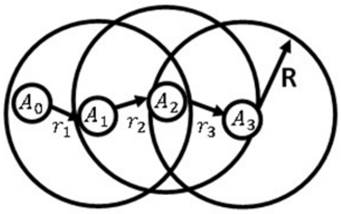


Figure 3. Query localization of RREQ packets.

4.2.2 Lower Bound

As seen from Figure 3, for all *i*, the smaller the value r_i is, the bigger the overlap area of the circles centered at A_{i-1} and A_i is, *i=2,3,..h*. Clearly, $hR \ge \sum_{i=1}^{h} r_i \ge d$. Under $0 \le r_i \le R$ (*i*=1,2 …*h*), to minimize the value of *S*, we take that $r_1 = min(R,d)$, $\sum_{i=1}^{h} r_i = d$, so $\sum_{i=2}^{h} r_i = d - \min(R,d)$, the points $A_1, A_2 \dots A_{h-1}$ will be in the line between A_0 and A_h. Figure 4 is one example, and the coverage area *S* is

$$S = \pi R^2 + \big(d - min(R,d)\big)2R$$

$$-\sum_{i=2}^{h}\left[\left(2R - \sqrt{R^2 - r_i{}^2/4}\right)r_i - 2R^2 arccos\left(\frac{\sqrt{R^2 - r_i{}^2/4}}{R}\right)\right]$$

Under the condition that $\sum_{i=2}^{h} r_i = d - min(R,d)$, $0 \le r_i \le R,\ i = 2,3 \dots h-1$, apply the Lagrange multiplier rule, we have

$$f(r_2, r_3 \dots r_h, \lambda) = S + \lambda\left(\sum_{i=2}^{h} r_i - d + min(R,d)\right).$$

To minimize the value of *f*, we have

$$\frac{df}{dr_i} = 2R - 2\sqrt{R^2 - r_i{}^2/4} + \lambda = 0, i = 2,3 \dots h$$

$$\frac{df}{d\lambda} = \sum_{i=2}^{h} r_i - d + min(R,d) = 0$$

when $r = r_i = \frac{d - min(R,d)}{h-1}$, $i = 2,3,\dots,h$, the value of S is minimized and denote by S_l, where

$$S_l = \pi R^2 + (d - min(d,R))2R - \Psi$$

$$\Psi = (h-1)\left[\left(2R - \sqrt{R^2 - r^2/4}\right)r - 2R^2 arccos\left(\frac{\sqrt{R^2 - r^2/4}}{R}\right)\right]$$

Where the value of Ψ is much smaller than the value of S_l, for simplicity, we will neglect Ψ, so

$$S_l \approx \pi R^2 + (d - min(d,R))2R, \tag{2}$$

$$N_l = \rho S_l - 1. \tag{3}$$

From Eq. (2) and (3), we can see that the routing overhead of Query Localization Optimization is *Ω*(*d*).

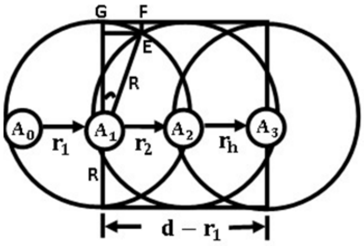


Figure 4. The minimization of *S* when $r_1 = min(R,d)$ and $\sum_{i=2}^{h} r_i = d - r_1$.

4.2.3 Upper Bound

To maximize the value of *S*, we set $r_i = R, (\ i = 2,3 \dots h)$. One such an example is illustrated in Figure 5. To calculate the overlap area $S_{overlap}$ of two circles, illustrated in Figure 6, with centered at points O_1 and O_2. We have

$$cos\,\alpha = \frac{R/2}{R} = \frac{1}{2},\ \ \alpha = \frac{\pi}{3}$$

$$S_{overlap} = 2\left(\frac{2\alpha}{2\pi}\pi R^2 - \frac{\sqrt{3}R}{2}.\frac{R}{2}\right) = \frac{\left(4\pi - 3\sqrt{3}\right)R^2}{6}, \tag{4}$$

It can be proved that, if circles $A_i \cap A_j = \phi, |i-j| \ge 3,\ i,j = 1,2,\dots,h$,and $A_{i-1} \cap A_{i+1} = A_{i-1} \cap A_i \cap A_{i+1}, i = 2,3 \dots h-1$, *S* is maximized and denote by S_u, where

$$S_u = h\pi R^2 - (h-1)S_{overlap.} \tag{5}$$

To make $A_{i-1} \cap A_{i+1} = A_{i-1} \cap A_i \cap A_{i+1}$, $i = 2,3 \dots h-1$, the angle $\angle A_{i-1}A_iA_{i+1}$ $(0 \le \angle A_{i-1}A_iA_{i+1} \le \pi)$ must be larger than a threshold of $\frac{2\pi}{3}$, illustrated in Figure 7. When $\angle A_{i-1}A_iA_{i+1} < 2\pi/3$, the coverage area by the *h* circles will be smaller than S_u. For example, the coverage area of the four circles in Figure 4 is $4\pi R^2 - 3S_{overlap} - K$, where *K* is the area of the black zone. However, the value S_u cannot always be achieved, in the following we show how to maximize $\angle A_{i-1}A_iA_{i+1}$ and how to minimize $A_i \cap A_j, |i-j| \ge 3, i,j = 2,3,\dots,h$.

If $d = hR$, then points $A_1, A_2 \dots A_{h-1}$ are all on the line $A_0\,A_h$, and $r_i = R,\ i = 1,2 \dots h$. Otherwise, if $d < hR$, the case becomes more complicated, as shown by Figure 8 (a) and (b). Let $r_i = R$, $i = 1,2,\dots,h$, point A_i, $i = 0,1,\dots,h$, is on a circle centered at *O*, where point *O* is on the perpendicular bisector of line A_0A_h, where the radius *r* of circle centered at *O* is calculated as follows. From Figure 8, we conclude that: $h.2.arcsin\frac{R/2}{r} = 2.arcsin\frac{d/2}{r}$ or $h.2.arcsin\frac{R/2}{r} = 2\pi - 2.arcsin\frac{d/2}{r}$. For a small *h*, we use the former; otherwise, we use the latter. The boundary case is when the points O and M superpose at a same point, then, $r = d/2$, $h.2.arcsin\frac{R/2}{d/2} = \pi$. So the formula of calculating r is

$$\begin{cases} h.arcsin\frac{R}{2r} = arcsin\frac{d}{2r}, & if \quad d \geq R \; and \; h \leq \frac{\pi}{2arcsin\frac{R}{d}} \\ h.arcsin\frac{R}{2r} = \pi - arcsin\frac{d}{2r}, & otherwise. \end{cases} \quad (6)$$

To make $\angle A_{i-1}A_iA_{i+1} \geq 2\pi/3$, we can prove that if $r \geq R$, the condition can be satisfied. When $0 < d < R,\ h = 3, 4, 5$, $R \leq d < 2R,\ h = 3$, and $R \leq d < \sqrt{3}R,\ h = 4$, r is less than R, but even if $r < R$, the coverage area is less than S_u, so the upper bound on the overhead of query localization optimization is

$$N_u \approx \rho S_u - 1. \quad (7)$$

From Eq. (4), (5), and (7), we can see that the routing overhead of query localization is $O(h)$. Most ad hoc routing protocols consider the best paths as those with minimum number of hop counts, while the value of the distance d between a source and a destination is a proportional the number of hops h. Assuming that $d = kh$ and k is a constant, then, the routing overhead is $O(d)$.

In summary, the routing overhead complexity of Query Localization Optimization is $\Theta(d)$.

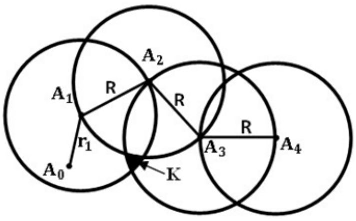


Figure 5. $\boldsymbol{r_i = R, i = 2,3 \ldots h}$.

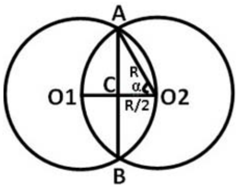


Figure 6. The overlap area of two circles.

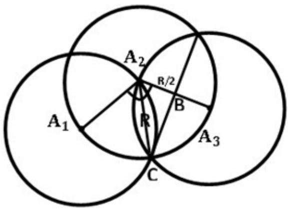


Figure 7. The boundary case where
$\boldsymbol{A_{i-1} \cap A_{i+1} = A_{i-1} \cap A_i \cap A_{i+1}\ for\ all\ i, i = 2,3 \ldots h-1}$.

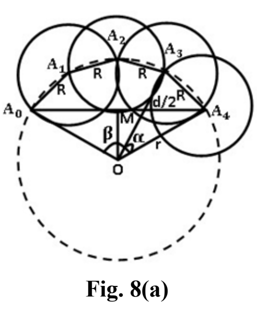


Fig. 8(a)

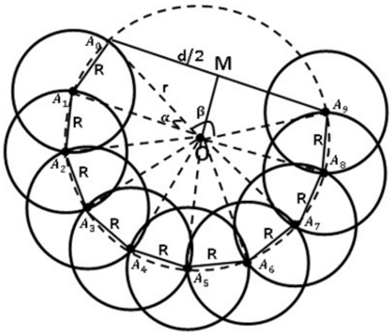


Fig. 8(b)

Figure 8. Maximization of $\boldsymbol{\angle A_{i-1}A_i, i = 2,3,\ldots,h-1}$ **and minimization of** $\boldsymbol{A_i \cap A_j,\ |i-j| \geq 3,\ i,j = 1,2,\ldots,h}$.

5. PERFORMANCE EVALUATION

5.1 Simulation Environment

We adopt a detailed simulation model based on ns-2 [6]. The distributed coordination function (DCF) of IEEE 802.11 for wireless LANs is used as the MAC layer protocol, and with a transmission rate of 1Mbps and a radio range of 250 meters.

The network is shown in Figure 9. The nodes in the network are deployed in a square with both width and length of 1,800 meters. The position of the six nodes are fixed, the nodes form three pairs. The traffic pattern consists of a CBR connection in each of the three pairs. The transmission rate is 5 packets per second, where every data packet contains 64 bytes. The x-coordinates of nodes 2, 4, and 6 are variables. The distances between the source nodes and destination nodes are set to be 300, 450, 600, 750, 900, 1,050, and 1,200 meters, respectively. The mobile nodes can randomly move within the rectangle, following the Random Waypoint Model with a randomly chosen speed bounded between the minimum speed and the maximum speed, where the minimum and maximum speeds are 1*m/s* and 20*m/s* respectively. Pause time is always set to zero. Three types of network densities are chosen: high density, moderate density and low density with 160, 110, and 80 nodes except the six nodes, respectively. The simulation duration is 600 seconds and each point in a plot represents an average of five runs with different random number of streams.

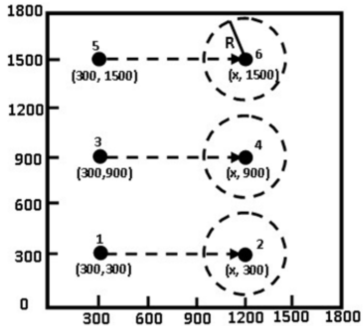


Figure 9. Simulation Topology.

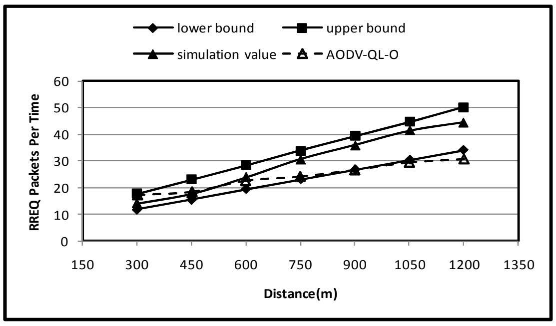
5.2 Evaluation Metrics

We use the following five metrics to measure the performance of the proposed approach. (1) RREQ packets per time unit, it is the number of RREQ packets broadcast during a single route discovery. (2) The delivery ratio, measured the ratio of the number of data packets reaching the destination nodes to the number of data packets sent by source nodes. (3) The average relative valid route time, measured the ratio of that of a protocol to that of AODV. Here the average valid route time of AODV is set as the baseline, which is always to be one. (4) The average delay, measured as the average end-to-end latency of data packets. And (5) The normalized routing overhead, measured as the total number of transmitted routing packets (hop-wise) to the number of data packets received by the destination nodes.

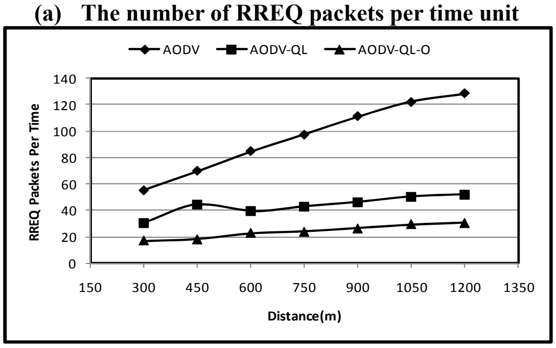
5.3 Simulation Results

Figure 10 shows the performance of various approaches by varying the distance between a source node and its destination node in high density networks. To compute the lower and upper bounds on the overhead of query localization optimization, the values of *d* and *h* must be known before hand, where *d* can be set by us, while the value of *h* can be calculated by averaging the hop count of data packets received by the destination nodes. We also collect the statistics of how many RREQ packets being sent when initializing route discovery by query localization optimization for the first route discovery. To do so, we hold down the optimization functions of local repair and sending replies from intermediate nodes in AODV, only the source nodes can initialize route discovery and the destination nodes reply the route request. Figure 10 (a) and (b) plot the number of RREQ packets on average per route discovery, and the lower and upper bounds on the number of RREQ packets. The data is the actual number of RREQ packets when utilizing Query Localization Optimization and holding down local repair and sending reply from intermediate nodes. It can be seen that the actual number of RREQ packets is between its lower bound and upper bound and more close to its upper bound. This tendency comes from the characteristic of Random Waypoint Mobility Model, nodes are not uniformly distributed. Paper [7] points out that the node distribution has a peak in the center of the area, and the probability that a node is located at the border of the area goes to zero. The number of RREQ packets sent by AODV-QL-O nearly reaches its lower bound, as local repair and sending replies from intermediate nodes can considerably reduce RREQ packets. From Figure 10 (b), the superiority of Query Localization is very prominent. The effect of our optimization is also significant. On average, AODV-QL-O can save more than 10 RREQ packets than AODV-QL.

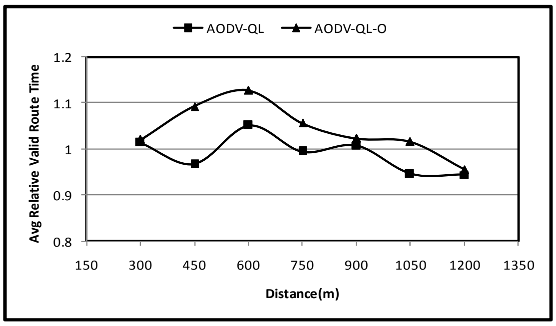
Figure 10 (c) illustrates the average relative valid route time of AODV-QL and AODV-QL-O. AODV-QL-O is better than AODV-QL in this aspect. The average relative valid route time of AODV-QL fluctuates with the distance. When the distance is larger than 900 meters, it falls to a level less than 1. However, in most cases, AODV-QL-O's level is always larger than 1. As a result, it will contribute a longer life time of the route and a better end-to-end delay in terms of data delivery. Figure 10(d) plots the delivery ratio performance of the three protocols, which is almost the same, which deteriorates significantly with the increase of the distance. Figure 10(e) shows that the average end-to-end delay of the mentioned protocols, the delay will increase with the increase of the distance. Among them, AODV-QL-O is the best, AODV follows, and AODV-QL is the worst. When the distance is larger than 600 meters, the end-to-end delay of AODV-QL is significantly longer than that of AODV, and the shorter life time of the routes selected by AODV-QL will increase the end-to-end delay of data delivery. Figure 10(f) demonstrates the normalized routing overheads of the three mentioned protocols. It is easily understood that the index will rise with the distance. The performance of AODV-QL's and AODV-QL-O's are much better than that of AODV. Because of topology limitation, AODV's route request zone will not be a circle, especially when the distance is far. We can also see that AODV-QL-O's normalized routing overhead is comparably better than that of AODV-QL, because AODV-QL-O has a smaller propagating area of RREQ packets and fewer route discoveries than those of AODV-QL.



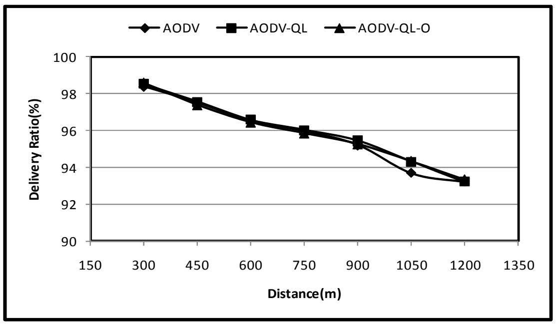
(a) The number of RREQ packets per time unit



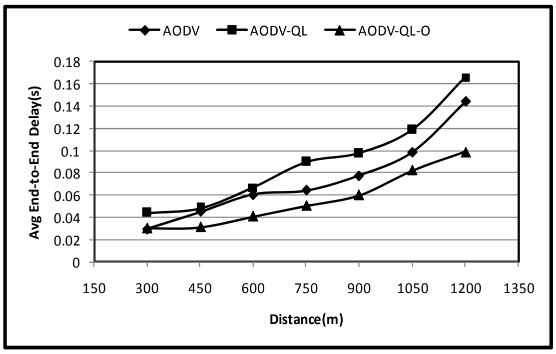
(b) The number of RREQ packets per time unit



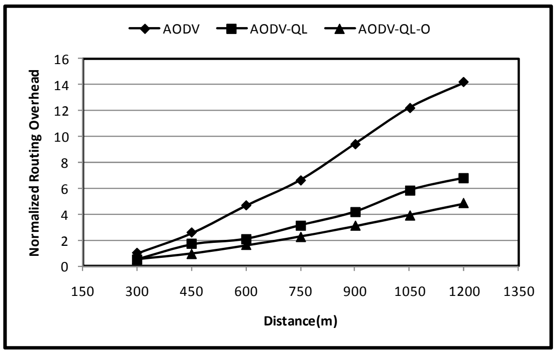
(c) The average relative valid route time



(d) The delivery ratio



(e) The average end-to-end delay



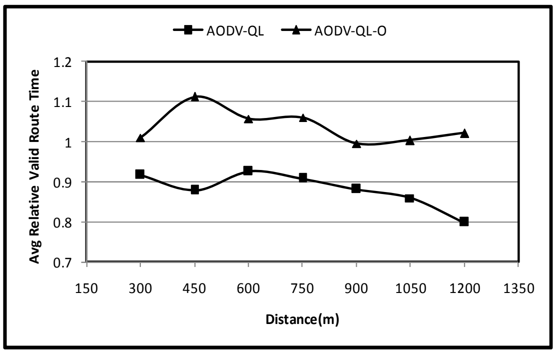
(f) The normalized routing overhead

Figure 10. Performance of different protocols by varying the distance between sources and destinations in high density networks.

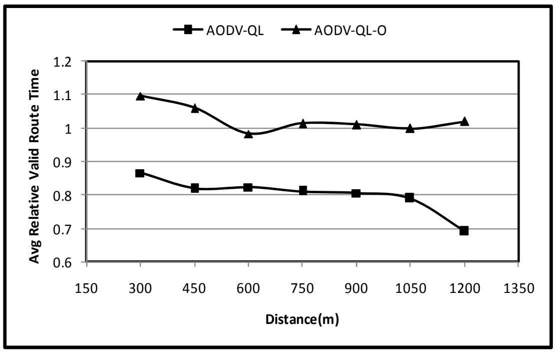
The performance of AODV-QL-O will deteriorate when the node density is low, because it is likely that it fails to find a route to the destination for the first route discovery, and the protocol will initiate more route discoveries afterwards, the average end-to-end delay will increase, too. The other two sets of experiments are carried out within moderate and low density networks, and the results are shown in Figure 11, only the results about Relative Valid Route Time, Delivery Ratio and Average End-to-end Delay are presented, the other performance tendencies are similar to Figure 10, omitted. Figure 11 (a) and (b) clearly demonstrate the shortcoming of the approaches in [3]. AODV-QL's average relative route time is much less than 1, while the average relative route time of AODV-QL-O maintains above or equal to 1.

In our experiments, the workload is light, so the affluence of routing packets' decreasing by Query Localization is not notable for delivery ratio. Figure 11 (c, d) shows the similar delivery ratio changing curves of the three protocols.

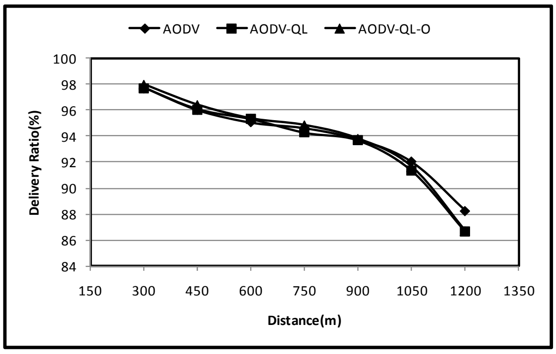
Figure 11(e) and (f) show that AODV and AODV-QL-O have almost identical performance in the end-to-end delay. However, the performance of AODV-QL is much worse when the distance is long, and the node density is low. From Figure 11, it can be seen that in sparse networks, the performance of AODV-QL-O does not deteriorate quickly, in terms of the delivery ratio and average end-to-end delay.



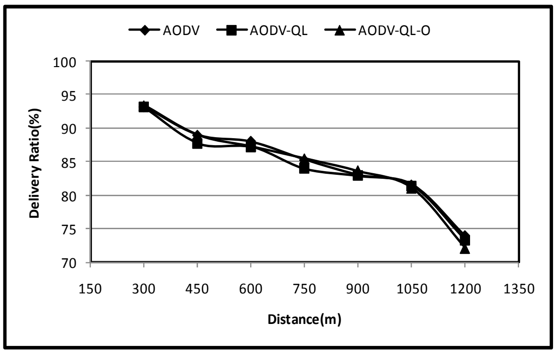
(a) The relative valid route time



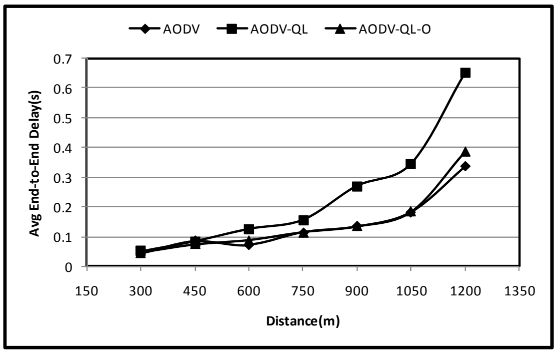
(b) The relative valid route time



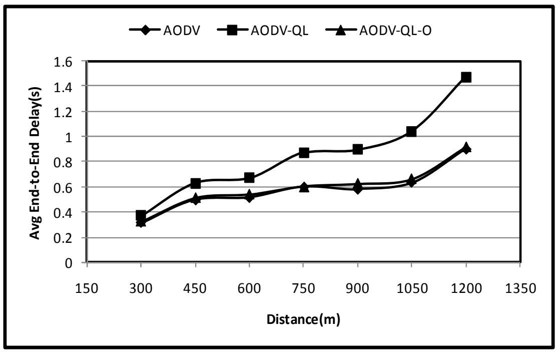
(c) The delivery ratio



(d) The delivery ratio



(e) The average end-to-end delay



(f) The average end-to-end delay

Figure 11. Performance by varying the distance in moderate and low density networks, where Fig. (a), (c), and (e) are moderate densities, while Fig. (b), (d), and (f) are low densities.

6. CONCLUSIONS

Query localization is a promising strategy to reduce the routing overhead by utilizing previous routing histories to limit route flood to a relatively small region. In this paper, we first addressed the shortcoming of two existing query localization-based approaches and propose an improved one. We then performed the analysis of routing overhead complexities of network-wide flooding and our solution. We finally conducted experimental simulation to validate our analysis. The experimental results demonstrate the proposed approach is efficient.

7. ACKNOWLEDGMENTS

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8. REFERENCES

[1]. D. Johnson, Y. Hu, and D. Maltz. The Dynamic Source Routing Protocol (DSR) for Mobile Ad Hoc Networks for IPv4 (February 2007). http://www.ietf.org/rfc/rfc4728.txt.

[2]. C. Perkins, E. Belding-Royer, and S. Das. Ad hoc On-Demand Distance Vector (AODV) Routing (July 2003). http://www.ietf.org/rfc/rfc3561.txt.

[3]. R. Castaneda, S. R. Das and M. K. Marina. Query Localization Techniques for On-demand Routing Protocols in Ad Hoc Networks. *Wireless Networks*, Vol. 8, 137-151, 2002.

[4]. N. Kothari, V. Bhandari, and D. Sanghi. Strategy for Query Localization in Ad Hoc on Demand Distance Vector Routing. *Proc. of TENCON*, IEEE, 2002.

[5]. Sun-Ju Lee and Mario Gerla, "AODV-BR: Backup Routing in Ad hoc Networks", *Proceedings of WCNC*, IEEE, 2000.

[6]. K. Fall and K. Varadhan, The ns Manual, http://www.isi.edu/nsnam/ns/ns-documentation.html, 2009.

[7]. C. Bettstetter and C. Wagner. The Spatial Node Distribution of the Random Waypoint Mobility Model. *Proc of the 1st German Workshop Mobile Ad hoc Networks*, 2002.