A Predictive and Synchronized Neighborhood Tracking Scheme for Mobile Ad Hoc Networks

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Abstract

In mobile ad hoc networks (MANETs), nodes mobility causes network topologies to change dynamically over time, which complicates important tasks such as broadcasting and routing. Neighborhood tracking is a task to determine the neighborhood local view of a mobile node in time which can facilitate the forwarding decision in the design of network protocols. In this paper, we propose a predictive synchronization solution to construct the updated and synchronized local view. Based on neighbors' historical information extracted from "Hello" messages, a node can track its time difference with any neighbor. Then the node can predict each neighbor's future location at the same time based on certain mobility prediction model to construct synchronized neighborhood view by collecting predicted locations. Simulation results validate the accuracy of our proposed tracking schemes. [1]

1 Introduction

Mobile ad hoc networks (MANETs) are composed of possibly mobile devices such as sensors, laptops, or PDAs. The absence of a fixed infrastructure in MANETs makes them suitable for applications such as military battlefields, disaster relief and emergency situations. However, the mobility of nodes leads to dynamic network topology changes which complicates important network tasks such as efficient broadcasting (select part of nodes and proper radius for emission) and routing.

In most position aware localized protocols for MANETs, each node emits "Hello" messages to advertise its presence and update its information. The update protocol can be classified into two kinds: periodical update and conditional update when there is considerable direction change.

[1]Dr. Jinsung Cho is the corresponding author.

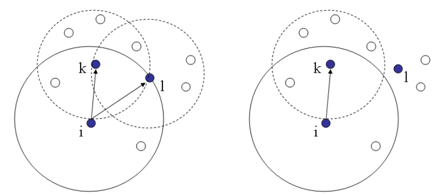

Figure 1. Impact of inaccurate local view.

In periodical update, "Hello" intervals at different nodes can be asynchronous to reduce message collision. Each node extracts its neighbors' information from latest received "Hello" messages to construct a local view of its neighborhood (e.g., 1-hop location information). However, there are two main problems in that kind of neighborhood local view construction scheme. 1) Outdated local view: when we consider a general case where broadcasts or routing occur within "Hello" message interval while nodes move during that interval, forward decisions of localized protocols will be based on outdated neighborhood view; 2) Asynchronous local view: asynchronous sample frequency at each node, asynchronous "Hello" intervals in periodical update, and different "Hello" intervals in conditional update will cause asynchronous information for each neighbor in neighborhood local view.

Forward decisions based on outdated and asynchronous neighborhood view may be inaccurate and hence cause delivery failure which can induce poor broadcast coverage or route failures. The left part of Fig.1 represents the neighborhood view of node i, and right part is the real physical topology. Based on inaccurate local view, node i selects k and l as forward nodes. Each circle corresponds to a forward node's transmission range. However, in the real physical topology node l moves out of the transmission range of i and can not receive the message and forward it. Neighborhood tracking is a task to determine the neighborhood local view of a mobile node in time which can facilitate to make the right forwarding decision. Therefore, it could be of significance to the design of network protocols.

To address asynchronism problem, we attach the current sending time into "Hello" messages. Nodes which receive "Hello" messages should include not only message contents but also reception time. By comparing reception time and sending time in "Hello" message, we can calculate the time difference between two nodes. To get a synchronized local view of any node S at any future time t, we set node S as the reference node and deduce its neighbor's synchronous time t'. To construct the updated neighborhood local view, we propose piecewise linear and nonlinear prediction models which make use of a node's latest two or one information to predict its future location. By aggregating predicted neighbors' location, node S can construct the updated and synchronous neighborhood view at actual transmission time.

The remainder is organized as follows: Section 2 presents related work and preliminary. In Section 3, we present our predictive and synchronized local view construction scheme in detail, and also provide some analytical study. Section 4 shows our simulation work and its results. In Section 5, we conclude this paper.

2 RELATED WORK

2.1 Mobility Management

The nodes mobility has great effect on the performance and capacity of mobile ad hoc networks, which is discussed in [7] and [4]. A lot of work on mobility management has been done for the design of routing protocols. In the work of Su et al. [9], location information is used to estimate the expiration time of the link between two adjacent hosts which determines the selection of route path. In [2], authors present an overview of existing mobility prediction schemes that have been proposed. However, those predictions are also for link availability and path reliability estimation.

There exist two kinds of work which try to maintain accurate topology view. First, in [6], a stable zone and a caution zone of each node have been defined based on a node's position, speed, and direction information obtained from GPS. Specifically, a stable zone is the area in which a mobile node can maintain relatively stable links with its neighbor nodes since they are located close to each other. A caution zone is the area in which a node can maintain unstable links with its neighbor nodes since they are relatively far from each other. Second, Wu and Dai have proposed a conservative "two transmission radius" method to compensate the outdated topology local view [10, 11, 12]. However, all the above approaches are passive since they just try to compensate the inaccuracy of network topology view rather than predict mobile nodes' positions to construct precise neighborhood local view in advance.

2.2 Preliminary

In MANETs update protocol [8] can be classified into periodical update with fixed interval and conditional update.

Conditional Update. Suppose that the periodic check for a particular node occurs at time t_c with actual location at (x_c, y_c, z_c). Further suppose that its own most recent update was generated at time t_{1h} with location (x_{1h}, y_{1h}, z_{1h}), speed v and direction (d_x, d_y, d_z). Then expected location (x_e, y_e, z_e) at t_c can be calculated as

$$\begin{cases} x_e = x_{1h} + (t_c - t_{1h}) \cdot v \cdot d_x \\ y_e = y_{1h} + (t_c - t_{1h}) \cdot v \cdot d_y \\ z_e = z_{1h} + (t_c - t_{1h}) \cdot v \cdot d_z. \end{cases} \tag{1}$$

Now check whether the deviated distance is larger than δ or not. That is, if $\sqrt{(x_e - x_c)^2 + (y_e - y_c)^2 + (z_e - z_c)^2} > \delta$, an update should be generated where δ is set by designers.

3 PROPOSED METHOD

In this section we propose a predictive synchronization scheme to construct updated and synchronized local view.

3.1 Predictive and Synchronized Neighborhood Tracking

To address the asynchronous and outdated local view problem, we propose to predict the location of node S and all its neighbors at the same future time t_p (with node S's clock) which is the node S's actual emission time t_b + broadcast delay time t_D. By collecting the predicted locations, node S can construct an updated and synchronized neighborhood local view. The delay time t_D includes not only the wireless network transmission delay t_e but also the packet and transmission processing time t_s. t_e is basically fixed in wireless networks while t_s can vary according to packet size.

Moreover, the prediction interval is also affected by some other factors and has a bound which we will analyze in next separate section. However there are still two issues: how to calculate neighbor nodes' corresponding prediction time and how to predict nodes' locations. To calculate any neighbor node A's prediction time t'_p, we can calculate its time difference to reference node S, t'_d. Then $t'_p = t_p + t'_d$. To get t'_d, we plan to include local sending time t_l in "hello" messages and also local received time t_r. Then the time difference between two nodes can be calculated as $t'_d = t_l - t_r + t_e$ where t_e is the wireless network transmission delay.

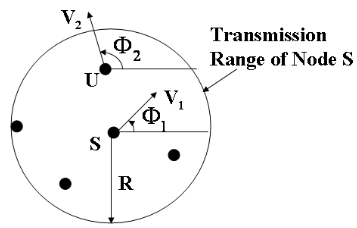

Figure 2. Analysis model.

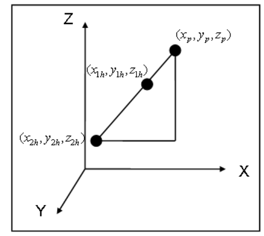

Figure 3. Location-based prediction model.

3.2 Analysis for Prediction Interval

When we schedule an actual transmission time for S, if within the prediction interval, neighbor nodes already move out of the transmission range of node S, our prediction scheme will have no meaning. Therefore we analyze the **Transmission Range Dwell Time**, T_{dwell}, the time period within which any neighbor node U stays in the transmission range of node S. R_{dwell} is the rate of crossing the boundary of its transmission range.

Fig. 2 shows an analytical model where we assume that node S moves with a velocity $\vec{V_1}$ and node U moves with a velocity $\vec{V_2}$. The relative velocity $\vec{V}$ of node U to node S is given by

$$\vec{V} = \vec{V_2} - \vec{V_1}. \tag{2}$$

The magnitude of $\vec{V}$ is given by

$$V = \sqrt{V_1^2 + V_2^2 - 2V_1V_2\cos(\Phi_1 - \Phi_2)}, \tag{3}$$

where V_1 and V_2 are the magnitudes of $\vec{V_1}$ and $\vec{V_2}$, respectively. The mean value of V is given by

$$\begin{aligned} E[V] \;\; = \;\; & \int_{V_{min}}^{V_{max}}\int_{V_{min}}^{V_{max}}\int_{0}^{2\pi}\int_{0}^{2\pi} \sqrt{v_1^2 + v_2^2 - 2v_1v_2\cos(\phi_1 - \phi_2)}\, f_{V_1,V_2,\Phi_1,\Phi_2}\left(v_1, v_2, \phi_1, \phi_2\right) d\phi_1 d\phi_2 \\ & dv_1 dv_2, \end{aligned} \tag{4}$$

where $f_{V_1,V_2,\Phi_1,\Phi_2}\left(v_1, v_2, \phi_1, \phi_2\right)$ is the joint pdf of the random variables V_1, V_2, Φ_1, Φ_2, V_{min} and V_{max} are the minimum and maximum moving speeds, the symbol $E[V]$ is an average value of the random variable V. Since the moving speeds V_1 and V_2 and directions Φ_1 and Φ_2 of nodes S and U are independent, Eq. (4) can be simplified

$$\begin{aligned} E[V] \;\; = \;\; & \int_{V_{min}}^{V_{max}}\int_{V_{min}}^{V_{max}}\int_{0}^{2\pi}\int_{0}^{2\pi} \sqrt{v_1^2 + v_2^2 - 2v_1v_2\cos(\phi_1 - \phi_2)}\, f_V\left(v_1\right) f_V\left(v_2\right) f_\Phi\left(\phi_1\right) f_\Phi\left(\phi_2\right) d\phi_1 \\ & d\phi_2 dv_1 dv_2. \end{aligned} \tag{5}$$

If Φ_1 and Φ_2 are uniformly distributed in $(0, 2\pi]$, Eq. (5) can be further rewritten as

$$\begin{aligned} E[V] \;\; = \;\; & \frac{1}{\pi^2}\int_{V_{min}}^{V_{max}}\int_{V_{min}}^{V_{max}} \left(v_1 + v_2\right) F_e\left(\frac{2\sqrt{v_1v_2}}{v_1 + v_2}\right) \\ & \cdot f_V\left(v_1\right) f_V\left(v_2\right) dv_1 dv_2, \end{aligned} \tag{6}$$

where $F_e(k) = \int_0^1 \sqrt{\frac{1-k^2t^2}{1-t^2}}dt$ is complete elliptic integral of the second kind. Therefore, now we can consider that node S is stationary, and node U is moving at a relative velocity.

Assume that nodes are distributed uniformly and nodes' moving direction is distributed uniformly over $[0, 2\pi]$, from [5] the mean value of R_{dwell} is given by

$$R_{dwell} = \frac{E[V]L}{\pi A}, \tag{7}$$

where A is the area of the transmission range and L is the perimeter of this area. Therefore

$$E[T_{dwell}] = \frac{\pi A}{E[V]L}. \tag{8}$$

In a word, our prediction interval should be bounded within the time $E[T_{dwell}]$.

3.3 Mobility Prediction

Camp et al. [1] have given a comprehensive survey on mobility models for MANETs, from which we can find that in some models nodes move linearly before changing direction. In the other models, they are not precisely linearly movement, nodes also move linearly in a segment view.

Location-based Prediction: Suppose that there are two latest updates for a particular node respectively at time t_{1h} and t_{2h} ($t_{1h} > t_{2h}$) with location information of (x_{1h}, y_{1h}, z_{1h}) and (x_{2h}, y_{2h}, z_{2h}). Assume at least within two successive update periods the node moves in a straight

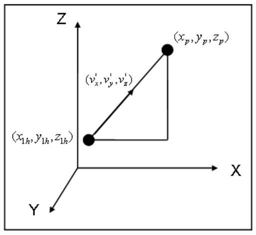

Figure 4. Velocity-aided prediction model.

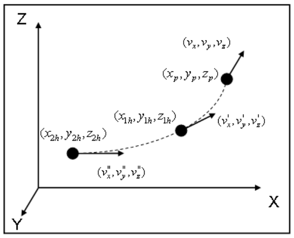

Figure 5. Constant acceleration model.

line with fixed speed (depicted in Fig. 3), we obtain

$$\begin{cases} \frac{x_{1h}-x_{2h}}{t_{1h}-t_{2h}} = \frac{x_p-x_{1h}}{t_p-t_{1h}} \\ \frac{y_{1h}-y_{2h}}{t_{1h}-t_{2h}} = \frac{y_p-y_{1h}}{t_p-t_{1h}} \\ \frac{z_{1h}-z_{2h}}{t_{1h}-t_{2h}} = \frac{z_p-z_{1h}}{t_p-t_{1h}}, \end{cases} \tag{9}$$

then the location (x_p, y_p, z_p) at a future time t_p can be calculated as

$$\begin{cases} x_p = x_{1h} + \frac{x_{1h}-x_{2h}}{t_{1h}-t_{2h}}(t_p - t_{1h}) \\ y_p = y_{1h} + \frac{y_{1h}-y_{2h}}{t_{1h}-t_{2h}}(t_p - t_{1h}) \\ z_p = z_{1h} + \frac{z_{1h}-z_{2h}}{t_{1h}-t_{2h}}(t_p - t_{1h}). \end{cases} \tag{10}$$

In the conditional update, however, this model cannot be used because the latest update represents considerable changes compared to previous update.

Velocity-aided Prediction: Let (v'_x, v'_y, v'_z) be the velocity of its latest update for a particular node. Assume the node moves with the speed within update period (depicted in Fig. 4), the location (x_p, y_p, z_p) at a future time t_p can be calculated as

$$\begin{cases} x_p = x_{1h} + v'_x(t_p - t_{1h}) \\ y_p = y_{1h} + v'_y(t_p - t_{1h}) \\ z_p = z_{1h} + v'_z(t_p - t_{1h}). \end{cases} \tag{11}$$

In high speed mobility networks we can assume the force on the moving node is constant, that is, nodes move with constant acceleration. **Constant Acceleration Prediction:** Let (v'_x, v'_y, v'_z) and (v''_x, v''_y, v''_z) respectively be the velocity

Table 1. Parameters for wireless node model

Parameters	Value
Frequency	2.4 GHz
Maximum transmission range	250 m
MAC protocol	802.11
Propagation model	free space/two ray ground

of those two update (depicted in Fig. 5). The principle of motion law are

$$V = v + at \tag{12}$$

and

$$S = vt + \frac{1}{2}at^2 = \bar{v}t = \frac{v+V}{2}t, \tag{13}$$

where S is the displacement, v is the initial velocity and a is the acceleration during period t. We employ V denoting the final velocity after period t.

Assume the fixed acceleration (a_x, a_y, a_z), and we apply above principle to X-dimension, we can obtain

$$\begin{cases} v'_x = v''_x + a_x(t_{1h} - t_{2h}) \\ v_x = v'_x + a_x(t_p - t_{1h}) \\ x_p - x_{1h} = \frac{(v'_x + v_x)}{2}(t_p - t_{1h}). \end{cases} \tag{14}$$

Then we can get the expected location x_p as:

$$x_p = x_{1h} + \frac{2v'_x + (v'_x - v''_x)\frac{t_p - t_{1h}}{t_{1h}-t_{2h}}}{2}(t_p - t_{1h}). \tag{15}$$

Since Y and Z dimensions are the same with X-dimension, we obtain

$$\begin{cases} x_p = x_{1h} + \frac{2v'_x + (v'_x - v''_x)\frac{t_p - t_{1h}}{t_{1h}-t_{2h}}}{2}(t_p - t_{1h}) \\ y_p = y_{1h} + \frac{2v'_y + (v'_y - v''_y)\frac{t_p - t_{1h}}{t_{1h}-t_{2h}}}{2}(t_p - t_{1h}) \\ z_p = z_{1h} + \frac{2v'_z + (v'_z - v''_z)\frac{t_p - t_{1h}}{t_{1h}-t_{2h}}}{2}(t_p - t_{1h}). \end{cases} \tag{16}$$

Finally, by collecting predicted locations, we can construct an updated and consistent neighborhood local view.

4 PERFORMANCE EVALUATION

4.1 Simulation Environment

We use ns-2.28 [3] and its CMU wireless extension as simulation tool and assume AT&T's Wave LAN PCMCIA card as wireless node model with parameters as listed in Table 1. To demonstrate the comprehensive effectiveness of our proposal, we perform experiments in not only linear (Random Waypoint) but also nonlinear (Gauss-Markov) mobility models [1] which are widely used in simulating protocols designed for MANETs.

Table 2. Simulation parameters

Parameters	Value
Simulation network size	900×900 m^2
Mobile nodes speed range	[0, 15] m/s
Nodes number	50
Simulation time	50 s
Periodical update/check interval	2 s
Prediction interval	20 ms
Reference distance of conditional update	1 m

4.2 Evaluation of Neighborhood Tracking

In neighborhood tracking, any node S is randomly chosen to predict its neighbor nodes' locations for constructing local view. Local view construction occurs within update interval. Table 2 displays our simulation parameters.

The sample of predicted local view with velocity-based prediction under periodical update is illustrated in Fig. 6 where the actual local view and local view based on update information are also shown for comparison. We can find that whatever in linear model or nonlinear mobile environment our predictive neighborhood views are almost the same as actual neighborhoods while update info based views show obvious inaccuracy.

To evaluate the inaccuracy of local view, we define the metric of position error (PE) as the average distance difference between neighbors' actual positions and their positions in neighborhood view. For any node S suppose there are K neighbors (including S itself) in its jth local view, and for any neighbor i let (x_i, y_i, z_i) represent the actual location and (x'_i, y'_i, z'_i) be the location in local view, the PE_j for the jth neighborhood can be calculated as

$$\sqrt{\frac{1}{K}\sum_{i=1}^{K}[(x'_i - x_i)^2 + (y'_i - y_i)^2 + (z'_i - z_i)^2]}. \quad (17)$$

Finally suppose we have W local views,

$$PE = \frac{1}{W}\sum_{j=1}^{W} PE_j; \quad (18)$$

The smaller the value of PE is, the more accurate the neighborhood local view is.

Table 3 and 4 show position error results under Random Waypoint and Gauss-Markov models in our simulation. From above simulation results we can demonstrate

- both periodical and conditional update info based view has more than three times inaccuracy compared with that of our tracking schemes, which proves the necessary and effectiveness of our proposition;

Table 3. PE under Random Waypoint model

Records Type	Prediction Scheme	PE Value
Periodical Update	Update Info Based	7.258410
	Location-based	0.755039
	Velocity-aided	0.003444
	Constant Acceleration	0.261483
Conditional Update	Update Info Based	9.267584
	Velocity-aided	0.000006
	Constant Acceleration	0.637606

Table 4. PE under Gauss-Markov Model

Records Type	Prediction Scheme	PE Value
Periodical Update	Update Info Based	7.407275
	Location-based	2.281239
	Velocity-aided	0.497334
	Constant Acceleration	1.046533
Conditional Update	Update Info Based	9.497269
	Velocity-aided	1.617758
	Constant Acceleration	2.813394

- our schemes have very small prediction inaccuracy (especially in linear mobility environment), that is, they can precisely track neighborhood;
- but different prediction models have different performance: velocity-aided scheme performs much better than other two methods and the constant acceleration model does better than location-based one;
- in addition, the mobility model and update protocol also affects the performance of our scheme: under different mobility models and update protocols the PE values are also different.

5 Conclusions

In this paper, we have addressed the inaccurate and asynchronous neighborhood view problem by proposing to predict all the neighbors' locations at the same future time. First, we present how to deduce the time difference and then calculate each neighbor's corresponding prediction time. Next, we have proposed the piece-wise linear and constant acceleration mobility prediction schemes for nodes' future locations prediction. Finally, we can construct an updated and synchronized neighborhood view by collecting all the predicted locations. In our simulation work, we compared our predicted neighborhood view with the update information based view and the result revealed that the views constructed by our neighborhood tracking schemes are much more accurate.

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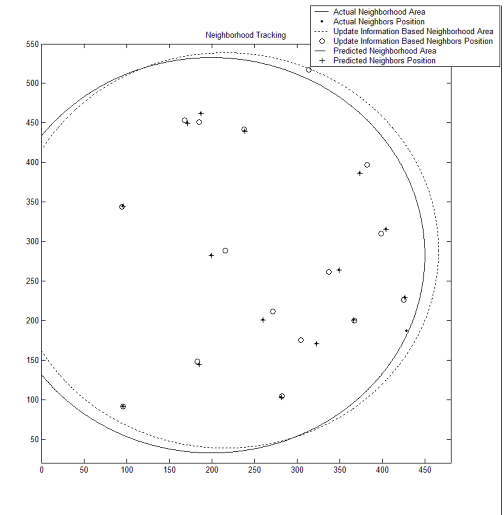
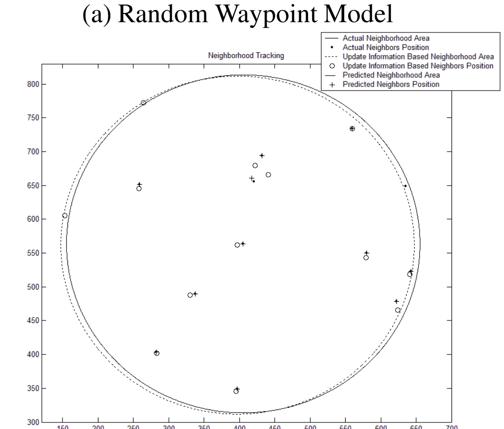


(a) Random Waypoint Model



(b) Gauss-Markov Model

Figure 6. Examples of neighborhood tracking in periodical update where the Z dimension coordinates of all the nodes are set 0**.**