Link Lifetime Prediction in Mobile Ad-Hoc Network Using Curve Fitting Method

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Abstract
In a real mobile ad-hoc network, a node usually moves to a pre-specified destination, and often exhibit non-random motion behavior. In such mobility patterns, the future motion behavior of a mobile node is correlated with its past and current mobility characteristics. In this paper, we propose an adaptive link lifetime prediction method. In our method, the prediction is made by exploiting the correlation of mobility parameters over time. Using curve fitting method, the proposed method learns how to predict the lifetime of a link between two adjacent mobile nodes based on their current related velocity and their distance history. Therefore, there is no need to extra information, e.g., signal strength, radio condition. Also in our algorithm, we do not impose any heavy calculation to the mobile nodes. Simulation results show the proposed algorithm predicts a link lifetime efficiently.

Key-words:
Mobile Ad-hoc Network, Link Lifetime Prediction, Curve Fitting Method

1. Introduction

A Mobile Ad-hoc Network (MANET) is a self-organizing and self-configuring multi-hop wireless network where all the nodes move independently in an arbitrary manner. MANET can be easily deployed since it does not need any fixed infrastructure, e.g., base stations, routers. Therefore, it is highly applicable to emergency deployments, military battlefields, natural disasters, and search and rescue missions.

In a MANET, when two nodes are within the transmission range of each other, they communicate directly; otherwise, they communicate indirectly through the intermediate nodes.

The nodes mobility results in considerable changes in the MANET topology, and it may even cause link breakage and route expiration. The best-known solutions proposed to reduce the effect of nodes mobility on the MANETs are based on mobility prediction. Using mobility prediction, link lifetime and therefore route stability can be estimated. So it can result in the low overhead routing process.

In a typical mobile network, nodes have some degree of regularity in their mobility pattern. For example, a car moving on a road is likely to follow the path of the road and a tank traveling across a battlefield is likely to maintain its heading and speed for some period of time before it changes them. Therefore, in a real MANET, the future motion behavior of the mobile node is correlated with its past and current mobility characteristics.

Node resources (e.g. supply power, computing power and memory) are limited in the MANET and nodes stop working if they run out of their resources. Therefore, it is important for every mobility prediction method to note these limitations. Imposing heavy calculation to mobile nodes increases their energy drain rate. So there is a trade-off between accuracy and resource consumption in every mobility prediction method.

Due to the above, in this paper, we are going to propose an adaptive prediction method in which link lifetime between mobile nodes is predicted more accurately despite not imposing heavy calculation to them.

The remaining parts of the paper are organized as follows. Section II presents related works on the mobility prediction and describes accuracy, resource consumption and constraints of these methods. We proposed our method in section III and then section IV follows with describing our performance evaluation setting, simulation experiments, and their corresponding results. Finally, future works and conclusion remarks are made in section V.

2. Related Works

As mentioned, mobility prediction is one of the most efficient ways to minimize the effect of topology changes on QoS of the MANET.

One of the simplest and most common mobility prediction methods is used in [1] and many others like [2], [3] and [4]. This method assumes that a mobile node moves at a fixed speed on a straight line and rarely changes its speed

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or its direction. So the next location of a mobile node can easily be predicted by equation (1).

$$x_{0+t} = x_0 + t(S \times Cos\theta)$$
$$y_{0+t} = y_0 + t(S \times Sin\theta) \quad (1)$$

Where (x_0, y_0) is current location of a mobile node, and (x_{0+t}, y_{0+t}) is the predicted location of the mobile node at t seconds later. S and θ represent current speed and direction of motion, respectively.

Based on equation (1), equation (2) is proposed in [5] to predict the link lifetime between two adjacent mobile nodes. Assume that i and j are adjacent mobile nodes with the same transmission range r, lifetime of the link between them can be calculated using equation (2).

$$t = \frac{-(ab + cd) + \sqrt{(a^2 + c^2)r^2 - (ad - bc)^2}}{a^2 + c^2} \quad (2)$$

Where

$$a = v_i \cos\theta_i - v_j \cos\theta_j$$
$$b = x_i - x_j$$
$$c = v_i \sin\theta_i - v_j \sin\theta_j$$
$$d = y_i - y_j$$

As already mentioned, in equations (1) and (2) it is assumed that a mobile node rarely changes its speed and direction. Since these assumptions are not so realized in a real network, the predicted results of these methods are inaccurate in real environments. This method is also used in [6], [7] and [8].

To improve accuracy, an enhancement to equation (1) is proposed in [9]. In this method, a coefficient is added to equation (1) which determine the dependency of the next location of a mobile node to its current speed and direction. Equation (3) shows this enhanced mobility prediction method. In this method, an appropriate value for α coefficient is estimated automatically using a simple learning automaton. Much more value for α makes predicted results less dependent on current speed and direction. So equation (3) can adapt its self to different mobility models.

$$x_{0+t} = x_0 + {}^{1}/_{\alpha}\left(t(S \times Cos\theta)\right)$$
$$y_{0+t} = y_0 + {}^{1}/_{\alpha}\left(t(S \times Sin\theta)\right) \quad (3)$$

Simulation results reported in [9] indicate that equation (3) can predict next location of mobile nodes more accurately than equation (1), but equation (3) still assumes that a mobile node move on a straight line at a fixed speed and non-realization of these assumptions can still make predicted results inaccurate.

Another adaptive mobility prediction method is proposed in [10]. In this method, a MANET is probabilistically modeled as a discrete-time Markov chain process with finite states where states correspond to location grids.

In this method, the physical area of network coverage is divided into a grid of size $a \times b$ (where a and b are dimensions of the grid) and each node has a unique ID and can move within the location grids on a grid-by-grid basis similar to Fig. 2.

In this method, each node collects and maintains a transition probability matrix, state matrix and some other additional information. In the transition probability matrix, $P_{i,j}$ is the probability of transition from state i to state j and it can be estimated using equation (4) where $n(i,j)$ is the number of times that state transition from i to j has occurred in the observed sequence.

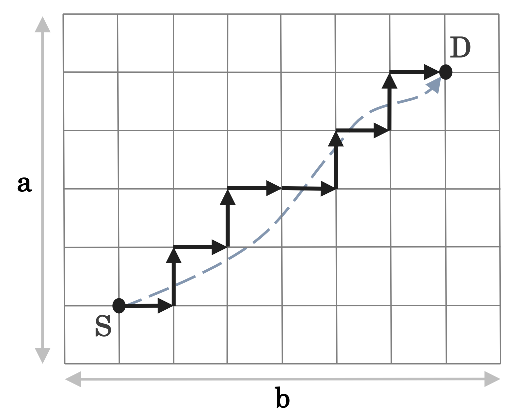

Fig. 1 Movement of a mobile node on a grid-by-grid basis

$$P = [P_{i,j}] = \frac{n(i,j)}{\sum_k n(i,k)} \quad (4)$$

State matrix is estimated using equation (5) where $n(i)$ is the number of times the initial state is equal to i.

$$Q = [Q_i] = \frac{n(i)}{\sum_k n(k)} \quad (5)$$

The estimation of matrices P and Q are determined from finite runs of Markov chain model. If the initial probability distribution of the states denoted by a row vector (Q_0) be known, the probability distribution of the next state in the Markov chain is computed as follows for any k:

$$Q_k = Q_0 P^k \quad (6)$$

This recent method has a weakness which makes it inapplicable in a real environment. Since the size of P and Q matrices are so dependent on the grid size, if the size of the grid becomes larger, it is impossible for each node to maintain P and Q matrices. So this method is not scalable and is applicable just in small area networks.

Using neural network, another adaptive mobility prediction method proposed in [11]. In this method, each node predicts its next location for next 100 seconds using a multi-layer recurrent neural network and then propagates predicted results through the network. Using this incoming information, nodes can predict the lifetime of their links to their adjacent nodes.

Another mobility prediction method based on neural network is proposed in [12]. In this method, the next location of a mobile node is predicted using single-hidden layer feedforward network.

According to simulation results reported in [11] and [12], these methods can predict motion behavior of a mobile node more accurate than previous methods, but there is still a considerable weakness in these methods.

Because of using the neural network, these method imposes heavy calculation to mobile nodes which lead to increase energy drain rate of them and decrease their lifetime.

Another prediction method based on genetic algorithm is proposed in [15]. Although this method imposes less calculation and process to mobile nodes than the method used the neural network, the complexity of calculation is still high for MANET's resource constrained mobile nodes.

We are going to propose an adaptive prediction method in next section which estimates the lifetime of links between adjacent nodes despite not imposing heavy calculation to them.

3. Link Lifetime Prediction Using Curve Fitting

If the distance of mobile nodes a and b at time t be known as $D_{a,b}(t)$, value of this function over time creates a time series. One of the most efficient ways to predict this time series is curve fitting method.

In real a MANET, the nodes usually travel to a pre-specified destination, and often exhibit non-random motion behaviors. So we can predict the future distance of two nodes based on their distance and relative speed history.

According to above, we assume that distance of two mobile nodes is a function of their relative speed and distance history at near time. Equation (7) shows this assumption, in which D_t is distance and Δv_t is the relative speed of nodes at time t. Predicted distance at time $t+k$ represented as PD_{t+k} in this equation.

$$PD_{t+k} = f(\Delta v_t, D_t, D_{t-1}, D_{t-2}) \tag{7}$$

Now, all we need is an accurate and also simple approximation for this equation which not enforces heavy calculation to mobile nodes.

3.1 Curve fitting using Taylor series

Taylor series is a representation of a function as an unlimited sum of terms that are calculated from the values of the function's derivatives at a single point. Equation (8) shows Taylor series for one-variable function f(x) [13].

$$f(x) = \sum_{n=0}^{\infty} \frac{f^{(n)}(x_0)}{n!}(x - x_0)^n \tag{8}$$

Using more terms of Taylor series results in more accurate and also more complex approximation. To reduce calculation, we can use the only first term of Taylor series ($n = 1$) which called linear approximation. Equation (9) shows one-variable function linear approximation.

$$f(x) \approx f(a) + f'(a)(x - a) = Ax + B \tag{9}$$

For multi-variable function f(w,x,y,z), linear approximation is shown in equation (10).

$$\begin{aligned} f(w,x,y,z) &\approx f(w_0,x_0,y_0,z_0) \\ &\quad + (w - w_0)\frac{\partial f}{\partial w}(w_0,x_0,y_0,z_0) \\ &\quad + (x - x_0)\frac{\partial f}{\partial x}(w_0,x_0,y_0,z_0) \\ &\quad + (y - y_0)\frac{\partial f}{\partial y}(w_0,x_0,y_0,z_0) \\ &\quad + (z - z_0)\frac{\partial f}{\partial z}(w_0,x_0,y_0,z_0) \\ &= A + Bw + Cx + Dy + Ez \end{aligned} \tag{10}$$

3.2 Error function and optimization method

According to equation (10) function $f(\Delta v_t, D_t, D_{t-1}, D_{t-2})$ can be approximated as equation (11) and error of this approximation is shown in equation (12).

$$\begin{aligned} PD_{t+k} &= f(\Delta v_t, D_t, D_{t-1}, D_{t-2}) \\ &\approx w_0 + w_1\Delta v + w_2 D_t + w_3 D_{t-1} + w_4 D_{t-2} \end{aligned} \tag{11}$$

$$E = |e| = |D_{t+k} - PD_{t+k}| \tag{12}$$

Now, error function should be minimized by choosing an appropriate value for coefficients w_i. To do so, we use gradient descent as an optimization method. According to this method, to minimize the error function, the new value of w_i should be calculated using equation (13) in which γ is the learning rate of optimization. Choosing a greater value for learning rate makes the new value of w_i less dependent to its old value.

$$w_{New} = w_{Old} - \gamma \frac{\partial E}{\partial w} \quad (13)$$

Based on equation (13), a new value for coefficients w_i in equation (11) are calculated in equation (14). Using this optimization, the error of approximation decreases and function $f(\Delta v_t, D_t, D_{t-1}, D_{t-2})$ is fitted in the better way in each step. We call this process predictor training.

$$\begin{aligned} w_0 &= w_0 - \gamma \frac{|e|}{e} \\ w_1 &= w_1 - \gamma \frac{|e|}{e} \Delta v \\ w_2 &= w_2 - \gamma \frac{|e|}{e} D_t \\ w_3 &= w_3 - \gamma \frac{|e|}{e} D_{t-1} \\ w_4 &= w_4 - \gamma \frac{|e|}{e} D_{t-2} \end{aligned} \quad (14)$$

3.3 Link lifetime prediction

To predict the distance of two mobile nodes for next n seconds, we need n predictor units. In this case, k-th predictor unit predicts the distance of nodes at k second later. Each predictor unit is consist of five variables which maintain coefficients w_i and also each one is trained separately.

Suppose that the transmission range of two adjacent mobile nodes be 100 meters and the predicted distance of them for next 8 seconds be like table I, predicted link lifetime is 5 seconds.

Table 1: distance of two mobile nodes

Time	1	2	3	4	5	6	7	8
Distance	66.3	70.0	79.9	87.2	96.1	100.3	1004.1	109.1

Using n predictor units, if a link lifetime is more than n seconds, it is not possible to predict the lifetime precisely and we can only predict that lifetime is more than n seconds. So we need a procedure to determine the optimum number of predictor units. More predictors lead to more calculation and a smaller number of predictors lead to inaccurate prediction.

4. Simulation

In this section we first define some simulation scenarios, then a procedure is provided to determine the optimum number of predictor units and finally, we evaluate our proposed method.

To generate mobility traces for our simulations, we used Mobisim [14] simulator. Mobisim can generate mobility traces which may contain each node's position, speed and motion direction angle at any time in various mobility models, speeds and other mobility model configurations.

4.1 Number of predictor units

Our simulation scenarios are shown in tables II and III. In these scenarios, we place only two mobile nodes in a MANET, but mobile nodes can be any number and the proposed method performance is independent of nodes count.

To determine the optimum number of the predictor units, we study lifetime of links created in the simulation 1. As it is shown in Fig. 3, 41% of links in the MANET with the max speed 10m/s have lifetime more than 15 seconds. This value for the MANETs with the max speed 20m/s and 30 m/s is 23% and 10% respectively.

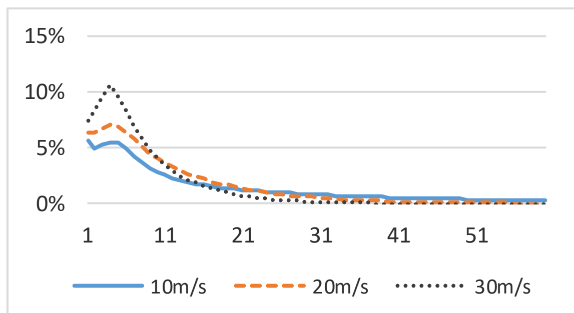

Fig. 3 Link lifetime analysis

According to link lifetime analysis result, shown in Fig. 3, if each mobile node has only 15 predictor units, in worth case, it cannot predict the exact lifetime of links with probability 41%. In this case, it just can be predicted that lifetime is more than 15 seconds.

Suppose that, a route is consist of 4 links and the predicted lifetime of the links are like Fig. 4. Since the stability of the route is equal to the minimum predicted link lifetime, so inaccurate link lifetime prediction cannot lead to inaccurate route stability prediction. In Fig. 4 lifetime of the link between node 2 and 3 is predicted inaccurately. But despite this inaccurate prediction, route stability is predicted precisely.

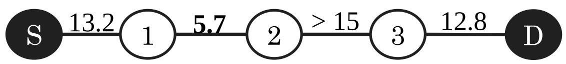

Fig. 4 Route stability

According to above, the number of predictor units can be determined using analysis of links lifetime of the MANET.

4.2 Proposed method evaluation

To evaluate our proposed method, in each simulation, mobile nodes are trained with 15 predictor units. Using these predictor units, a mobile node cannot exactly predict the lifetime of links which are stable more than 15 seconds. In this case, lifetime is predicted as 15 seconds.

At the beginning of the simulation, coefficient wi in each predictor unit is initialized with a default value and during the training process, the optimum value is achieved.

Table 2:Simulation 1 Parameters

Description	Simulation 1
Simulation duration	1.000.000 s
Number of nodes	2
Simulation area size	1000m x 1000m
Transmission range	100m
Mobility Model	Random Walk
Minimum speed	0 m/s
Maximum speed	5m/s, 10m/s, 15m/s, 20m/s, 25m/s, 30m/s
Walk Duration	5 s

Table 3: Simulation 2 Parameters

Description	Simulation 2
Simulation duration	1.000.000 s
Number of nodes	2
Simulation area size	1000m x 1000m
Transmission range	100m
Mobility Model	Markov
Minimum speed	0 m/s
Maximum speed	5m/s, 10m/s, 15m/s, 20m/s, 25m/s, 30m/s
Memory factor	0.8

Among mobility prediction methods, presented in section II, Equation 2 is more applicable in a real MANET.

According to the above, the Equation 2 is chosen to be compared with our proposed method. Fig. 5 and Fig. 6 show, our proposed method predicts links lifetime more accurate than Equation 2. In these charts, vertical and horizontal axes indicate link lifetime prediction (LLP) average error and simulation max speed, respectively.

Nodes mobility model in simulation 1 and 2 are Random walk and Markov. We perform each simulation several times with different max speed. In each time, the average error of link lifetime prediction is reported for both methods. In the MANETs with higher max speed, the average lifetime of links is smaller and therefore error of prediction for both methods become smaller.

According to the simulation results, our proposed method predicts the lifetime of links created in a MANET more accurate than Equation 2. But more important improvement is, our proposed method is just based on basic mathematical operation while Equation 2 uses square root and trigonometric ratios.

In order to calculate trigonometric ratios, a mobile node must be equipped with more expensive and more complex processor which could handle complex arithmetic operations. As mentioned, heavy calculation raises energy drain rate of mobile nodes and consequently, it decreases their life duration.

Therefore, complex calculation not only increases MANET cost but also decreases MANET lifetime.

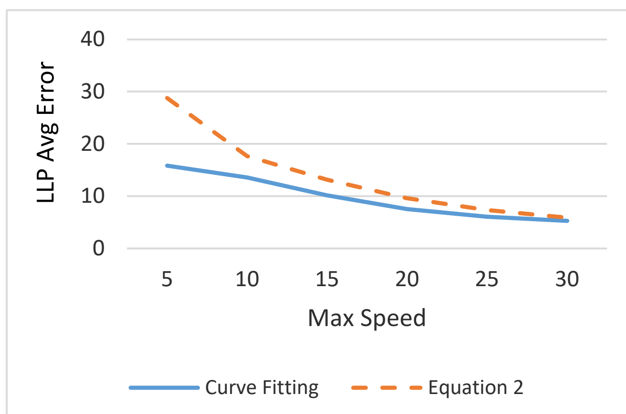

Fig. 5 Link lifetime prediction average error in Sim.1

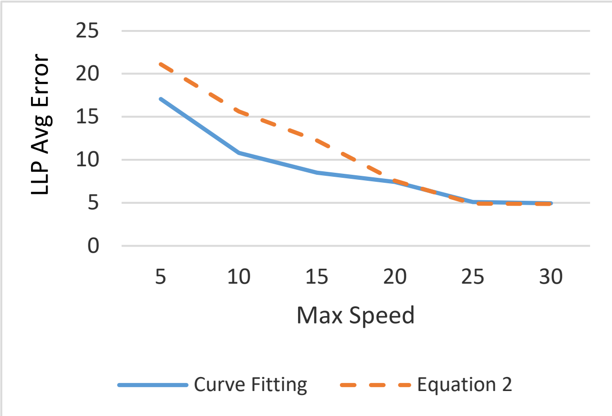

Fig. 6 Link lifetime prediction average error in Sim.2

5. Conclusion

Accurate prediction of the link lifetime in a MANET can enhance network performance. Since MANETs nodes are power constrained, imposing heavy calculation to them may lead to increase their energy drain rate.

In this paper, we first, studied some of the mobility prediction methods and discussed their constraint and applicability in a real MANET. Then we presented our adaptive prediction method which is based on curve fitting method and predicts the lifetime of links created in a MANET despite not imposing heavy calculation to its nodes.

There is a balance between accuracy and calculation in the proposed method. Using more predictor unit results in more accurate prediction and also heavier calculation. Simulation results showed our proposed method accuracy. Some advantage of proposed method is listed as below:

It can predict link lifetime accurately.

1. It is adaptive, which means proposed method can adjust itself to any changes in the network.
2. It does not force any heavy calculation to mobile nodes.
3. Since the proposed method is based on no restrictive assumption, it is applicable in any real MANET.

In the future work, we are going to compare MANET mobility prediction method according to their energy consumption.

References

[1] M. Al-Hattab and J. I. Agbinnya, “Topology prediction and convergence for networks on mobile vehicles,” 2008 International Conference on Computer and Communication Engineering, pp. 266–269, May 2008.

[2] H. Cha and I. Han, “QoS routing mechanism using mobility prediction of node in ad-hoc network,” Proceedings of the 6th ACM international symposium on Mobility management and wireless access - MobiWac '08., p. 53, 2008.

[3] N. Meghanathan, “Location prediction based routing protocol for mobile ad hoc networks,” IEEE GLOBECOM 2008 - 2008 IEEE Global Telecommunications Conference, pp. 1–5, 2008.

[4] S. H. Shah and K. Nahrstedt, “Predictive location-based QoS routing in mobile ad hoc networks,” 2002 IEEE International Conference on Communications. Conference Proceedings. ICC 2002, pp. 1022–1027, 2002.

[5] W. Su and M. Gerla, “IPv6 flow handoff in ad hoc wireless networks using mobility prediction,” Seamless Interconnection for Universal Services. Global Telecommunications Conference. GLOBECOM'99., 1999, vol. 1, pp. 271–275.

[6] B. H. Sathyaraj and R. C. Doss, “Route maintenance using mobility prediction for mobile ad hoc networks,” IEEE International Conference on Mobile Ad hoc and Sensor Systems Conference, 2005, pp. 6–101.

[7] N. Wang and S. Chang, “A reliable on-demand routing protocol for mobile ad hoc networks with mobility prediction,” Computer Communications, vol. 29, no. 1, pp. 123–135, Dec. 2005.

[8] A. Rhim and Z. Dziong, “Routing based on link expiration time for MANET performance improvement,” 2009 IEEE 9th Malaysia International Conference on Communications (MICC), pp. 555–560, December 2009.

[9] S. M. Mousavi, H. R. Rabiee, M. Moshref, and a. Dabirmoghaddam, “Model Based Adaptive Mobility Prediction in Mobile Ad-Hoc Networks,” 2007 International Conference on Wireless Communications, Networking and Mobile Computing, pp. 1713–1716, Sep. 2007.

[10] M. Denko, “Mobility prediction schemes in wireless ad hoc networks”, Multimedia Systems and Applications Series Advanced Wired and Wireless Networks, pp. 171–186, 2004.

[11] H. Kaaniche and F. Kamoun, “Mobility Prediction in Wireless Ad Hoc Networks using Neural Networks,” Arxiv preprint arXiv:1004.4610, vol. 2, no. 1, pp. 95–101, 2010.

[12] L. Ghouti, T. R. Sheltami, and K. S. Alutaibi, “Mobility prediction in mobile Ad Hoc networks using extreme learning machines,” Procedia Computer Science, vol. 19, no. Ant, pp. 305–312, 2013.

[13] J. Jiang, Large sample techniques for statistics, vol. 2. New York: Springer, 2010, p. 83.

[14] S. M. Mousavi, M. Moshref, H. R. Rabiee, A.Dabirmoghaddam, "Mobisim" a graphical mobility model trace generator for mobile ad-hoc networks. http://ce.sharif.edu/~sm_mousavi/mobisim.html

[15] R. Suraj, S. Tapaswi, S. Yousef, K. K. Pattanaik, and M. Cole, “Mobility prediction in mobile ad hoc networks using a lightweight genetic algorithm,” Wireless Netw Wireless Networks, 2015.