Energy Aware Mobility Prediction in Wireless Sensor Networks

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***Abstract*—Mobility of sensor nodes in wireless sensor networks significantly reduces the quality of services returned by broadcasting and routing protocols. This paper investigates the mobility factors in predicting the next location of sensor nodes to guarantee the accuracy of forwarding decisions. Based on historical location information and angular movement, nodes predict the positions of one-hop neighbors. Since this work predicts the basic mobility behaviors of the sensor nodes (i.e., speed, direction and degree of randomness), it can be also used to estimate neighborhood time, route reliability and so on. The simulation results show that the proposed work precisely estimates the next location of sensor nodes.**

***Index Terms*—Mobility, Mobility prediction, WSN.**

I. Introduction

In many wireless sensor network applications, the individual sensor nodes are mostly accepted to be stable. However, some recent applications of WSNs like medical care, habitat monitoring, disaster response, etc. make use of mobile sensor nodes. In these applications different nodes often have different mobility patterns where some nodes are extremely nomadic, while others are primarily stationary. This does a random change in the network topology since sensor nodes are free to move arbitrarily with different velocities. Mobility of sensor nodes brings about a broad orbit of fresh challenges for wireless sensor network protocol designers since mobility significantly reduces the caliber of service rendered by these protocols. Since mobility patterns may take on a substantial part in setting the protocol operation, the mobility prediction is an imperative issue and needs to be taken so as to produce the most efficient protocols.

The mobility of sensor nodes is generally hard to predict because mobility parameters of the sensor nodes are not well understood. However, in realistic situations, the sensor nodes exhibit some degree of regularity in the mobility pattern, and often exhibit non-random motion behaviors. In such mobility patterns, there exists a correlation of the future motion behavior of the sensor node with its past and current mobility characteristics. Thus, the memoryless mobility models are not easily suited to emulate such a mobility behavior [1]. A great deal of mobility patterns have been aimed to emulate the motion behavior of the mobile nodes and a survey of many is presented in [2]–[4].

The state-of-art solutions present in the literature estimate of the future location of the sensor node by predicting the mobility characteristics of the sensor node. This study suggests a prediction algorithm which periodically predicts the location of a sensor node. By applying this algorithm whether a sensor node moves linearly or non-linearly, we can able to call its next position. The best-known solutions presented in the literature normally transmit *Hello Messages* to bring down the prediction error. Broadly speaking, the *Hello Messages* consists of the location, speed, direction of movement, residual energy, the ID of the sensor node, etc. However, the proposed algorithm transmits only the angle by which the sensor node has deviated from its linear path of motion. Hence, only by transmitting the angle, the other nodes can be easily able to pull up the information about the future position of the sensor node which has informed about the angle. In this work, the three-axis accelerometer is used to sense the angular movement [5].

The remainder of the paper is organized as follows: Section III presents the system model. The proposed protocol is presented in Section IV. Simulation results is described in Section V and finally conclusions and future work is given in Section VI.

II. Related Work

The mobility prediction schemes which seek to estimate the mobility characteristics of the mobile sensor nodes are the most common answers to ease the estimate of neighborhood time,link availability, route reliability,network partitioning prediction, etc. For the past couple of decades, mobility prediction has received unexampled attention from the research community. The best-known solutions present in the literature estimate the future location of the sensor node by predicting the mobility characteristics of the sensor nodes.

Mobility prediction for cellular networks has been widely researched and a substantial number of strategies have been proposed, however, it is in the early stage in the multi-hop networks. The Markov model has proven to be useful in predicting the mobility of a mobile node [6], [7]. The major problem with the Markov- based models is that the mobility can be predicted by dividing the geographical area into a larger number of regions of a smaller size. Though this increases the prediction accuracy, but significantly overloads the network.

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In addition, since there is no a fixed infrastructure in a wireless sensor network, a fixed physical partitioning my not be possible.

In [1], an adaptive learning automata-based mobility prediction method is suggested in which the prediction is built based on the Gauss-Markov random process. It exploits the correlation of the mobility parameters over time. This algorithm employs a continuous-valued reinforcement scheme and finds out how to anticipate the future mobility behaviors relying only on the mobility history.

In reference [8], by piggybacking GPS based location information on data packets the link expiration time between any two mobile nodes is calculated.It exploits the nonrandom movement patterns of mobile nodes to predict the future state of the network. Mahapatro *et al.* [9] proposed a mathematical framework to model and study the link availability time. In this method, the relative speed between two neighboring mobile sensor nodes is taken into consideration in estimating the neighborhood time. Chellapa *et al.* [10] introduced a mobility prediction scheme that offers the role of a new sector-based tracking of mobile users, with a sector-numbering system to predict user movements. A geographic routing protocol that features Quality of Service (QoS) predictions based on device mobility is presented in [11].This protocol calculates a parameter known as motion stability based on a node's mobility pattern.

In [12],a neighborhood tracking scheme to assure the accuracy of forwarding decisions has been projected. Based on historical location information, nodes predict the positions of neighbors, and then construct an updated and consistent neighborhood local view. Three prediction models namely location-based prediction, velocity-aided prediction and nonlinear (constant acceleration) model has been proposed.

Capka *et al.* [13] presented a neural network prediction system that is able to capture some of the mobility patterns exhibited by mobile nodes moving in a wireless environment. In [14], a neural network based method for mobility prediction in Ad Hoc networks has been proposed. This method consists of a multi-layer and recurrent neural network using back propagation through time algorithm for training.

III. System Model

A. Mobility Model

Different types of mobility have different degrees of impact on the network topology. Thus, we consider the following node mobility model to evaluate the performance of the proposed detection algorithm.

- *Random Waypoint mobility model* In this model, a node alternates between the moving and the pausing phases [3]. A node moves from its current location to a new location by randomly choosing a direction and speed in which it will travel. The new speed and direction are both chosen from $[v_{max}, v_{min}]$ and $[0, 2\pi]$ respectively.

B. Network Model

The system under consideration accommodates n number of nodes out of which some are mobile, and some are primarily stationary. Each node in the network is assigned with a unique ID. Each node occupies a position (x_t, y_t) inside of a fixed geographic area $(l \times l\ m^2)$ at time t and is initially uniformly distributed. Every node independently moves and obeys the aforementioned mobility model. The mobility model maintains the uniform node spatial distribution over time. Two nodes n_i and n_j are within transmission range r_{tx}, if the Euclidean distance $d(n_i, n_j)$ between n_i and n_j is less than r_{tx}. Each node maintains a neighbor table $N(.)$. The topology graph $G(t) = (V, E(t))$ consists of a set of vertices V representing the nodes of the network and the set $E(t)$ of undirected edges corresponding to communication links between nodes at time t.

IV. The Proposed Algorithm

This algorithm mainly consists of three phases, namely the prediction phase, linear transformation and angular movement detection and prediction of the future position.

After the deployment, each sensor node records the first two readings at regular time interval T and broadcast these two location information. Upon meeting these two location information from neighbor sensor nodes, each sensor node in the network start predicting the future placement of all the nodes at one-hop space. This future location at time $2T$ is determined as

$$X_3 = X_2 + v(T)\cos\phi,$$
$$Y_3 = Y_2 + v(T)\sin\phi$$

where

$$v(T) = \frac{\sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}}{T}$$
$$\phi = \cos^{-1}\left(\frac{X_2 - X_1}{\sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}}\right)$$

X_1, X_2, Y_1 and Y_2 are the co-ordinates at time zero (i.e., immediately after deployement) and T respectively. X_3, and Y_3 are the co-ordinates of the predicted location at $2T$.

Now at time nT the predicted location and actual location of that node is checked. If the difference between the actual and predicted location is less than a threshold value, then the next prediction of the location at time $(n+1)T$ will be done. When the predicted location is getting same with that of the actual location, it goes on predicting the future locations with the given data. If the difference between the actual and predicted location is more than a threshold value then the predicted position is not same with the actual location. The predicted location will not be same as that of the actual location due to the following reasons.

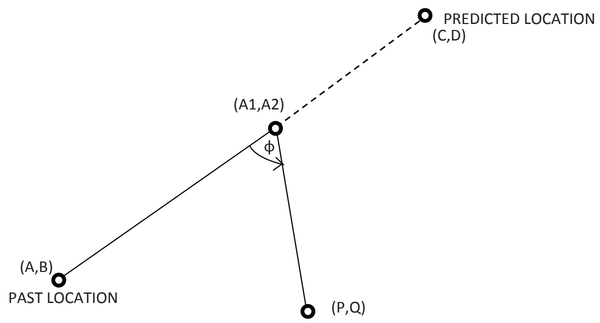


Figure 1.

1) The node moves linearly for some time and it changes its direction with a certain angle and again moves in a linear path.
2) The node follws the previous path but changes its speed.

Reason 1:

Normally the sensor node never move in a straight path. It changes its direction ofmovement. As shown in the Fig. 1, let's say the past position of the sensor node was (A, B) at time $(n-1)T$. Using the previous stored data (like velocity, past position and past moving direction), the neighbour nodes predict the future position of that node as (C, D) at time nT. However, if the node changes its direction at a certain time instant between time $(n-1)T$ and nT this prediction does not work. To address this problem, a three axis accelerometer [5] is used to sense the change in direction and the node broadcasts the new moving direction information to the neighbour nodes. Upon receiving the new direction information all the neighbour nodes predict the new future location.

As shown in Fig. 1, the direction in which the sensor node was moving at time $(n-1)T$ is given by

$$\Phi_1 = \tan^{-1}\left(\frac{D-B}{C-A}\right) \tag{1}$$

The slope is given by

$$S_1 = \tan(\Phi_1) \tag{2}$$

If two lines having slopes S_1 and S_2 cross each other then the angle between them is given by

$$\Phi = \tan^{-1}\left(\frac{S_2 - S_1}{1 + S_1 S_2}\right) \tag{3}$$

Since Φ and S_1 are known, S_2 can be calculated as

$$S_2 = \left(\frac{S_1 + \tan(\Phi)}{1 - S_1 \tan(\Phi)}\right) \tag{4}$$

Now, the sensor node will move in the direction $\Phi_2 = \tan^{-1} S_2$. The new location can be predicted as

$$P = A_1 + UD\cos(tan^{-1}(S_2)) \tag{5}$$
$$Q = A_2 + UD\sin(tan^{-1}(S_2)) \tag{6}$$

where A_1 and A_2 is the location where the node has changed its direction and is given by

$$A_1 = A + vt_1\cos(tan^{-1}(S_1)) \tag{7}$$
$$A_2 = B + vt_1\sin(tan^{-1}(S_1)) \tag{8}$$

where t_1 =Time at which the reception of angle information occurred % T.

The Velocity (v) of the node can be calculated as

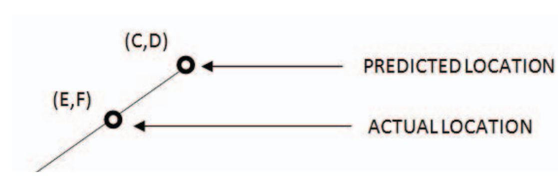
$$v = \frac{\sqrt{(C-A)^2 + (B-D)^2}}{T} \tag{9}$$

The the uncovered distance (UD) is given by

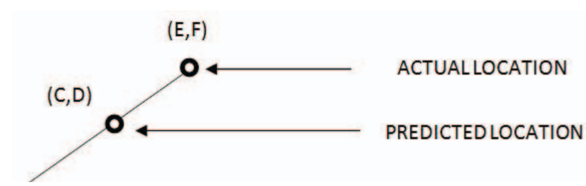
$$UD = \sqrt{(A-B)^2 + (C-D)^2} - \sqrt{(A-B)^2 + (A_1 - A_2)^2} \tag{10}$$

Reason 2:

In practice the speed of the node changes frome time to time and thus the node deviates from the predicted location. However, the predicted location and actual location are having the same direction of motion. the proposed algorithm transmits the distance $(Dist.)$ between the previous location (i.e at time $(n-1)T$) and the present location (i.e at time nT). Upon receiving these information the neighbour nodes calculate the actual location (E, F). As shown in Fig. 2, (C, D) are the



(a)



(b)

Figure 2.

coordinates of the predicted location at time nT and (E, F) are the coordinates of the actual location at time nT.

$$E = A + Dist.\cos\left(\tan^{-1}\frac{D-B}{C-A}\right)$$

$$F = A + Dist.\sin\left(\tan^{-1}\frac{D-B}{C-A}\right) \tag{11}$$

where A, B are the coordinates of past location at time $(n-1)T$ and C, D are the coordinates of predicted location for time nT.

V. Simulation Results

The performance of the proposed scheme via simulations is presented in this section. The performance metrics namely average prediction error is used to evaluate the performance of the proposed algorithm.

This work uses Castalia-2.3b, a state of the art WSN simulator based on the OMNET++ platform. All simulations are conducted on networks using the IEEE 802.15.4 at the MAC layer. The free space physical layer model is adopted where all nodes within the transmission range of a transmitting node receive a packet transmitted by the node after a very short propagation delay. The set of simulation parameters is summarized in Table I.

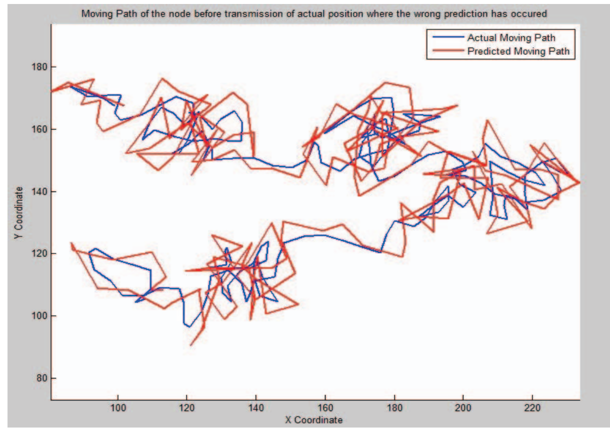
Table I
SIMULATION PARAMETERS

Parameter	Value
Number of sensors	1000
Network grid	From (0, 0) to (1000, 1000)
Sink	At (75,150)
Transmission range	50 m
Initial energy	1 $J/node$
Propagation delay	25 μsec
T	$3sec$
Simulation time	600 sec

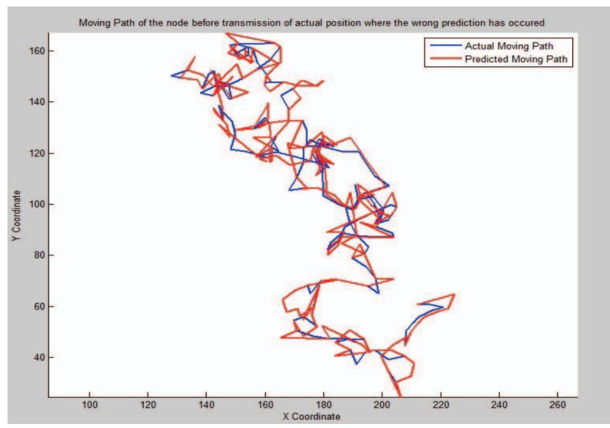
Fig 3(a) and 3(b) shows a the efficacy of the proposed algorithm over the algorithm prioposed by Deldar *et al.* [15]. This experiment shows the comparison on actual moving path and the predicted moving path. It is observed thet in [15], the predicted moving path and the actual moving path are different in most of the instances. Fig 4 compares the average prediction error. This experiment has been carried out for different velocities like 2,4,6,8,10,12,14,16 m/sec. It is observed that the proposed algorithm outperforms Deldar *et al.* Algorithm [15].

VI. Conclusions

This work addresses the fundamental problem of predicting the future location of sensor nodes in a dynamic network. Proper invesigation of historical location information and angular movement make the algorithm outperforms the existing stste-of-art algorithms.



(a) Deldar *et al.* Algorithm [15]



(b) Proposed Algorithm

Figure 3.

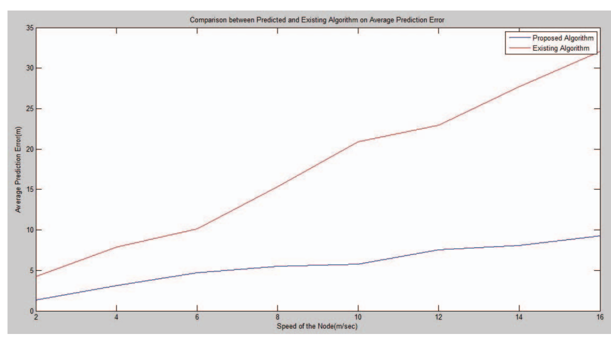


Figure 4. Prediction error

References

[1] J. A. Torkestani, "Mobility prediction in mobile wireless networks," *Journal of Network and Computer Applications*, vol. 35, no. 5, pp. 1633 – 1645, 2012.

[2] A. Jardosh, E. M. Belding-Royer, K. C. Almeroth, and S. Suri, "Towards realistic mobility models for mobile ad hoc networks," in *Proceedings of the 9th Annual International Conference on Mobile Computing and Networking*, ser. MobiCom '03. ACM, 2003, pp. 217–229.

[3] T. Camp, J. Boleng, and V. Davies, "A survey of mobility models for ad hoc network research," *Wireless Communications and Mobile Computing*, vol. 2, no. 5, pp. 483–502, 2002.

[4] J. Harri, F. Filali, and C. Bonne, "Mobility models for vehicular ad hoc networks: a survey and taxonomy," *IEEE Communications Surveys & Tutorials*, vol. 11, no. 4, pp. 19 – 41, 2009.

[5] M. Pedley, "Tilt sensing using a three-axis accelerometer," Freescale Semiconductor Application Note, Tech. Rep. AN3461, 2013.

[6] F. Lassabe, P. Canalda, P. Chatonnay, and F. Spies, "Predictivemobility models based on kth markov models," in *Pervasive Services, 2006 ACS/IEEE International Conference on*, June 2006, pp. 303–306.

[7] S. Bellahsene and L. Kloul, "A new markov-based mobility prediction algorithm for mobile networks," in *Computer Performance Engineering*, ser. Lecture Notes in Computer Science. Springer Berlin Heidelberg, 2010, vol. 6342, pp. 37–50.

[8] W. Su and M. Gerla, "Ipv6 flow handoff in ad hoc wireless networks using mobility prediction," in *Global Telecommunications Conference, 1999. GLOBECOM '99*, vol. 1A, 1999, pp. 271–275 vol.1a.

[9] A. Mahapatro and P. Khilar, "Mobility and energy aware distributed clustering protocol for ad hoc sensor networks," in *Annual IEEE India*

Conference (INDICON), Dec 2011, pp. 1–7.

[10] R. Chellapa, A. Jennings, and N. Shenoy, "A comparative study of mobility prediction in fixed wireless networks and mobile ad hoc networks," in *Communications, 2003. ICC '03. IEEE International Conference on*, vol. 2, May 2003, pp. 891–895 vol.2.

[11] S. Shah and K. Nahrstedt, "Predictive location-based qos routing in mobile ad hoc networks," in *Communications, 2002. ICC 2002. IEEE International Conference on*, vol. 2, 2002, pp. 1022–1027.

[12] H. Xu and J. Garcia-Luna-Aceves, "Neighborhood tracking for mobile ad hoc networks," *Computer Networks*, vol. 53, no. 10, pp. 1683 – 1696, 2009.

[13] J. Capka and R. Boutaba, "Mobility prediction in wireless networks using neural networks," in *Management of Multimedia Networks and Services*, ser. Lecture Notes in Computer Science, J. Vicente and D. Hutchison, Eds. Springer Berlin Heidelberg, 2004, vol. 3271, pp. 320–333.

[14] H. KAANICHE and F. KAMOUN, "Mobilitypredictioninwirelessadhocnetworksusing neural networks," *JournalofTelecommunications*, vol. 2, no. 1, pp. 95–101, 2010.

[15] F. Deldar and M. Yaghmaee, "Designing an energy efficient prediction-based algorithm for target tracking in wireless sensor networks," in *International Conference on Wireless Communications and Signal Processing (WCSP)*, Nov 2011, pp. 1–6.