Prediction of Movement of Wireless Nodes in Mobile Ad-hoc Networks

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***Abstract*—The main aim of the paper is a generic framework for prediction algorithm of the direction and speed of future movement of nodes based on the information of current net-work status. Since the nodes move continually with only a limited amount of energy, it is necessary to focus on the energy efficiency of the communication process during designing new methods and functions. Recently, the combination of the directional antennas within mobile devices has been studied in many areas. The main contribution of this paper is improvement the mobility prediction mobile nodes which is provided with directional antennas.**

Keywords—Ad hoc network, mobility model, GPS, mobility prediction.

I. Introduction

A Mobile ad hoc network is a wireless network of mobile nodes connected by a wireless link without central control. Each node in a MANET can move independently in any direction, therefore links to other devices will change frequently. And each node makes its decision based on the network situation, without any reference infrastructure and nodes can thus behave as routers or hosts. Since the nodes in MANET move continually, there are weak and untrustworthy links between them. So the tracking of movement is very important if the location of MNs is to be predicted.

Generally, mobile prediction is a method for estimating the trajectory of the future position of the nodes. This topic has been studied in various fields, such as cellular networks and routing for wireless mobile ad hoc networks [16], [17], [18].

It is clear that the application of cellular networks operates with more different prerequisites for mobility prediction than for ad hoc networks, the hardware of the networks and the behavior of the nodes are radically different. However, the problem of mobility prediction is the same, whether used in wireless networks with fixed infrastructure or in wireless mobile ad hoc networks.

The mobility prediction in MANET has some general assumptions as shown in following [15]:

- Each node can move in the network.
- There is not any a pre-information about the physical environment of the network.
- It is possible to observe the current geographic location, speed and moving direction of a node via GPS.
- The behavior of the nodes shows some pattern: since the nodes move randomly, this assumption is very important to estimate the future situation of the network.

In general, there are two main parts of the mobility prediction algorithm, the state observation and the prediction. The state observation is responsible for tracking the case of the movement of the node such as a GPS device [1]. The output of the observation is the input of the prediction part which forms the system model from these input parameters.

One of the mobility prediction methods used in MANET depends on the previous node movement patterns to predict the future location of a mobile node. For modeling the mobility behavior, this method use different mobility models such as circle models and track model [13]. But this method is not suitable when the changes in node's movement are unpredictable. Another mobility prediction method depends on the feature of MANET's physical topology; therefore it needs to know the node location and mobility information by using Global Positioning System (GPS) in the outdoor environment [14].

II. Mobility Models for MANET

Mobility models represent the behavior of mobile nodes, and how their location and velocity change over time. Since mobility modeling plays an important role in the simulations of MANET, many mobility models have been studied to mimic the movements of real mobile nodes. A good survey of most of the mobility models used for simulation can be found in [2]. Some mobility models are discussed in the following:

A. Random walk mobility model:

The Random Walk was first represented mathematically by Einstein in 1926 [3]. In this mobility model, a mobile node can move randomly, which means that the direction and speed of moving are selected randomly with uniformly distributed. Both the speed and the direction are limited by a pre-defined range, [speedmin; speedmax] and [0; 2π] respectively.

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Each movement in the random walk mobility model occurs in either a constant time period t or at a constant distance travelled d, at the end of which a new direction and speed are calculated. If a node reaches the border of the area, it selects a new direction. Many derivatives of the random walk mobility model have been studied including the one-dimensional, two-dimensional, three-dimensional, and d-dimensional walks [4]. Fig. 1 shows an example of the movement pattern of a mobile node based on the Random Walk Mobility.

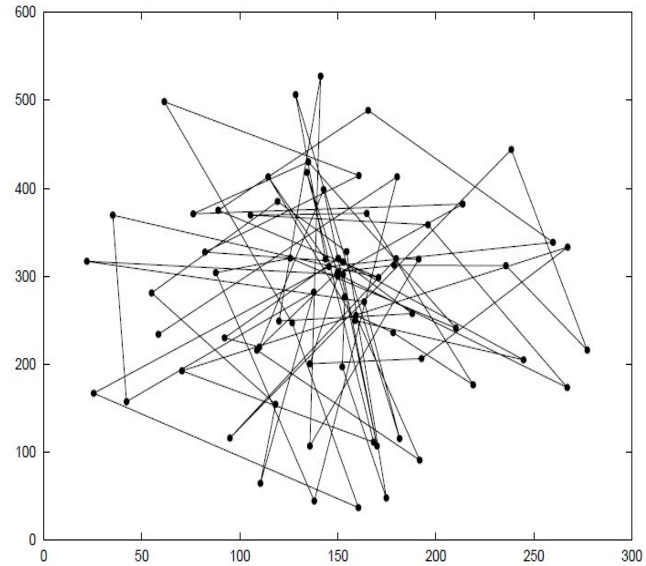

Fig. 1. Movement pattern of an MN using the 2-D Random Walk Mobility Model (time).

B. Random waypoint mobility model:

The Random Waypoint is one of the most popular mobility models used to evaluate the mobility prediction in MANET. With this model, the node moves from its current position to a new one by randomly selecting destination and speed. The distribution of speed is uniform within a range [speedmin, speedmax]. When the node reaches its destination, it waits for a certain time (pause time) and then starts moving again

We note that the random waypoint mobility model is similar to the random walk mobility model if the pause time is zero and [speedmin; speedmax] random waypoint= [speedmin; speedmax] random walk [2], [5]. An example of the random waypoint movement is shown in Fig. 2.

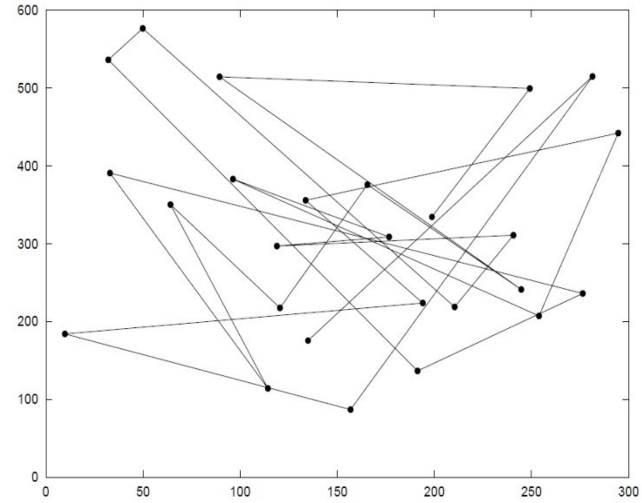

Fig. 2. Travelling pattern of an MN using the 2-D Random Waypoint Mobility Model.

III. DIRECTIONAL ANTENNAS BASED MANET

Typically, a MANET uses omnidirectional antennas, it means each node can transmit and receive signals from all directions. With MAC protocols such as IEEE 802.11, since two nodes communicate using a given channel, all the other neighbouring nodes keep silent. Recently, the combination of the directional antennas within mobile devices has been studied for many areas, because of the advantages of directional antennas in terms of power consumption, reducing the interference, and increasing the packet throughput. Many MAC protocols have been proposed that suitably adapt 802.11 to directional antennas [6], [7], [8], [9], [10]

A. Antenna model

It is supposed that there is a MANET of n Mobile Nodes (MNs), where each MN has directional antennas with non-overlapping directions and all nodes use the same wireless channel. The antennas of a node cover all directions. The MN is equipped with a system for defining its position and speed, such as the Global Position System (GPS), which also provides a synchronized clock [11]. The MN has a Directional NAV (DNAV), when the medium is busy in a certain direction, the DNAV defers the node's access the medium in this direction. A node is in the Omni mode when it is not aware of the direction from which a signal might be coming. When a signal is detected, the antenna begins to receive the signal with an omnidirectional gain. While the node is receiving the signal, the antenna switches to the directional mode. However, there is a need for predicting the right direction of transmission or reception [8]. The main problem of using directional antennas is caused by the frequent node mobility, there is a need for predicting the right direction of transmission or reception.

B. Location and Mobility Aware (LMA) MAC protocol

MAC protocol is adapted for MANETs with directional antennas [12]. It is assumed that each MN has a Location Table (LT) in which the location information of its neighbours is

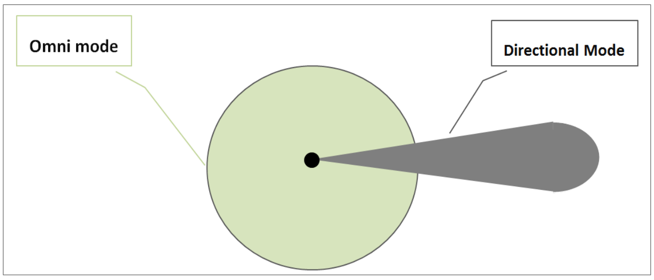

Fig. 3. Operation mode of the node.

temporarily stored; however, at the beginning of communication the LT is empty. We assume that an idle MN listens to the medium using all antennas; this is called the Omni-Listen (OL) mode. On the contrary, when an MN listens using a directional antenna, this is called the Directional-Listen (DL) mode, Fig. 4. The MN updates its NAV Directionally (DNAV) to prevent such an MN from access to the medium in the corresponding direction.

If there is a transmission between two nodes, the radiations of antennas have to be adjusted according to the predicted direction toward the destination node. The LMA MAC protocol assumes that all MNs move at a constant speed and angle during a short period of time, and the k^{th} item in the LT is:

$$LT(k) = (Timestamo(k), nodeID(k), position(x_k, y_k), Movingangle(\alpha_k), speed\,(S_k), TTL_k) \quad (1)$$

Where: $1 \le k \le n$, TTL_k is Time To Live of k^{th} content, $TTL_k = 0$ at each registration of $LT(k)$ and then TTL_k increases with time. When it exceeds a certain threshold T, the $LT(k)$ is deleted from the MN's LT.

When an MN intends to start a new transmission, it uses either an Omni-listen/ Omni- RTS (OL/ ORTS) or a Directional-listen/ Directional- RTS (DL/DRTS), depending on the current information in its LT. Fig. 6 illustrates the LMA MAC protocol where the medium is idle, the node A wants to send data to B, and A's LT does not have any information about the location of its neighbors.

Thus A uses the OL/ ORTS mode and sends an ORTS packet which includes the location information of A: the time instant of ORTS transmission (t_r), the node ID, the current position $P_A(t_r) = (x_A(t_r), y_A(t_r))$, the moving angle ($\alpha_A$) and the speed ($S_A$).

All A's neighbours (B, C, D), which listen to ORTS, will register A's information in their location tables, so the B's LT, C's LT and D's LT will be updated as:

$$LT_B(A) = LT_C(A) = LT_D(A) = (t_r, ID_A, P_A(t_r), \alpha_A, S_A, TTL_A) \quad (2)$$

where the value of TTLA is zero at every update of LT (A). And then the destination B responds by sending a DCTS, where the direction of CTS is calculated as follow:

$$\theta_{t_c} = \tan^{-1}\frac{y_B(t_c) - y_A(t_c)}{X_B(t_c) - X_A(t_c)} \quad (3)$$

where t_c is the time instant of sending DCTS from B to A, while $P_A(t_c)$ is calculated from as:

$$P_A(t_c) = \begin{cases} x_A(t_c) = \begin{cases} x_A(t_r) + S_A\cos\alpha_A(t_c - t_r) \\ y_A(t_r) + S_A\sin\alpha_A(t_c - t_r) \end{cases} \\ y_A(t_c) = \end{cases} \quad (4)$$

When MN C receives DCTS from B, it sets its LT and sets its DNAV timer, thus C will not be allowed to access the medium in this direction. But the node C can transmit to any other node which is out of the DNAV range and is in the C's LT. C has registered the location information of both MNs A and B, so it can adjust its DNAV(C), depending on the movement of these MNs.

Now A and B are aware of the location of each other. The directional data transmission is started according to the transmission angle θ_{data} from the node A to the node B where θ_{data} is computed as:

$$\theta_{data}(t_i) = \tan^{-1}\frac{y_A(t_i) - y_B(t_i)}{X_A(t_i) - X_B(t_i)} \quad (5)$$

Where t_i ranges between the starting and the stopping time instants for data transmission, so that $\theta_{data}(t_i)$ changes with time depending on the MN's movement, and it can be adapted on the basis of existing antennas. The position of nodes at t_i is calculated using the information of location in their LTs as:

$$P_A(t_i) = \begin{cases} x_A(t_i) = \begin{cases} x_A(t_r) + S_A\cos\alpha_A(t_i - t_r) \\ y_A(t_r) + S_A\sin\alpha_A(t_i - t_r) \end{cases} \\ y_A(t_i) = \end{cases} \quad (6)$$

$$P_B(t_i) = \begin{cases} x_B(t_i) = x_B(t_c) + S_B\cos\alpha_B(t_i - t_c) \\ y_B(t_i) = y_B(t_c) + S_B\sin\alpha_B(t_i - t_c) \end{cases} \quad (7)$$

After obtaining the transmission angle, the antenna beams of the nodes A and B are pointed in the predicted direction and the transmission can begin. If the data transmission is completed, the node B will send directionally ACK to the node A.

The LMA protocol is used in MANETs with directional antennas to predict the transmission angle between the transmitter and receiver. The predicted angle is not accurate, because the moving angle of the destination can be changed during the data transmission thus causing data loss. It is therefore important to calculate the time interval for which the node recorded in the LT will stay within the transmission range of the node which forms this LT. This time interval is calculated based on the distance between the transmitter and receiver and speed [12].

The prediction accuracy would be increased if the information of the nodes movement pattern was known.

As a matter of fact, MN moves randomly without reference to a defined path. When mobile nodes are equipped with directional antennas for both transmission and reception, the mobility prediction faces some of the challenges listed below:

- Accuracy of mobility prediction depends on complete awareness of the network topology and mobility behaviour of nodes.
- Mobility prediction is mostly based on a mobility model of the network, but it is impossible to achieve 100% accuracy. If nodes move regularly, the movement prediction can be more accurate. However, regular nodes can sometimes behave unpredictably.

IV. Mobility Prediction for MANET Networks

Let us suppose that each node can build its virtual map depending on its location over the time. The probability of visiting a location in the future depends on a fixed number of previously visited locations. Suppose there are finite possible locations $x_1, x_2, \ldots, x_n$ from independent observations of the node within a specified area. Thus $X_R = \{x_1, x_2, \ldots, x_n\}$ is the set of possible states of the position of node R. The matrix of transition probabilities between these positions is:

$$P = \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & & \vdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{pmatrix} = \begin{pmatrix} P_{1j} \\ P_{2j} \\ \\ P_{nj} \end{pmatrix} \tag{8}$$

where P_{ij} is the probability of move from position x_i to position x_j, and P_{ii} is the probability of stay in the same position. For example, if the node A located at position x_1 and has four probable positions, the set of states is $X_A = \{x_1, x_2, x_3, x_4\}$, as illustrated in Fig. 5. The first row P_{1j} of matrix P represents the probability of mobility from position x_1 to other positions $\{x_1, x_2, x_3, x_4\}$:

$$P_{1j} = \begin{pmatrix} p_{11} & p_{12} & p_{13} & p_{14} \end{pmatrix} \tag{9}$$

At each location i, the probability of the node moving to another location j is calculated as:

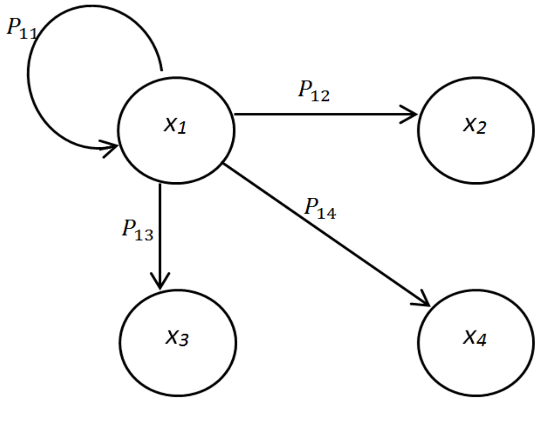

Fig. 4. The probable states of node A from position x_1

$$p_{ij} = p(X_i / X_j) \tag{10}$$

where $j = 0,1,\ldots\ldots n$, and $p(X_i / X_j)$ is a conditional probability. For the previous example, $j = 1,2,3,4$ and $i=1$. And then the node selects the next location which achieves the maximum P_{ij}:

$$P_{ij'} = P(X_i / X_{j'}) = \max\left[P(X_i / X_j)\right] \tag{11}$$

For all $j = 0,1,\ldots\ldots n$.

$X_{j'}$ represents the next position of the node, thus the node considers that there is a straight path between X_i and $X_{j'}$ and saves it in the virtual map. By repeating this process for all locations X_1, X_2, ... X_n, the node builds its virtual map $P_{ij'}$ and uses it in the control massage between the sending nodes.

For example, when the node A intends to send a message to the node B, the (RTS/ CTS) handshaking occurs [12]. The RTS packet includes the location information about A: the time instant of RTS transmission t_r, the node ID, current position $P_A(t_r) = (x_A(t_r), y_A(t_r))$, and speed S_A. In addition, the most probable coordinates of its next position $P_{A'}(t_r) = (x_{A'}(t_r), y_{A'}(t_r))$ calculated according to the A's virtual map are also transmitted, Fig. 6. Therefore the node B saves A's information in its LT:

$$LT_B(A) = (t_r, ID_A, P_A(t_r), S_A, P_{A'}(t_r), TTL_A) \tag{12}$$

The CTS packet from B includes the location information about B, and the node A saves this information in its LT:

$$LT_A(B) = (t_c, ID_B, P_B(t_c), S_B, P_{B'}(t_c), TTL_B) \tag{13}$$

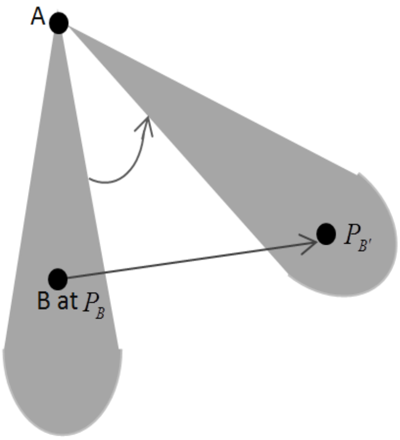

Fig. 5. The antenna of node A is pointed to the predicted direction of node B

Thus the distance between the position of B and $P_{B'}(t_c)$ is:

$$D = \sqrt{(x_{B'} - x_B)^2 + (y_{B'} - y_B)^2} \tag{14}$$

The node A can estimate the position of the node B at t_{c+1} from figure (6) using similarity of triangles:

$$\frac{x_B(t_{c+1}) - x_B(t_c)}{x_{B'}(t_c) - x_B(t_c)} = \frac{y_B(t_{c+1}) - y_B(t_c)}{y_{B'}(t_c) - y_B(t_c)} = \frac{(t_{c+1} - t_c)S_B}{D} \tag{15}$$

Hence,

$$\begin{aligned} x_B(t_{c+1}) &= x_B(t_c) + (x_{B'}(t_c) - x_B(t_c))\frac{(t_{c+1} - t_c)S_B}{D} \\ y_B(t_{c+1}) &= y_B(t_c) + (y_{B'}(t_c) - y_B(t_c))\frac{(t_{c+1} - t_c)S_B}{D} \end{aligned} \tag{16}$$

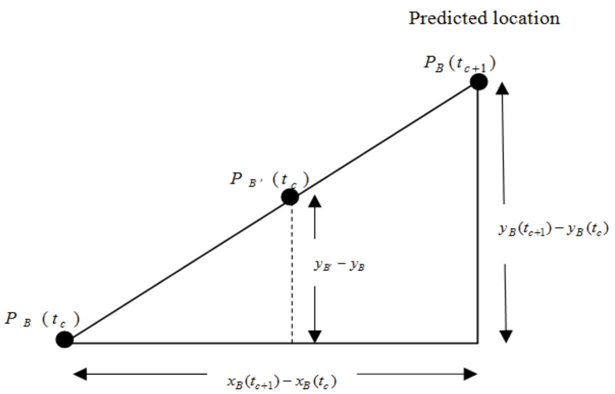

Fig. 6. Prediction of location using the current and the next position

Thus, the transmission angle of data from the node A to B at t_{c+1} is:

$$\theta_{data}(t_{c+1}) = \tan^{-1}\frac{y_A(t_{c+1}) - y_B(t_{c+1})}{X_A(t_{c+1}) - X_B(t_{c+1})} \tag{17}$$

Then the antenna of the nodes A and B is pointed to the predicted direction and the nodes start sending data. But during the transmission between A and B, it is possible that position $P_{B'}$ is achieved by B and B will continue its movement to the next new position, thus the directional beacon of the node B will distribute this new information to B's neighbors within the transmission range, whereby the node A updates B's location information to estimate the new direction of the node B.

This scheme provides an adaptive location prediction mechanism. It proactively predicts future locations of communicating nodes and minimizes location updating, thereby reducing communication delay.

V. CONCLUSION

This paper proposes the mobility prediction to estimate the future situation of the MANET networks, where some of mobility models have been studied to mimic the movements of real mobile nodes: the Random Walk and Random waypoint mobility models. The prediction accuracy would be increased if the information of the nodes movement pattern was known. Thus I propose a method where each node can build its virtual map of moving depending on its location over the time. Thereby, the mobile nodes use this map to define the next step in the control message between the sending nodes. The power consumption and the interference will be decreased.

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