A Location Prediction Algorithm for Directional Communication

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Abstract—Directional antennas concentrate the transmitted power into a specified direction and form a directional beam pointing to a receiver. Directional communication can bring benefits in terms of power consumption, spatial reuse and security. Using direction antennas implies the transmitters must know the directions of receivers. In this paper, we propose an efficient algorithm to predict the future location of a mobile node in Ad hoc networks where nodes use directional antennas to communicate with each other. Our algorithm is based on the mobility characteristic we extracted from a real military mobile Ad hoc networks trace, and the algorithm efficiency is about 95.3%. Our algorithm can be employed by directional antennas with adaptive beamwidths or fixed beamwidth.

I. INTRODUCTION

Mobile Ad hoc networks (MANETs) consist of wireless mobile nodes that communicate with each other. The communication is used in collaborative, distributed mobile computing and especially in scenarios where wired networks are simply ineffective or implausible, such as disaster recovery and survival search. Typically, the common assumption about ad hoc network communication is that nodes are equipped with omni-directional antennas and communication among them is dynamic and temporary.

Omni-directional antennas have a 360° coverage angle and do not need to be pointed at each other when they communicate. Omni-directional antennas send signals towards all horizontal directions and form an approximate circular radiation region [1]–[3]. However, since the power is broadcasted in all directions, and only the receiver in a specified direction should receive the signals, a lot of energy is wasted.

Directional antennas have several advantages over omni-directional antennas. A directional antenna can form a directional beam pointing to the specified direction of the receiver. This increases the potential for spatial reuse or decrease the power consumed by the transmitter [18]–[20]. On the other hand, those nodes outside of the radiation region of a directional antenna receive little radiated power from the transmitter and have little chance receiving interference from the transmitting node.

II. RELATED WORK

Location management includes two strategies: location tracking and location prediction. Location tracking periodically records the current location of the mobile nodes, and is a passive strategy. Existing location tracking techniques typically use distance or angle measurements from a fixed set of reference points and apply triangulation techniques to solve for unknown locations [4], [5].

S. Roy et al. proposed a mechanism for estimating the location of each node in the network using a pair of reference nodes and the angle of arrival of best signal from
each reference node [4]. To initiate a location tracking, a node broadcasts 12 directional beacons at 30° interval. Each node records the received signal strength and the direction from which it receives this packet in its Neighborhood link State Table, and sends back a response that contains the received signal strength. Then, the transmitter knows the best possible direction to access each of its neighbors. However, as nodes in the mobile Ad hoc networks move frequently, they must always update their information about neighbors by broadcasting the tracking packet and waiting for the responses.

Jaehoon Jeong et al. suggested a minimal contour tracking algorithm (MCTA) that uses the vehicular kinematics to reduce the tracking area [5]. Since the mobile node could not reach all the tracking area during a limited time according to its vehicular kinematics, they prune out from the tracking circle the most unlikely region that the node cannot visit during some limited time. MCTA minimizes the number of working sensor nodes to save communication energy consumption. This algorithm requires the user to put a lot of sensors into an area. However, this is not always available in all Ad hoc network applications.

Location prediction is an active dynamic strategy, which forecasts a mobile node’s location based on this node’s movement model. One way to know the future location of a mobile node is to require the node to indicate its destination and speed; we can employ this node’s future destination and current speed to calculate its future location [8]. Unfortunately, in some scenarios, the mobile node does not know its destination or next direction. Some researchers have proposed some mobility prediction algorithms.

Liu and Maquire proposed an aggressive mobility management scheme, in which an algorithm predicts the future location of a mobile user according to the user’s previous movement patterns [6]. By combining the predictive mobility management algorithm with a mobility agent scheme, the management system can prepare service and data at the locations to which the user is moving. The main drawback of their algorithm is its high sensitivity to so-called “random movements.” Any movement that cannot be classified by the simple mobility patterns defined is classified as random movement. Prediction performance of their algorithm decreases linearly with the increase in the random factor.

In [7], G. Yavas et al. proposed a data mining approach for location prediction in mobile environments. They divided the coverage region network into neighboring cells and use a directed graph to represent the network region. Cells in the coverage region are considered to be the vertices of this graph and an edge between two vertices means these two cells are neighboring regions. Then they use sequential pattern mining method to mine user mobility patterns from user actual paths. In order to employ their method, users must know the condition of coverage region and develop a directed graph. The algorithm can be used in the location prediction in a fixed and limited region and already having users’ mobility traces in that region.

Figure 1 depicts the tracks of 64 jeeps. From this figure, we know these 64 vehicles moved from the start point to the end point along two separate routes as the two solid lines show. We focus on the directional patterns of these mobile nodes. Direction characteristic describes a node’s direction of travel. Prediction performance of their algorithm decreases linearly with the increase in the random factor.

III. MOBILITY ANALYSIS

The traces we studied here were collected from a military MANET consists of 64 vehicles. The vehicles were organized into teams and traveled over an area of approximately 240 square kilometers near Lakehurst, New Jersey, USA for 180 minutes. The system logged every vehicle’s ID and GPS geographic locations throughout the period each second. We do not analyse the characteristics of synthetic mobility models such as Random Way Point, because the mobility characteristics in hostile conditions are totally different from that in synthetic condition.

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Since formulation (1) does not tell us whether the vehicle turned left or right, we obtain this information using coordinate transform. In the original coordinate system, the angular distance between the last direction vector \( \vec{AB} \) and the x-axis is \( \alpha \). In the coordinate transformation, we define the direction of the last direction vector \( \vec{AB} \) as the positive direction of x-axis in the new coordinate system as Figure 3 shows. Then we calculate the new coordinates \((x', y')\) of point C in the new coordinate system using equation (2). If the vehicle’s new coordinate \( y' \) is positive, it means that the vehicle turns left, otherwise the vehicle turns right and we replace \( \theta \) with \(-\theta\).

\[
(x', y') = (x, y) \cdot \begin{pmatrix} \cos \alpha & -\sin \alpha \\ \sin \alpha & \cos \alpha \end{pmatrix}
\]

(2)

Figure 4 is the frequency histogram of the relative direction angles of the above vehicles during the 180 minutes of the trace. This figure shows that most of time, a vehicle turns its original direction to left or right slightly. Rarely did a mobile turn sharply.

![Image](image-url)

**Fig. 3. Coordinate transform**

**Fig. 4. The frequency histogram of relative direction angles**

Table 1 depicts the distribution of absolute relative direction angle during the whole 180 minutes. From the statistics we can simply conclude that a mobile node does not select its new direction randomly from a uniform distribution \( (0^\circ, 180^\circ) \). Most of the absolute relative direction angles are smaller than \( 30^\circ \). We can make use of this characteristic to predict a node’s future direction.

### IV. Antenna Model

Antennas are either omni-directional antenna or directional antenna [2], [3]. Omni-directional antennas scatter the signals in all directions and only a small faction of the overall energy reaches the desired receiver. Directional transmission overcomes this disadvantage by concentrating signal strength in the main lobe direction and form a directional beam towards the specified direction of the receiver.

![Image](image-url)

**Fig. 5. RF radiation patterns of omni-directional antenna (a) and directional antenna (b)**

Figure 5 illustrate the RF radiation patterns of the idealized omni-directional antenna and a directional antenna [13], [14]. The smaller parasitic lobes in Figure 5 (b) are called "side lobes" that potentially can produce harmful interference to other receivers. However, for simplicity, we do not consider side lobes for the rest of the paper.

In our model, we assume an antenna can work in two modes: omni mode and directional mode, it sends data in directional mode and receives data both in omni mode and directional mode [13], [14]. Nodes are equipped with GPS modules to know their GPS geographic locations. If nodes have nothing to transmit, their antennas work in omni mode to detect signals. When a node wants to send some data while it doesn’t know the location of the receiver, its antenna will work in omni mode and transmit a Request To Send (RTS) message to the whole area around it. If the desired receiver receives this RTS, it sends back a Clean To Send (CTS) message to the sender. The CTS message includes the receiver’s GPS geographic location. When the sender receives the CTS from the receiver, it knows the receiver’s GPS geographic location, then it switches the antenna in directional mode and forms a directional beam in the direction of the receiver to transmit data [15]–[17]. After a receiver has received all the data, or the transmission has lasted for a silent duration, the receiver

<table>
<thead>
<tr>
<th>Angle(°)</th>
<th>0-30</th>
<th>30-60</th>
<th>60-90</th>
<th>90-120</th>
<th>120-150</th>
<th>150-180</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution</td>
<td>93.08%</td>
<td>3.9%</td>
<td>1.73%</td>
<td>0.43%</td>
<td>0.43%</td>
<td>0.43%</td>
</tr>
</tbody>
</table>

**TABLE I**

DISTRIBUTION OF ABSOLUTE ANGULAR CHANGE IN DIRECTION.
will send an Acknowledgement (ACK) packet to the sender to update its current location. If a receiver can not continue to receive the data that are not finished, it will broadcast a Request To Resend (RTR) packet in all directions to inform the sender its current location and the sender will resend the data that is sent in last silent duration. The receiver’s antenna can receive data both in omni and directional mode. Receiver and sender can communicate over a larger distance when both antennas are operating in directional mode.

An antenna’s beamwidth is usually understood as the half-power beamwidth, i.e., the angle between the two directions in which the directive gain of the major radiation lobe is one half of the peak radiation intensity [3]. Half the power expressed in decibels is -3dB, so the half power beamwidth is sometimes referred to as the 3dB beamwidth as Figure 6 shows.

![Fig. 6. The beamwidth of directional beam](image)

It is possible to make adaptive antennas using arrays of radiating elements [22]. For a linear array, we can steer the beam by altering the phase and amplitude of the currents applied to each radiating element and we could change the beamwidth by changing the effective number of radiating elements. Therefore, the altering of beamwidth is not continuous and can only be done with finite increments. In general, the larger the extent of the array elements the narrower is the beamwidth. Here we consider the ability of altering the beamwidth to be an optional property. As will be shown in the next section, as long as a directional antenna can provide sufficient beamwidth, our algorithm can predict a mobile node’s future location efficiently.

V. LOCATION PREDICTION ALGORITHM

Here we employ the analysis we have made to develop our location prediction algorithm. We begin by introducing some assumptions and preconditions.

A. Precondition

- In our model, the receiver sends to the transmitters their GPS geographic locations only once during a specific time interval call the silent duration. During silent durations, a sender must predict a receiver’s location.
- A receiver’s velocity does not vary acutely when it is moving, so the distance it covers during the silent duration is approximately the same.
- The directional antenna can alter its beamwidth, which can only be \( \theta_i \), \( i = 1, 2, ..., n \), where \( \theta_1 < \theta_2 < ... < \theta_n \).
- According to the direction characteristic we have studied from the traces, in most situations, a node turns its original direction to left or right within 30 degree range. We assume a node’s next relative direction angle to be still in the range (-30°, 30°).

B. Algorithm

We use the following steps to predict the locations of a receiver during the silent duration. We denote the last two geographical locations of a receiver as \( A (x_{i-1}, y_{i-1}) \) and \( B (x_i, y_i) \), respectively. As illustrated in Figure 7, we denote the distance between the \( A \) and \( B \) by \( d_i \) and the distance from the transmitter to the receiver by \( D_i \).

**Step 1.** Make a line \( l \) passing through the last two locations \( A \) and \( B \). The formulation of this line is \( y = kx + c \), where \( k \) and \( c \) are calculated by equation (3).

\[
\begin{align*}
k &= \frac{y_i - y_{i-1}}{x_i - x_{i-1}}, \\
c &= \frac{x_i y_{i-1} - x_{i-1} y_i}{x_i - x_{i-1}}, \quad x_i \neq x_{i-1}.
\end{align*}
\]

**Step 2.** Make an equilateral triangle whose one vertex is at \( B \) position and its center \( (x_{i+1}, y_{i+1}) \) is on line \( l \) as Figure 7 shows. The length of edges of this equilateral triangle is \( d_i \) that is the length of the distance this node covers during last silent duration. We calculate the coordinate of the equilateral triangle’s center, \( (x_{i+1}, y_{i+1}) \), by equation (4).

\[
\begin{align*}
x_{i+1} &= x_i + \frac{\sqrt{3}d_i}{3} \frac{x_i - x_{i-1}}{|x_i - x_{i-1}|} \cos(\text{arctan}(|k|)), \\
y_{i+1} &= y_i + \frac{\sqrt{3}d_i}{6} \frac{y_i - y_{i-1}}{|y_i - y_{i-1}|} \sin(\text{arctan}(k)),
\end{align*}
\]

\( x_i \neq x_{i-1}, y_i \neq y_{i-1} \).

**Step 3.** Draw a circle that can contain the equilateral triangle with smallest radius. The circle and the equilateral triangle have the same center, \( (x_{i+1}, y_{i+1}) \), and the radius of the circle is \( r_i \):

\[
r_i = \frac{\sqrt{3}d_i}{3}.
\]

**Step 4.** Calculate the needed beamwidth by equation (6).

\[
\alpha = 2 \arcsin\left(\frac{r_i}{D_i}\right),
\]

where \( r_i \) is calculated by equation (5), \( D_i \) is the distance from the transmitter to the receiver. The practical beamwidth employed is

\[
\text{beamwidth} = \begin{cases} 
\theta_1 & \text{if } \alpha \leq \theta_1; \\
\theta_i & \text{if } \theta_{i-1} \leq \alpha \leq \theta_i; \\
\theta_n & \text{if } \alpha \geq \theta_n.
\end{cases}
\]
C. Evaluation

We employ the method described in [12] to evaluate our algorithm. We split the data set in two sets: a training set and a test set. We made the mobility analysis on the training set. The algorithm is then used to predict the locations for the node in the test set. We define the algorithm efficiency to be the average probabilities of a mobile node being in the scope of our transmitter’s directional radiation beam and use it to evaluate our algorithm.

We now describe the simulation experiment for investigating the effect of our algorithm. We assume nodes in our trace to be the receivers, and they move as they did in the trace. We randomly select 50 positions in the experiment area as transmitter locations where we place a directional antenna to send signals. We calculate the average probability of a receiver being in the transmitters’ directional beam during the 180 minutes of the trace. The available beamwidths in our experiment are 5 and 10 degree. To make the experiment more credible, we further repeat the experiment 50 times and use the average value. We assume the silent duration is 10 seconds.

Figure 8 is average probabilities of a mobile node being in our transmitters’ directional radiation beam. This figure shows that these average probabilities are usually very high. The average algorithm efficiency of 50 experiments is 95.3%. However, in the simulation, nodes communicate with each other using omni antennas. We can see that though we employ directional antennas to transmit signals, our algorithm still attain very high efficiency in location prediction. Most importantly, using directional antennas to send signals has clear benefit in terms power consumption, spatial reuse and security [18]–[21].

Figure 9 shows the algorithm efficiencies with different antenna beamwidths. In this experiment, we assume the beamwidth of the directional antenna is fixed. As we can see from Figure 9, if an antenna’s beamwidth is as narrow as 2°, the algorithm efficiency is less than 0.7. This is reasonable because if the beamwidth is narrower than the beamwidth our algorithm needs, the beam region of the directional antenna cannot cover the circle in which the receiver is moving. Therefore the algorithm efficiency will decrease. When the beamwidth is wider than 10°, the algorithm efficiency is almost constant, because if most of the node’s future locations are in the area that our algorithm predicts with 10°beamwidth, it does not make much difference in algorithm efficiency even if we increase this antenna’s beamwidth.

Figure 10 shows the algorithm efficiencies with different silent durations. This figure shows that the algorithm efficiency decreases sharply when the silent duration increases. If the average velocity of a vehicle in our trace is about 60km/h, this vehicle can cover more than 330 meters during 20 seconds or 500 meters during 30 seconds. During the distance of more
than 300 meters, a vehicle might change its direction with an absolute relative direction angle being larger than 30°.

Fig. 10. Algorithm efficiency with different silent durations.

VI. CONCLUSION

In this paper, we have proposed an efficient algorithm to predict the future location of a mobile node in Ad hoc networks. In this network, nodes employ directional antennas to communicate with each other. Using directional antenna to send signals can bring us benefit in power consumption and spatial reuse. We apply the direction characteristic extracted from a trace in our location prediction algorithm. Experiment results show the average algorithm efficiency is as high as 95.3%. We also studied the influence of different antenna beamwidths and silent durations on the algorithm efficiency, and explained the reasons of the influence. Directional antennas with adaptive beamwidths or fixed beamwidth can make use of our algorithm to predict a mobile node’s future location.

For future work, we will consider the movements and communication between homogeneous mobile nodes, different adaptive transmission strategies as well as evaluate the security aspects of the algorithm to its efficiency.

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REFERENCES