An Estimated Distance-Based Routing Protocol
For Mobile Ad hoc Networks

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Abstract—
In mobile ad hoc networks (MANETs), the network topology changes frequently and unpredictably due to the arbitrary mobility of nodes. This feature leads to frequent path failures and route reconstructions, which causes an increase in the routing control overhead. Thus, it is imperative to reduce the overhead of route discovery in the design of routing protocols of MANETs. In this paper, we propose an estimated distance (EstD)-based routing protocol (EDRP) to steer a route discovery in the general direction of a destination, which can restrict the propagation range of route request (RREQ) and reduce the routing overhead. In the EDRP, the change regularity of the received signal strength (RSS) is exploited to estimate the geometrical distance between a pair of nodes, which is called the estimated geometrical distance (EGD). Simulation experiments based on a random waypoint (RWP) model show that the EGD can effectively reflect the actual distance when it is less than the expected value of the distance [which is called the estimation radius (E-Radius)] between any node pairs. We also propose an estimated topological distance (ETD), which is a topology-based EstD, as an aid to the EGD, which can mitigate the effect of inaccurate EGD. The EstD is a combination of EGD and ETD. In the protocol, every node evaluates the link quality through the computational process of the EGD to eliminate the weak links and then uses the EstD (EGD and ETD) to steer the RREQ packets toward the destination.

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INTRODUCTION

MOBILE ad hoc networks (MANETs) are multihop wire- less networks with mobile nodes that can move freely. Due to a dynamic topology and limited resources, developing a dynamic routing protocol that can efficiently find a routing path with low control overhead is crucial to MANETs.

In MANETs, since the nodes arbitrarily move, the network topology changes frequently and unpredictably. The frequent link breakages lead to frequent path failures and route reconstructions, which increase the overhead of the routing protocol and result in lower packet delivery ratio and longer end-to-end delay. It is very important to reduce the routing overhead in route discovery and maintenance. In view of this, we propose a novel route discovery mechanism based on the estimated distance (EstD) to reduce the control overhead of routing protocols in MANETs.

Many routing protocols have been proposed for MANETs in the past few years.
According to whether they depend on physical position knowledge, these protocols can be divided into topology- and position-based protocols. The topology-based routing protocols use link information to establish a path. When a node needs to discover a route, it broadcasts a route request (RREQ) packet to its neighbors. Due to a lack of position information, each node blindly rebroadcasts the received RREQ until the route is established. Although flooding is an effective mechanism for route discovery, it propagates the RREQ through the entire network, which is an unnecessary operation.

The initial motivation of our protocol is as follows: if a source node or an intermediate node possesses distance or direction information about a destination node, then it can be used to steer the route discovery toward the general direction of the destination. The directed route discovery may restrict the propagation of RREQ packets within a narrow region, which includes the destination, and avoid the region that is far away from the destination. Thus, the number of RREQ packets can significantly be reduced.

Position-based routing protocols that know the physical position of the nodes have a feature to restrict the propagation of RREQ packets within a narrow region. However, the geographic knowledge is not available in many scenarios. In the absence of positioning service, we need a method to estimate the distance or direction to the destination. Thus, we combine the position-based routing features into on-demand routing protocols and propose an EstD-based routing protocol (EDRP) in the absence of positioning service to improve the route discovery.

**PROPOSAL STATEMENT**

We propose an algorithm to estimate the distance of two nodes without positioning service. The EstD includes two parts: a) The estimated geometrical distance (EGD) b) The estimated topological distance (ETD).

By using the EstD, we divide the entire network area into three zones: a) src-Zone; b) dst-Zone; and c) other-Zone. In each different zone, we adopt a different strategy to forward RREQ packets.

We propose a method utilizing the computational process of the EGD to evaluate the quality of link between neighbors and then exclude the weak links.

By the combination of exclusion of weak links and utilizing the EstD (EGD and ETD) to steer the propagation direction of RREQ packets to the general direction of the destination, the protocol can significantly reduce the routing overhead and improve the routing performance in dense or high-mobility networks.

**ESTIMATING GEOMETRICAL DISTANCE BASED ON CHANGE REGULARITY OF RECEIVED SIGNAL STRENGTH IN CONTACT TIME**

This section describes the computation of EGD and analyzes the properties of the EGD. By using the properties, we design an efficient routing protocol.

A. Computation of EGD

To estimate the future geometrical distance of a two-node pair after the two nodes left each other’s transmission range, we summarize the change regularity of the distance when they are in contact time. The change regularity of distance in contact time can be used to estimate the future distance because the mobility process has a locality feature.
A change in distance can be reflected by a change in the RSS. Since the RSS measurement is available for almost all wireless devices we can use the measured RSS and radio propagation model to calculate the distance. This idea is somehow related to the signal-stability-based adaptive (SSA) routing protocol, and the distinctive feature of the SSA is to use the signal strength to find and maintain stable routes. However, our idea is to use the change of signal strength to obtain the correlation of distance and time.

The researchers in positioning have taken into account the error of RSS and have obtained many valuable results that can be used in our routing mechanism. The EGD is computed as follows.

Fig. 1. Calculation of EGD

We assume that nodes $N_i$ and $N_j$ move at velocities of $v_i$ and $v_j$. If we consider node $N_i$ as a reference frame, then node $N_j$ moves at a relative velocity of $v = v_j - v_i$. According to the locality feature, node $N_j$ keeps this relative velocity in some distance.

Fig. 1 shows the calculation of the EGD. When node $N_j$ is in node $N_i$’s transmission range, assuming at times $T_0$, $T_1$, and $T_2$, node $N_i$ receives packets from $N_j$ with signal strengths $P_0$, $P_1$, and $P_2$, then $N_i$ can use a radio propagation model to calculate the distances $D_0$, $D_1$, and $D_2$ from $N_j$. Using the six values of $T_i$ and $D_i$, $i = 0, 1, 2$, node $N_i$ can obtain the relative velocity $v$ of $N_j$ with itself. We assume that at time $T$ ($T > T_2$), node $N_j$ still keeps the relative velocity $v$ with $N_i$, and the distances between nodes $N_j$ and $N_i$ are represented by the following equations:

$$\begin{align*}
D_1^2 &= D_0^2 + (vt_1)^2 - 2D_0(vt_1)\cos\theta \\
D_2^2 &= D_0^2 + (vt_2)^2 - 2D_0(vt_2)\cos\theta \\
D(t)^2 &= D_0^2 + (vt)^2 - 2D_0(vt)\cos\theta
\end{align*}$$

(1)

Where $t_1 = T_1 - T_0$, $t_2 = T_2 - T_0$, and $t = T - T_0$. According to the first two equations, we can solve $v$ and $\theta$, and then, we derive

$$D(t) = \sqrt{At^2 + Bt + C}$$

Where

$$\begin{align*}
A &= -\frac{1}{t_1 t_2} D_0^2 - \frac{1}{t_1(t_2 - t_1)} D_1^2 + \frac{1}{t_2(t_2 - t_1)} D_2^2 \\
B &= -(\frac{1}{t_1} + \frac{1}{t_2}) D_0^2 + \frac{t_2}{t_1(t_2 - t_1)} D_1^2 - \frac{t_1}{t_2(t_2 - t_1)} D_2^2 \\
C &= D_0^2
\end{align*}$$

(2)
Note that $D_0$, $D_1$, and $D_2$, as well as $T_0$, $T_1$, and $T_2$, are iteratively calculated. That means when node $N_i$ receives the $k$th ($k > 2$) packet from $N_j$, we do the following iterative calculation: $T_0 \leftarrow T_k - 2$, $T_1 \leftarrow T_k - 1$, and $T_2 \leftarrow T_k$; and $D_0 \leftarrow D_k - 2$, $D_1 \leftarrow D_k - 1$, and $D_2 \leftarrow D_k$. Thus, $T_i$ and $D_i$, $i = 0, 1, 2$, are always the last three packets’ transmission times and distances. Then, each node needs a table to store the encounter information such as $T_i$ and $D_i$, $i = 0, 1, 2$, and the size of the table is $O(n)$, where $n$ is the number of nodes.

Now, $EGD\ (t) = D(t) = (At^2 + Bt + C)^{1/2}$ is represented as a function of time $t$, and $t$ is the difference between the current time and the time of the third to the last packet received from node $N_j$.

Fig. 2. Empirical mean of distance conditional on the EGD.

B. Properties of EGD

To observe the relationship between the EGD and the actual distance, we plot the empirical conditional mean of the actual distance between node pairs, conditional on their EGD. Fig. 2 shows this empirical mean of the distance for the RWP model, over a rectangle surface, whose length is 1600 m and its width is set from 600 to 1600 m. Each point in the graph is computed by considering all the node pairs whose EGD is within a certain interval and averaging over the distance between these node pairs.

In our research, we find that the turning point of the EGD converging to a constant value happens near the expected value $E\{L\}$ of distance $L$ between any two independent random points sampled from a uniform distribution. For a rectangular network area $a \times b$ ($a \geq b$), letting $b = ka$ ($0 < k \leq 1$), the expected value $E\{L\}$ of $L$ is represented in below equation.

$$E\{L\} = \left\{ \frac{1}{15} \left[ \frac{1}{k^2} + \frac{1}{k^3} + \sqrt{1 + k^2} \left( 3 - \frac{1}{k^2} - k^2 \right) \right] + \frac{1}{6} \left[ k^2 \text{arcosh} \left( \frac{\sqrt{1 + k^2}}{k} \right) + \frac{1}{k} \text{arcosh} \left( \sqrt{1 + k^2} \right) \right] \right\} \times a$$

with $\text{arcosh}(x) = \ln(x + (x^2 - 1)^{1/2})$. The use of (3) is further explained in detail as follows.

From Fig. 2, the EGD carries no information about the relative positions of two nodes when it is greater than $E\{L\}$. That implies that only when the EGD is less than $E\{L\}$ can it be
used to estimate the actual distance of node pairs. Thus, we use $E\{L\}$ as an E-Radius and a circle, whose center is node $N_i$ and radius is set to E-Radius, as node $N_i$ ’s E-Zone.

$E\{L\}$ is monotonically increasing with respect to $k$. For $k \to 0$, $\lim_{k \to 0} E\{L\} = \frac{1}{3}a$, and for $k = 1$, $E\{L\} = 0.5214a$. Then, we have the following property.

![Graph](image.png)

**Fig. 3. Maximum length/Expected length**

**Property 1:** For any network area $a \times b (a \geq b)$, the effective estimate range of the EGD is between $(0.3333a, 0.5214a]$, and the effective estimate range increases as $b/a$ increases.

For any node pairs in a rectangle of $a \times b(a\geq b)$, the maximum distance among them is

$$M\{L\} = \sqrt{a^2 + b^2} = \sqrt{1 + k^2} \times a \quad (b = ka).$$

To inspect the capacity of estimation using the EGD, we define $H\{L\} = M\{L\}/E\{L\}$ to describe how many E-Zones can cover the whole distance between any node pairs.

When $k$ increases from 0 to 1, the $H\{L\}$ is shown in Fig. 3. From Fig. 3, $H\{L\}$ is monotonically decreasing with respect to $k$, and the maximum $H\{L\}$ is 3 (when $k \to 0$). Then, we have the following property.

**Property 2:** For any network area of $a \times b (a \geq b)$, at most three E-Zones can cover any node pairs in this area.

According to Property 2, the distance of any source and destination nodes cannot be greater than three E-Radius. That implies that a path from a source to a destination at most passes through three E-Zones: 1) the zone that takes the source node as a center; 2) the zone that takes the destination node as another center; and 3) a mid-zone, if it exists, which is in the middle of the preceding two zones.

C. Dividing Network Area into Zones Based on E-Radius

As described in previous section, a node can effectively estimate the distance to other nodes that are in its E-Zone. Then, we define the E-Zone of the source node as src-Zone and the E-Zone of the destination node as dst-Zone. Except for src-Zone and dst-Zone, according to Property 2, at most, three E-Zones can cover any node pairs, and thus, the rest area other-Zone is only one of the three situations:

1) mid-Zone, which is in the middle of src-Zone and dst-Zone;
2) src-Bound, which is the bound zone in the side of src-Zone; and
3) dst-Bound, which is the bound zone in the side of dst-Zone. One example of the divided zones is shown in fig.4.
To investigate the relationship between $L$ and E-Radius, we obtain the probabilities of $L \leq \text{E-Radius}$, $L \leq 2\text{E-Radius}$, and $L \leq 3\text{E-Radius}$, which are shown in Fig. 5., presented the probability density function (pdf) of $L$ and the expected value $E\{L\}$ of $L$ (refer to [20, Eq. (21)]). We have mentioned that E-Radius is equal to $E\{L\}$. According to the pdf of $L$ and its expected value $E\{L\}$, we can obtain formulas of the probability of $L \leq \text{E-Radius}$, $L \leq 2\text{E-Radius}$, and $L \leq 3\text{E-Radius}$ about $a$ and $b$, where $a$ and $b$ are the length and width of a network area, respectively. We can use these formulas to plot Fig. 5. We find that, for most of the network area, the probability of $L \leq 2\text{E-Radius}$ is greater than 90%, which implies that for any source and destination nodes, the probability of the intersection of src-Zone and dst-Zone is greater than 90%, and the probability of existing mid-Zone is lower than 10%.

Now, we can obtain the basic property of the propagation of RREQ packets in route discovery. For most route discoveries, the RREQ packet is either in src-Zone or in dst-Zone, and the situation that needs to pass through the mid-Zone is less than 10%. src-Bound and dst-Bound should be avoided. Then, according to the preceding property, we design a new routing protocol.

**PROTOCOL ANALYSIS AND PERFORMANCE EVALUATION**

We compare the performance of our proposed protocol with that of other protocols using NS-2 simulator. We implement our proposed protocol by modifying the current AODV implementation in NS-2. We also compares the routing performance of the EDRP with that of the PGP in, which is a similar protocol in recent literature, and the conventional AODV. The PGP uses hints that combine the elapsed and contact times between two nodes to estimate the distance of a node to the destination and uses it to steer the RREQ to the destination.

**CONCLUSION**

In this paper, we have proposed EDRP to reduce the routing control overhead by restricting the propagation range of RREQ packets. The EstD is a combination of EGD and ETD. We use the EstD to divide the network area to 3 zones, and in each different zone we adopt a different strategy to forward RREQ packets. The EGD uses the change regularity of RSS to estimate the future distance after a node leaves the transmission range of another node, and thus, it can reflect the future information to a certain extent.
REFERENCES