

Mobility Prediction in Mobile Ad Hoc Networks

Damianos Gavalas

Department of Cultural Technology and Communication,
University of the Aegean
Trikoupi & Faonos St., 811 00, Mytilene, Lesvos, Greece
Phone: (+30) 22510 36643
Fax: (+30) 22510 36629
Email: dgavalas@aegean.gr

Charalampos Konstantopoulos

Department of Informatics
University of Piraeus
Karaoli & Dimitriou St., 185 34 Piraeus, Greece
Phone: (+30) 210 4142263
Fax: (+30) 210 4142264
Email: konstant@cti.gr

Basilis Mamalis

Department of Informatics
Technological Educational Institution of Athens
Ag. Spyridonos St., 122 10, Athens, Greece
Phone: (+30) 210 5910974
Fax: (+30) 210 5910975
Email: vmamalis@teiath.gr

Grammati Pantziou

Department of Informatics
Technological Educational Institution of Athens
Ag. Spyridonos St., 122 10, Athens, Greece
Phone: (+30) 210 5385827
Fax: (+30) 210 5910975
Email: pantziou@teiath.gr

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ABSTRACT

A Mobile Ad hoc NETWORK (MANET) is a collection of wireless mobile nodes forming a network without using any existing infrastructure. All mobile nodes function as mobile routers that discover and maintain routes to other mobile nodes of the network and therefore, can be connected dynamically in an arbitrary manner. The mobility attribute of MANETs is a very significant one. The mobile nodes may follow different mobility patterns that may affect connectivity, and in turn protocol mechanisms and performance. Mobility prediction may positively affect the service-oriented aspects as well as the application-oriented aspects of ad hoc networking. At the network level, accurate node mobility prediction may be critical to tasks such as call admission control, reservation of network resources, pre-configuration of services and QoS provisioning. At the application level, user mobility prediction in combination with user's profile may provide the user with enhanced location-based wireless services, such as route guidance, local traffic information and on-line advertising. In this chapter we present the most important mobility prediction schemes for MANETs in the literature, focusing on their main design principles and characteristics.

INTRODUCTION

Mobile ad hoc networks are self-organizing and self-configuring multi-hop wireless networks capable of adaptive re-configuration when they are affected by node mobility. A mobile ad hoc network is composed of peer nodes with equal networking capabilities which are able to function as mobile routers i.e., to forward packets and maintain routes. Packets can be forwarded in multi-hops from the source nodes to the destination nodes with no need for underlying fixed network infrastructure (e.g. routers and base stations). Therefore, mobile ad hoc networks are not constrained in their deployment by any need for underlying infrastructure and they can be deployed rapidly in situations where wireless access to a backbone is impossible and an infrastructure is difficult to install (e.g., disaster recovery). In addition to the traditional problems of wireless networks (bandwidth optimization and transmission quality enhancement) mobile ad hoc networks introduce new issues such as ad-hoc addressing, increased energy constraints, self-configuration and adaptive reconfiguration, as network topology is affected by node mobility. Furthermore, because of the real time nature of ad hoc network applications (e.g., collaborative mobile computing, battlefield communications, emergency search and rescue operations, disaster recovery), data traffic is routed under timing constraints requiring proactive route construction and maintenance procedures.

Mobility prediction may positively affect the service-oriented aspects (network level) of ad hoc networking as well as the application-oriented aspects (application level). At the network level, accurate mobility prediction may be critical to tasks such as call admission control, congestion control, reservation of network resources, pre-configuration of services and QoS provisioning. At the application level, user

mobility prediction in combination with user's profile may provide the user with enhanced location-based wireless services, such as route guidance, local traffic information, tourism services, on-line advertising, etc. Given that 4G and beyond wireless ad hoc and hybrid networks will support real-time multimedia applications, the need for mobility prediction is of great significance.

Because of the importance of mobility prediction in ad hoc networks, there is a significant amount of research work on the topic, while in some cases the proposed techniques follow ideas or approaches used in fixed infrastructure type networks. However, prediction approaches for fixed infrastructure type networks are usually inappropriate in the case of ad hoc networks since: (1) Mobility prediction in fixed wireless networks is based on the use of a static underlying network infrastructure, while in ad hoc networks mobility prediction must be done in a highly dynamic environment, where the network topology is changing and the mobility of other nodes should be taken into consideration. (2) Ad hoc networks are usually applied in emergency operations and military environments, where future node movements cannot be based on a record of previous movements because of the dissimilar requirements of each situation. (3) Since mobility prediction methods for ad hoc networks are executed on the mobile nodes, they should be more light-weight than the methods for fixed wireless networks, typically executed on the base stations.

In this chapter we shall present the most important mobility prediction schemes for mobile ad hoc networks in the literature, focusing on their main design principles and characteristics.

BACKGROUND

Wireless mobile networks can be classified as infrastructure-based networks and ad hoc networks. The former type includes networks with fixed base stations and each mobile node connects to the network by communicating with a base station which is within its communication range. A Mobile Ad hoc NETWORK (MANET) is a collection of wireless mobile nodes forming a network without using any existing infrastructure. All mobile nodes function as mobile routers that discover and maintain routes to other mobile nodes of the network and therefore, can be connected dynamically in an arbitrary manner. Therefore, a MANET is self-organized i.e., it is deployed and managed independently of any preexisting infrastructure, while it autonomously determines its own configuration parameters such as position identification, power control, routing and addressing.

Ad hoc network applications vary and their environment may change dynamically and unpredictably. The ad hoc protocols at various layers need to self-tune to adjust to the changes of the environment and to the requirements of the different applications. In addition, MANETs can grow to several thousands of nodes, while their self configuring nature cannot tolerate a physically hierarchical structure to handle the issue of network scalability, as infrastructure type networks do. Therefore, designing scalable MANETs is a very critical challenge.

The mobility attribute of MANETs is a very significant one. The mobile nodes may follow different mobility patterns (e.g., individual random mobility, group mobility, etc.) that may affect connectivity (i.e., links), and in turn protocol mechanisms and performance. Therefore, the mobility model may have an important impact on the selection of a routing scheme and influence the network performance. Several mobility models have been used to model mobile node's movement

(Chellapa-Doss et al., 2004). Some of these models are the following: The *Random Walk model*, which defines user movement from one position to the next with memoryless randomly selected speed and direction. The *Random Waypoint model*, which defines user movement as a series of pause and motion periods. The user stays at a particular position for a specified period of time before moving to the next position in a randomly selected direction with speed uniformly distributed in an interval $[0, Maxspeed]$. Since, the movement of ad hoc mobile nodes frequently exhibit group mobility characteristics, a number of group mobility models have also been proposed. For example, in the *Reference Point Group Mobility Model (RPGM)*, the nodes in the network are organized into mobility groups. Each mobility group has a logical group center, the *reference point*, which defines the movement of the entire group. The member nodes of the group are physically distributed in the vicinity of the *reference point* and the location of each mobile node is described by its physical displacement from the group's reference point.

Many mobile ad hoc networks applications require real-time flow for delivering data packets under strict timing constraints, in environments that are characterized by frequent topology changes. To maintain high-quality service for such applications, the data routing should not only reflect the change of mobile node's location and/or topology changes, as the *reactive or on demand* routing schemes do, but anticipate the movement behavior of mobile nodes employing *proactive* routing procedures. If each mobile node's future location and network topology changes can be predicted accurately enough, then route reconstruction can be done prior to topology changes without overburdening the network with a large number of control packets. Thus, services are pre-connected and pre-assigned at the mobile node's new location before the node moves into the new location. The end user receives immediately services at the new location, almost as efficiently as at the previous location. Therefore, the employment of mobility prediction techniques is very crucial in the design of efficient routing schemes.

It is well known that flat routing schemes do not scale well in terms of performance, while routing on top of a logically hierarchical structures, e.g. a clustered topology, is much more scalable as the flooding traffic is under control. Clustering (McDonald and Znatti, 1999b; Yu and Chong, 2005) is a promising approach for enhancing the scalability of MANETs in the face of frequent topology changes. Clusters are dynamic groupings of mobile nodes. A representative of each cluster is elected as a *cluster head (CH)* and a mobile node, which serves as intermediate for inter-cluster communication, is called a *gateway*. CHs hold routing and topology information while the boundaries of a cluster are defined by the transmission area of its CH. The feasibility of a clustering method is determined by the stability of the cluster structure that it creates, despite network topology changes. Otherwise, frequent reclustering is required thereby, creating a large volume of control messages which in turn consume considerable bandwidth and drain mobile nodes' energy quickly. As the main cause for topology changes in a MANET is node mobility, an efficient clustering method should seriously take the movements of mobile nodes into account in order to form clustering structures resistant to the node mobility. Therefore, employing efficient mobility prediction techniques for cluster formation and maintenance ensures the construction of a relatively stable clustering structure (virtual backbone) that is highly resistant to the topological changes of the ad hoc network.

MOBILITY PREDICTION METHODS AND THEIR APPLICATIONS

We classify the mobility prediction methods for mobile ad hoc networks into three categories as follows (Figure 1):

- A. *Movement history based prediction methods*, which predict the “future” location of a mobile user based on his movement history (i.e., previous user movement patterns).
- B. *Physical topology based mobility prediction methods*, which base their prediction on the use of the characteristics of MANET’s physical topology and therefore, require the use of a Global Positioning System (GPS) to obtain exact node location and mobility information.
- C. *Logical topology based mobility prediction methods*, which choose a logical topology of the MANET (e.g. a clustering structure) over which they apply their prediction process. On the contrary to the previous category, they do not require exact location and mobility information and thus they do not make use of a GPS. Estimated values of node location and mobility information may be obtained by other means (e.g, using signal attenuation versus travelled distance to estimate internode distances, or inferring the mobility of each node from how different is the neighbourhood of the node over time).

For each one of the above mentioned categories, we present well-known prediction methods, classifying them according to their applications and/or the specific prediction method they are based on.

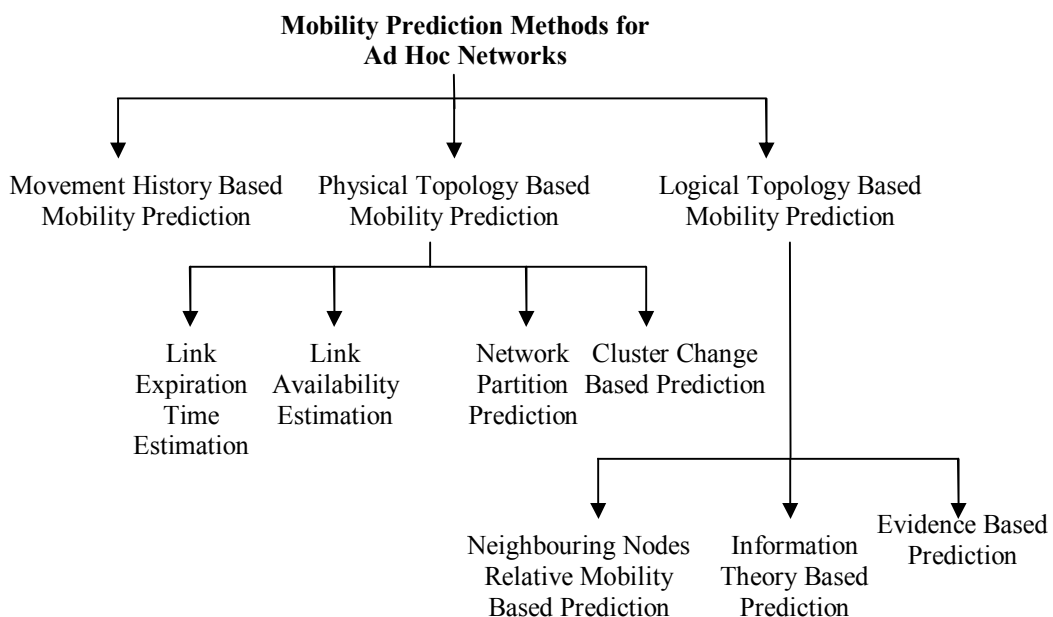


Figure 1. Classification of the mobility prediction methods

A. Movement History Based Mobility Prediction

A number of motion prediction algorithms mainly for fixed wireless networks, e.g. (Liu and Maguire, 1996; Erbas et al., 2001) has been proposed which predict the

“future” location of a mobile user based on the user’s movement history (i.e, previous user movement patterns). The algorithms use different mobility models (e.g., the movement circle model, the movement track model, the Markov chain model) to model the user mobility behavior, exploiting the fact that the movement of a mobile user consists of a random and a regular movement part. The regularity in human movement behavior derives from certain activities that are repeated within a defined period of time (e.g., going to work every day or visiting a family member every week). The proposed schemes consist of regularity-pattern recognition algorithms and motion prediction algorithms and they are very critical for supporting high quality services for mobile applications. For example, by predicting the future location of a mobile user according to his/her movement history, routing may be pre-arranged, resources may be pre-allocated, services may be pre-assigned at the new location before the user moves into it.

The above methods fail in the case that there are unpredictable changes in user’s behavior. Also, there are additional problems when these methods are applied in MANETs because of the nature of those networks applications (military environments, emergency search and rescue operations). Due to dynamic topology and non regular requirements in such applications node mobility prediction based on the movement history is not always feasible and/or efficient.

B. Physical Topology Based Mobility Prediction

1. Link expiration time estimation

By exploiting the fact that in real world situations, usually, a mobile node’s movement is not completely random but the node travels in a predictable manner, we can predict the future state of the network topology. By predicting the future state of the network topology, the route reconstruction can be done effectively prior to route breaks and without generating excessive control overhead.

We say that there *exists a wireless link* between two nodes p and q of a MANET if and only if p and q are within the transmission range, say r , of each other, i.e., the distance between their placement is smaller than r . In (Su and Gerla, 1999) a mobility prediction method is presented for estimating the expiration time of the wireless link between two adjacent ad hoc nodes as a way to enhance various unicast and multicast routing protocols. By predicting the link expiration time for any link on a route R , the route’s R expiration time is estimated as the least of the link expiration time values of all links on R . Based on this prediction, routes are reconfigured before they disconnect. The estimation of the link expiration time or in other words, the time period T that two ad hoc nodes being within mutual transmission range, remain connected, is done as follows. Let (x_i, y_i) and (x_j, y_j) be the positions of nodes i and j , respectively. Let also v_i and v_j be the speeds, θ_i and θ_j be the moving directions of nodes i and j , respectively, and TX their transmission range. Then, the amount of time T the mobile nodes i and j will stay connected is given by:

$$T = \frac{-(ab + cd) + \sqrt{(a^2 + c^2)TX^2 - (ad - cb)^2}}{(a^2 + c^2)}$$

where $a = v_i \cos \theta_i - v_j \cos \theta_j$, $b = x_i - x_j$, $c = v_i \sin \theta_i - v_j \sin \theta_j$, $d = y_i - y_j$. The exact location and mobility information of each mobile node can be provided by a GPS device. In cases that the use of GPS to compute exact location information is not

possible, then approximate values for inter-node distances are computed as follows: Transmission power samples are measured periodically from packets received from a node's neighbour. From this information each node can compute the rate of change for a particular neighbour's power level (Su et al., 2001). Therefore, the time that the power level drops below the acceptable value can be fairly easily estimated. However, the link expiration time method requires exact location and mobility information while using power attenuation for distance estimation is not accurate.

The above mobility prediction mechanism works well in the case of simple node mobility patterns with no sudden changes in the moving directions and speeds, and when the mobility information (obtained from GPS) is accurate. The mechanism was applied to some of the most popular wireless ad hoc routing protocols and simulation results showed that these protocols performed better than their counterparts without mobility prediction (i.e., more data packets were delivered to destinations and the control packets were utilized more efficiently (Su et al., 2001)). Specifically, results show that the Flow Oriented Routing unicast Protocol (FORP) (Lee et al. Gerla, 2001) and Distance Vector (DV) unicast protocol enhanced with mobility prediction offer packet delivery ratios of 0.9 (i.e., 10% of packet loss) for speeds up to 70 km/h. Also, the On-Demand Multicast Routing Protocol (ODMRP) (Lee et al., 2001) with mobility prediction performs better than its counterpart without prediction and offers packet delivery ratio of 0.9 (i.e., 10% of packet loss) for speeds up to 70 km/h (Chellapa-Doss et al., 2004).

2. Link availability estimation

A probabilistic link availability model which can predict the future status of a wireless link is proposed in (McDonald and Znabi, 1999a; McDonald and Znabi, 1999b). The *link availability* is defined as the probability that there is an active link between two mobile nodes at time $t+T$ given that there is an active link between them at time t . Note that a link may experience one or more failures and recoveries in the time interval between t and $t+T$. Note that the metric is not practical as a criterion to select a path between two nodes, because if a link fails, then rerouting should immediately take place rather than waiting for the failed link to become available again. But, the link availability criterion is useful during the clustering process as it can be used by mobile nodes to select more reliable neighbours to form more stable clusters.

In (Jiang et al., 2001) a prediction-based link availability estimation and a routing metric in terms of path reliability based on the link availability estimation are presented. The basic idea of this estimation is as follows:

Given an estimation T of the expiration time (i.e., the continuously available time) for an active link $\{v,u\}$ between two nodes v and u at time t (computed e.g., by using the link expiration time algorithm of (Su and Gerla, 1999) presented above), the availability $L(T)$ of link $\{v,u\}$ is defined as

$$L(T) = Pr \{ \text{the link } \{v,u\} \text{ lasts from time } t \text{ to time } t+T \text{ given that the link is available at time } t \}$$

which indicates the probability that the link $\{v,u\}$ will be continuously available from time t to time $t+T$. The calculation of $L(T)$ is divided into two parts: the link availability $L_1(T)$ when the speeds and moving directions of the nodes v and u remain unchanged from time t to time $t+T$, and the link availability $L_2(T)$ for the other cases. That is, $L(T) = L_1(T) + L_2(T)$. Assuming that the mobility epoch (a random length

interval during which node movement is unchanged) is exponentially distributed with mean λ^{-1} , the nodes' movements are independent of each other and the exponential distribution is 'memoryless', $L_1(T)$ is given by:

$$L_1(T) = [1 - E(T)]^2 = e^{-2\lambda T}$$

An accurate estimation of $L_2(T)$ is not easy due to difficulties in learning the changes in link status caused by changes in nodes' movement. A conservative prediction $L_{min}(T)$ of link availability $L_2(T)$ is given in (Jiang et al., 2001) as follows:

$$L_{min}(T) = (1 - e^{-2\lambda T}) / 2\lambda T + \lambda T e^{-2\lambda T} / 2$$

Using the estimation of $L(T)$, a routing metric based on $L(T) \times T$ is given in (Jiang et al., 2001) that offers improved network performance, according to simulation results. Note that in highly volatile environments, it is possible that the mobility epoch (during which the mobility of the user is unchanged) is usually very small. This will necessitate a large number of estimations that increase the control overhead.

3. Group mobility and network partition prediction

Network partition occurs when groups of mobile nodes follow diverse mobility patterns, which cause the separation of the network into disconnected subnetworks. Predicting the occurrence and the timing of network partitioning allows MANET applications to improve their performance by acting in advance and preventing disruptions caused by the partitioning.

A method for network partition prediction which exploits group mobility patterns to compute the remainder time before separation is proposed in (Wang and Li, 2002). In order to describe the basic idea of the method, we consider a simple case of a network consisting of two mobility groups C_i and C_j each moving with velocities $V_i = (vx_i, vy_i)$ and $V_j = (vx_j, vy_j)$ respectively. The relative mobility between them is obtained by fixing one group, say C_i , as stationary. Then the effective velocity V_{ij} at which C_j is moving away from C_i is given by:

$$V_{ij} = V_j + (-V_i), \text{ where } V_{ij} = (vx_{ij}, vy_{ij}) = (vx_j - vx_i, vy_j - vy_i)$$

Assume that the two groups cover a circular region of diameter D , wherein the nodes are uniformly distributed. Assume also that the groups are in perfect overlap. Then, in order for the two groups to separate, C_j must move past a distance of the diameter D of C_i 's coverage area. Hence, the time taken for the two groups to change from total overlap to complete separation is given by:

$$T_{ij} = D / (vx_{ij}^2 + vy_{ij}^2)^{1/2}$$

In a network made up of many diverse mobility groups, whose nodes are initially dispersed and inter-mixed, given the mean group velocities, the time of separation can be calculated for any pair of mobility groups. The occurrence of partitioning is predicted as a sequence of the expected time of separations between the different pairs of mobility groups in the network.

The network partition prediction method uses a low-complexity data clustering algorithm that accurately determines the mobility groups and their mobility

parameters as well as the group membership of each mobile node. The problem is that the prediction algorithm assumes that group and node velocities are time invariant, which is not a realistic assumption for most MANET applications.

4. Cluster change based prediction

In a clustered ad hoc network each mobile node belongs to a cluster while the position of each mobile node is defined with respect to the cluster head of the cluster it belongs to. A mobile node changes the cluster it belongs to as affected by mobility. The *sectorized* ad hoc mobility prediction algorithm is based on the principle that in order to achieve maximum prediction accuracy the prediction process should be restricted to areas of the network with nodes of high cluster change probability (Chellapa-Doss et al., 2003a; Chellapa-Doss et al., 2003b). The algorithm introduces the *sectorized cluster structure* i.e., the cluster is divided into three regions with respect to the probability of cluster change as follows:

- (i) The *No-Cluster Change (No-CC)* region of each cluster, which contains the nodes of the cluster that are within communication range of each other and they do not satisfy the requirements for membership to any neighbouring cluster. Thus, for the nodes in the No-CC region cluster change is not possible.
- (ii) The *Low-Cluster Change (Low-CC)* region of each cluster, which contains the nodes of the cluster that are reachable by all nodes in the No-CC region, either directly, or through other intermediate nodes belonging to the No-CC region. Thus, for the nodes in Low-CC region the probability of cluster change is fairly low.
- (iii) The *High-Cluster Change (Hi-CC)* region of each cluster, which contains the nodes of the cluster that are not reachable by any node in the No-CC region, either directly, or through other intermediate nodes belonging to the No-CC region. The nodes in the Hi-CC region are reachable only through the nodes in the Low-CC region and the probability of cluster change for a node in this region is higher than for nodes in the Low-CC region.

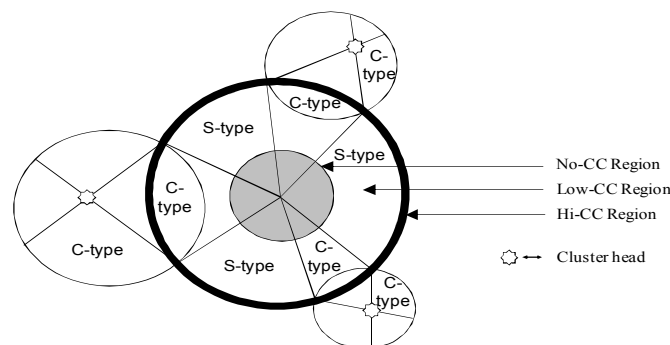


Figure 2: The sectorized cluster structure

The cluster is further divided into *sectors* (Figure 2), (Chellapa-Doss et al., 2003; Chellapa-Doss et al., 2004). Two types of sectors are introduced depending on whether or not the sector is adjacent to a neighbouring cluster. *C-type cluster-sectors* that are adjacent to neighbour clusters, and *S-type cluster-sectors* that are not. It is

only from C-type clusters that cluster change is possible. Each C-type cluster-sector is adjacent to only one neighbouring cluster and it is only to this cluster that the node can cluster change to. Nodes in S-type cluster-sectors are not candidates for cluster change as there are no adjacent clusters present.

The cluster sector-numbering scheme (Chellapa-Doss et al., 2003; Chellapa-Doss et al., 2004) is used to predict the next cluster change depending on the mobile node's position in the cluster and its moving direction in the Hi-CC region. The method uses a GPS to build the sectors and locate the mobile nodes positions. Note that, the cluster-sector numbering scheme, as a prediction method, may sit on top of any other ad hoc network clustering algorithm that may be in use.

C. Logical Topology Based Mobility Prediction

1. Neighbouring Nodes Relative Mobility Based Prediction

Many researchers have acknowledged the importance of node mobility estimation for building clustering schemes more stable and less reactive to topological changes of ad-hoc networks. Authors in (McDonald and Znatti, 1999b) propose the (a,t) clustering scheme, where mobile nodes form clusters according to a path availability criterion. The network is partitioned into clusters of mobile nodes, that are mutually reachable along cluster internal paths which are expected to be available for a period of time t with a probability of at least a . The parameters of this model are predefined. In addition, it is assumed that the movement of each mobile node is random and entirely independent of the movements of other mobile nodes. However, this random walk model cannot always capture some node mobility patterns occurring in practice in MANETs.

MOBIC in (Basu et al., 2001) elects as CHs the mobile nodes which exhibit the lowest mobility in their neighbourhood. Each node compares the receiving signal strength from its neighbours over the time and uses the variance in these values as an indication of how fast this mobile node is moving in relation to the neighbouring nodes. MOBIC uses only the current mobility to determine the most suitable mobile nodes for CHs.

As an extension of MOBIC, MobDHop (Er and Seah, 2004; Er and Seah, 2006) also uses the variability in receiving signal strength as a hint of neighbourhood mobility and builds variable-diameter clusters. It uses more samples of receiving signal than MOBIC to estimate the predicted mobility, while the prediction model is based on the assumption that the future mobility patterns of mobile nodes will be exactly the same as those of the recent past.

MAPLE (Palit et al., 2006) is another clustering algorithm which also infers node mobility from measurements of the received signal strength. In particular, each mobile node belonging to a cluster can estimate its distance from its CH by using the well-known formula (Schwartz, 2005) of the signal attenuation versus travelled distance. Then, based on past measurements, mobile nodes use a linear model for estimating their future distance from their CH. This helps mobile nodes to proactively join another cluster if they are going to soon leave their current cluster. However, MAPLE does not take node mobility into account during CH election. Specifically, mobile nodes contend for free frames (i.e., time slots) in a single shared broadcast channel during the cluster formation phase and mobile nodes that first reserve the available frames in this phase become CHs. Thus, the election of CHs is mostly a random procedure and it is not based on some CH suitability criteria. In addition, the

algorithm sets an upper bound on the number of clusters in the network as well as on the number of mobile nodes per cluster.

2. Information theory based mobility prediction

Information theory based techniques for node mobility prediction have been first employed in (Bhattacharya and Das, 2002), where the authors focused on the problem of mobile tracking and localization in cellular networks. Later, Sivavakeesar et. al (Sivavakeesar et al., 2004) used the basic technique of (Bhattacharya and Das, 2002) in their cluster formation algorithm for MANETs. In their work they assume that a geographical area is divided into circular-shaped regions (virtual clusters) and each mobile node knows the virtual cluster where it is currently in.

In (Konstantopoulos et al., 2006; Konstantopoulos et al., 2008) a mobility-aware technique for cluster formation and maintenance is proposed. The main idea in the technique is to estimate the future mobility of mobile nodes so as to select cluster heads that will exhibit the lowest predicted mobility in comparison to the other mobile nodes. As a measure of node mobility rate, it is used the probability of a mobile node having the same mobile nodes in its neighbourhood for sufficiently long time. A high probability value for a mobile node indicates either a relatively immobile node or the existence of a group of nodes around this particular node that exhibits the same mobility pattern. Whatever the case is, this mobile node is apparently a good candidate for a CH, because in all probability, it will serve the same neighbours for a long time. For estimating the predicted mobility of a mobile node, it is assumed that the movements of nodes are not random but demonstrate a regular pattern (Camp et al., 2002), which can be predicted, provided that enough “historic” information has been gathered for the movements of each mobile node. For the organization of the historic record and the estimation of future mobility based on this record, prediction techniques from the field of data compression are used. Specifically, the problem of estimating the future neighbourhoods of a mobile node is reduced to that of predicting the next characters in a text given that we have already seen a particular text context. Then, by using context modelling techniques (Bell et al., 1990), the probability of stable neighbourhood around a node can be reliably estimated. The most important characteristic of these methods is the on-line learning of the probability model used for predicting the next character/neighbourhood. This is essential in the case of MANETs because the movements of individual nodes as well as the strong correlation, existing in the movements of these hosts, cannot be easily described by predefined random models. The method does not make any use of a fixed geographical partition in contrast to previous work (Bhattacharya and Das, 2002; Sivavakeesar et al., 2004) and thus, the notion of cells is irrelevant to this technique. Also for measuring the mobility, the method does not use any special purpose hardware such as GPS, but the mobility of each node is inferred from how different is the neighbourhood of the node over time.

Besides the stability of the clustering structure, an important objective in cluster creation is keeping the number of elected CHs relatively low, so that the virtual backbone built over these mobile nodes, to be of correspondingly small size and hence routing update protocols can be efficiently ran on this backbone. The well-known highest degree clustering algorithm (Gerla and Tsai, 1995) is a clustering scheme that creates a relatively small number of one-hop clusters and thus a small-size routing backbone. In this technique, each mobile node having the highest degree among all its neighbours is elected as CH. The degree of a mobile node is defined as

the number of its one-hop adjacent nodes. The main weakness of the technique is the frequent CH changes due to node mobility. In (Konstantopoulos et al., 2008), a new clustering algorithm (named MobHiD) is proposed which combines the highest degree technique with the mobility prediction scheme, and ensures a relatively small as well as stable virtual backbone despite node mobility.

Note that the mobility prediction technique is of independent interest and may be combined with other clustering algorithms to enhance the stability of the derived clustering structure in the presence of topology changes.

3. Evidence based mobility prediction

The Dempster-Shafer (DS) theory of evidence developed by A. Dempster (Dempster, 1968) and extended by G. Shafer (Shafer, 1975) has attracted considerable attention as an approach that enables combination of different information sources (called *evidences*) to reach decisions in situations characterized by a high degree of uncertainty. In the DS theory, if a probability p is assigned to an event, then $1-p$ represents the confidence not assigned to this event. $1-p$ represents ignorance and uncertainty and it is not necessarily assigned to the opposite event. The main advantage of the DS theory of evidence is its ability to model the narrowing of a hypothesis with the accumulation of evidences and to explicitly represent uncertainty in the form of ignorance or reservation of judgment. The DS theory provides the possibility of giving to different evidences weights according to their relevance and importance in the final decision. It also provides an operation, called the *Dempster's rule of combination*, for combining evidences.

In (Saman and Karmouch, 2005), the DS theory of evidence is used for user mobility prediction based on the use of contextual information. The method can accurately predict user's traveling trajectory using knowledge of mobile user's profile and preferences and analyzed spatial information. Note that knowledge of such contextual information is very important for mobile environments because they may adapt their services according to users' specific demands. Uncertainty of the user's navigation behavior is captured by gathering pieces of evidence concerning different groups of candidate future locations. These groups are then refined to predict the user's future location, when evidence accumulates using the Dempster's combination rule. The method does not require the existence of history of users' movements.

In (Dekar and Kheddouci, 2008) a mobility prediction scheme is proposed that uses the DS theory of evidence to predict the future position of a mobile node based on relevant criteria. The scheme exploits the ability of the DS theory of evidence to explicitly represent uncertainty, which is the main characteristic of the mobility prediction problem. The mobility prediction process is working on a cluster based topology and is performed by a *prediction agent* whose role is to predict the mobile nodes' future clusters before they leave their current clusters. To this end, cluster nodes are organized into the following categories: (a) the *central* nodes, which are either cluster heads or have a link whose strength is greater than a certain value with another central node, (b) the *border* nodes, which have a neighbour that belongs to another cluster, and (c) the *intermediate* nodes, which are neither border nodes nor intermediate nodes. According to this organization, the prediction process is performed only on the border nodes, because only these nodes have neighbours that belong to another cluster, and therefore, can leave their cluster and join another one. The prediction agent uses the following main categories of criteria to predict each mobile node's future cluster:

- (i) The *physical criteria*, which express the mobile node's physical movement. Such criteria include: *the candidate cluster radius* (if a cluster has the maximum radius it cannot receive new nodes as members), *the links strength with each candidate cluster* (this criterion chooses the candidate cluster with whom the mobile node has the maximum number of strong links) and *the links strength evolution with each candidate cluster* (this criterion chooses the candidate cluster to which the mobile node gets closer).
- (ii) The *semantic criteria*, which are used to select a cluster when the physical criteria can not do it clearly (e.g., there are several clusters that can be the future cluster according to the physical criteria). Such criteria include: *the user requested services* (this criterion chooses the candidate cluster that contains the most services used by the mobile) and *the user profile* (this criterion chooses the candidate cluster whose profile is the most relevant to the user profile).

By using the DS theory of evidence as a modelling method, the above criteria are weighted according to their importance. Then, the Dempster's rule of combination is applied to combine the different criteria (evidences) and to select the appropriate candidate cluster as the mobile node's future cluster. The method does not require the use of a GPS, as the signal strength may be used to estimate the link strengths and to estimate the distances among the mobile nodes. The mobility prediction scheme has been applied to the Zone Routing Protocol (Haas and Pearlman, 1999) and simulation results have shown its efficiency.

FUTURE TRENDS

So far, ad hoc networks have been deployed for special cases such as battlefield or emergency scenarios. However, this technology is soon expected to be considered as a common place and support our every-day activities and also will coexist with fixed-infrastructure wireless networks (4G networks). The plethora of multimedia services and applications that will run over these networks will pose severe requirements for real-time continuous data flow with guaranteed data rate (QoS requirements). In this new context, predicting the mobile user's future location and the network topology change may significantly improve the QoS parameters by achieving route discovery and route reconstruction prior to the user's movement and to the topology change.

This unification of different wireless technologies does not pose only challenges but also offer opportunities for more accurate mobility prediction methods. The new techniques could be two-tier. The most powerful part could be executed in base stations where advanced machine learning methods could be applied for determining the future positions of mobile nodes at a certain resolution. For more detailed determination of node movements, each node will apply "light-weight" method based only on local information around the node. This also will alleviate the problem incurred in all localization methods in fixed-infrastructure networks where nodes should frequently send position information to the base station in order that the base station keep track of the movements of nodes. Another advantage of the combined centralized and distributed scheme is that base stations collecting information from large node population could reach safer conclusions with regard to node movements as statistical phenomenon. In contrast, each node alone based only on the local view coming from its neighborhood can fail sometimes to determine the behavior of nodes in a larger scale.

The deployment of ad-hoc networks alongside with fixed-infrastructure networks in urban areas also changes some of the basic assumptions about the application field of these networks. Now, the users of mobile devices are not necessarily members of a team that act for a special purpose such as soldiers in a battle-field scenario or rescuers in an emergency scenario but they can be persons not related in an obvious way. So, the correlation of mobile nodes in an urban area is more implicit and hence more difficult to find. Sometimes, it may be possible to infer correlation by taking also into account other restrictions that exist in the movements of persons in a city. For instance, when two nodes are moving along a road, it is sure that the direction of movements of two nodes is the same and cannot change before the next crossroads. Apparently here it is implied that each node is aware of its surrounding topology. This information can be obtained from the base station or from a navigation system now commonly placed in new mobile phones.

In a more general setting, the main issue is the discovery of the relations rising in a large population of individuals. The social behavior observed can be valuable information for inferring correlation among movements of the users of mobile devices. Results from the social networks theory (Da Fontoura et al., 2007) commonly used in the science of sociology could help reveal this kind of relations and thus could be very useful for enhancing predicting capability with regard to the mobile node movements. Also, trace information gathered from the huge number of mobile phones currently in use can provide rich behavioral data that can be studied and then used for deducing safer conclusions about the common behavioral patterns met in large populations (Eagle and Pentland, 2006).

From the discussion above, it becomes evident that although a relatively important number of mobility prediction schemes have already been proposed, there are still issues that should be addressed and improved in the design of such schemes as now more clues about the future behavior of mobile nodes are available and thus they can be used for improving the prediction of mobility of mobile nodes.

CONCLUSION

Mobility prediction, i.e., estimating the trajectory of future positions of the mobile nodes in MANETs, positively affect the service-oriented as well as the application-oriented aspects of ad hoc networking. The employment of mobility prediction techniques at the network level is very crucial in the design of efficient routing schemes, while at the application level, in combination with user's profile may provide the user with enhanced personalized wireless services. This chapter presents well-known mobility prediction schemes classifying them according to the specific prediction methods they employ and/or according to their applications.

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KEY TERMS AND THEIR DEFINITION

Ad hoc routing protocol: A convention or standard that specifies how nodes communicate with each other to exchange information that allows them to select routes between any two nodes in a mobile ad-hoc network.

Cluster: Dynamic group of mobile nodes with a *cluster head (CH)*, i.e., a mobile node that holds routing and topology information. The boundaries of a cluster are defined by the transmission area of its CH.

Clustering: The process of partitioning the mobile nodes into dynamic groups, called clusters.

Global Positioning System (GPS): A space-based radionavigation system that provides reliable positioning, navigation, and timing services to users. For anyone with a GPS receiver, the system provides accurate location and time information on a continuous worldwide basis.

Mobile ad hoc network (MANET): A self-organizing and self-configuring multi-hop wireless network capable of adaptive re-configuration when it is affected by node mobility, which does not rely on a fixed infrastructure.

Mobility Prediction: The problem of estimating the trajectory of future positions of the nodes in mobile networks.

Network Scalability: The ability of a network to support the continuous increase of the network parameters (such as mobility rate, traffic rate, and network size) without degrading network performance.

Signal attenuation: A general term that refers to any reduction in the strength of a signal.