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An OpNet Implementation of Gauss-Markov mobility model and integration of link prediction algorithm in DSR protocol: A cross-layer approach

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Abstract

Cross layer design has been identified as a key mechanism to cope with instabilities caused by nodes mobility in wireless ad hoc networks. In this kind of networks, the fluctuations induced by the nodes movement result in channel variation that strongly affects the network layers functions such as scheduling, routing and flow control. To deal effectively with these fluctuations, we need to design a model for predicting the changes in the channel state and use them according to the networks needs. In this paper we propose an extension of the Dynamic Source Routing Protocol (DSR) which takes advantage of the link quality prediction in order to increase the probability that the selected paths will provide the required characteristics. The mobility of the nodes follows the Gauss-Markov (GM) model, which was implemented by using the OPNET modeler tools. Furthermore, the DSR was modified in order to integrate the predicted link parameter and the simulated model performances are compared to the standard DSR.

Introduction

A MANET can be seen as an autonomous system or a multi-hop wireless extension. As an autonomous system, it has its own routing protocols and network management mechanisms and should provide a flexible and seamless access to the Internet. Recently, with the rising popularity of multimedia applications and potential commercial/military usage of MANET, Quality of Service (QoS) support in MANET has become very crucial. There are still lots of improvement to achieve before ensuring to multimedia applications in MANET, the same level of services as in wired and wireless networks. This is due to different reasons. First the dynamism of the nodes, which work also as routers, causes a frequent topology change in some unpredicted way. Second, the scarcity of the bandwidth and the limitations in power of the nodes add some constraints on the frequency and size of the control information exchanged in order to adapt to the network status. Finally the performances of the protocols at different level are interrelated in such a way that can affect the overall performance of the system. The low level of the system performances is due to several reasons – insufficient power of nodes, - high level of interferences, - nodes mobility and - network scalability. Following this, the deployment of efficient routing protocols is very challenging in mobile ad hoc networks, since the network topology is instable.

Recently some work done on cross-layer in MANET [1-2] show some improvements in the network performance compare to layering architecture. The principle of cross layer is essentially based on cooperation between protocols in order to adapt their operating mode to data collected from the others layers of the system. By combining with the cross layer architecture, a model for predicting some well defined parameters, it is possible to achieve better performances of the protocols dealing with network functions. For example the routing algorithm can be designed in such a way, that considers the future topology of the network (based on a power prediction) while searching for the optimal paths. Another possibility is the use of predicted nodes mobility pattern to differentiate between two identical paths during route discovery. It is worthwhile to mention that a cross-layer architecture design doesn't imply a non layered protocols design. Instead, the modular independence of each layer is always maintained during development but cooperation between layers is introduced by a separate interface through which the different layers can share information

Consequently prediction of link layer parameter and cooperation between physical layer and network layer can lead to fast adaptability of the network to the link variations and prevent link breakage while supporting the applications QoS. For example in [3], the authors demonstrate the influence of physical layers parameters such as power and distance on different routing protocols. Their establish important relation between the transmitted power of mobile nodes and number of lost packets and reach the conclusion that, performing routing on links with transmitted power exceeding a specific threshold value, prevent drastically the packet errors to occur.

The purpose of our studies is to develop a model for predicting some important low layers parameters of the mobile network and then exploit this knowledge for making routing decisions and maintenance. In our studies, we focus on the prediction of the low layers characteristics since the channel variation usually occurs at this level. Since mobility is one of the reasons for low performances of routing protocols, we choose to start with a model for predicting the link status in terms of node connectivity. Using a prediction algorithm allow the network to better deal with instabilities cause by node mobility. Dealing with this instability by propagating information about the nodes location can rapidly lead to valuable bandwidth and energy utilizations. For example the geographic routing algorithms, that are based on the knowledge of the destination node geographical coordinates, require an efficient location service and a distributed database that can record the location of every destination node. In order to achieve this, every change in the network topology has to be signaled and recorded in the database, what inevitably leads to lot of control information exchange. Unfortunately, when the nodes movement pattern is very high, the node position changes very often and the updates information become obsolete and that can lead to waste of network resources. One way to minimize the update frequency is to use some movement prediction algorithm on each node and integrate this prediction into the routing protocol. Since the prediction is done on each node and used when the source has some information to send, no extra bandwidth is used for update. The prediction is done based on the Gauss Markov mobility model. The reasons below this choice will be explained later. We chose to make some modifications to the DSR (Dynamic Source Routing) protocol in order to integrate to it the prediction algorithm.

In the original DSR protocol, each node can maintain one or multiple route to any destination in the network. When a node needs to send a packet to a particular destination, it looks in its cache to find if it already has a path for this destination. If not, it broadcasts a route request to it neighbors. To take into account the predicted link state value, we modify the route discovery process so that when a node received a route request and it doesn't have a path to the destination, it broadcasts the request only if the link (connected it to the sender of the packet) status is stable enough to allow the transmission of the QoS constrained applications without overusing the networks resources. The route maintenance procedure is performed not only as a procedure to signal link breakage but also as an indication to the source of new opportunities in the neighborhood that can be used by the source to increase its actual quality of service.

This paper is composed of tree parts. In the following section, we review the current routing protocols that are based node or link state parameters. The section 3 describes the Gauss Markov Mobility model which will be refer later as GMM. The nodes density, speed and direction changes are obtained and compared to Random Waypoint model (RWM). In section 4, the DSR routing protocol performances are analyzed on GMM. In section 5, we introduced our prediction algorithm, the modified DSR protocol and some preliminaries results. Finally, the last section concludes this paper and presents the future direction of our work.

Related work on routing protocols

In mobile ad hoc networks, the performance of routing protocols depends mainly on the mobility of nodes. Since the networks topology is very variable, an algorithm that exploits the actual or prediction of future position of the nodes can help improve the performance of the routing algorithm. There is in the literature different algorithms that use mobility prediction and node position estimations for the routing purpose.

In [4], the authors introduced a prediction-based link availability algorithm that estimates the probability $L(Tp)$ that an active link at time t_o will last to time $t_0 + T_p$. The estimation of $L(Tp)$ is based on a prediction of a continuous time period T_p during which the node will last from time to, assuming that the nodes will keep their current movement (direction and speed) unchanged. The routing algorithm then chooses route according to the precedent estimations.

Assuming that the node has the same mobility epoch length in the network, which is exponentially distributed, the link availability is expressed as:

$$L(T_p) = L_1(T_p) + L_2(T_p) \quad (1)$$

Where $L_1(T_p)$ and $L_2(T_p)$ represented respectively the link availability during the time where the node movement is unchanged and variable. Once the node made the prediction for the time T_p, it then calculates the real time T_r, during which the link will last from to. If the time $T_r > T_p$, then it sets the predicted time to the new estimated value. This algorithm supposes a moment during which the node movement changes or not and can lead to more control packet exchanged.

In [5] the authors used the speed and the position of the node to predict when the partitioning of the planar graph will occur and which links are critical in the network. The node x, y positions are obtained from a location aware equipment such as a GPS (Global System Positioning). At some periodic moment, the node updates information regarding it critical time. This time represents the moment when the distance between the two nodes will exceed the transmission range with a threshold probability which is a system given value. One drawback of this model is that it relies strongly on the location aware equipment for the positions estimation. Another main factor is that the algorithm doesn't give any indication in the computation of the probability threshold value. However, the authors mention the fact that it is a function of the node speed. There's neither any indication on the computation on the frequency of update. But we can assume that this update frequency can be based on the speed of the mobility node. The higher the speed, the more frequent the system will have to do the update of nodes position. However, if this frequency is too large, it will cause lot of control information exchanged and lead to waste of networks resources.

Overview of existing mobility models

Random waypoint model is used in many works for simulating mobile ad hoc protocols performances. Unfortunately, RWM is a very simple model in which the node chooses randomly a new position and then calculates the distance to cover before reach that position. Based on this distance and according to a chosen randomly speed, the node moves to it new position and pauses for a predefined time. The movement continues after the pause time by following the same procedure. This mobility model has some drawback. First there is no functionality that considers the case when the node reaches the borders of the simulation area. In this situation, the node gets stack at one place and the only alternative left is to make some random trials until it new position replaces him in the mobility domain. The consequence is that the network topology at some moment will contain some relatively fixed nodes which are localized at the border of the simulation area. Another behavior of the random waypoint mobility model is the high probability of nodes to choose a new position situated at the center of the mobility movement area causing the nodes to converge to the center of the mobility domain at some moment of the simulation. These results were proven in [6]. Based on a formulation of the RWM in a discreet-time stochastic model, the authors showed that the RWM model leads to a non-uniform spatial distribution of the nodes which causes a very high concentration of the nodes at the center of the network region. Considering the impact of the node spatial distribution on some important network characteristics such as interferences, connectivity, routes availability and link breakage, the comparison of results from the different protocols analyzes can be misinterpreted. For example, the convergence of the nodes to one area can increase the links quality in some area and for some routing protocol like DSR increase the probability that a node already have a path to the destination in its route cache, which also can affect the real performances of the simulated protocol. In the worst case, because some few nodes will be localized near the edges, the network can suffer from partition. One last point that we observe for the RWM is the fact that the node direction and speed aren't related to their precedent values after the update. In reality, the nest directions of nodes are highly dependant from their actual speeds. The higher the node speed, the smaller will be its direction change when considering real life scenario of mobility on a street or in a conference room. A comparison made in [3] has shown that the RWM has the highest packet delivery ratio, the lowest end to end delay and the lowest average count compare to other mobility models like the random walk and the random Direction Mobility Models.

After considering these facts, in order to better analyze the performances of the network routing protocols, it is important to use mobility environment that best suits realistic human mobility pattern.

Random Gauss Markov Model

A Gauss Markov process is a Gaussian process that has an exponential correlation function. This type of model is chosen for many reasons. First, because it best describes the correlation of the node's velocity in time and second, it's possible to resolve the border problem by carefully choosing the model parameters. In the GMM, the node speed and direction at a certain time depend on its previous speed and direction values. While the update time is predefined, the difference between two consecutives states is a random variable. The node computes its new speed and directions based on the corresponding previous states values and start to move in that direction. The random part of the process is maintained by adding to the speed a uniform distributed value at every update time. Since the speed can take a null value, this represent a pause in the node movement that is also random and therefore best represent a realistic scenario.

From [3] the node movement is represented by speed and direction as in the following equations:

$$V(t+dt) = \min[\max(V(t)+dV, V_{\min}), V_{\max}] \quad \textbf{(2)}$$

$$\theta(t+dt) = \theta(t) + \Delta\theta \quad \textbf{(3)}$$

Where:

V_{max} is the maximum allowed speed for the mobile nodes;
V_{min} is the minimum allowed speed for the mobile nodes;
V(t+dt) is the node speed at time (t+dt);
V(t) is the node speed at time t;
dV is a uniform distributed random variable over $[-\Delta V_{\max}, \Delta V_{\max}]$;
$\Delta\theta$ is a uniform distributed random variable over $[-\alpha, \alpha]$;
$\theta(t+dt)$ and $\theta(t)$ are the directions of the node at time (t+dt) and t respectively.

Figure 1 shows the pattern of a node moving with a Gauss Markov Mobility model.

In order to consider the border problem, we introduced some change in the node mobility pattern. A test on the node next position is made at each update. If this position is outside the network region or on the border, then the node paused and changed it direction for 180 degrees. It then chooses a new direction from $[-\alpha, \alpha]$ at the next update.

Following are the comparisons of the node densities in both RGM and RWM.

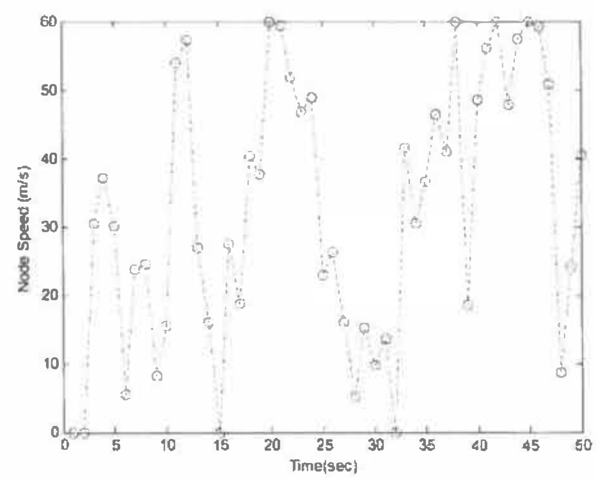

Figure 1: Mobile node pattern in GMM

DSR protocol performances in GMM

We were interesting in the two important cases for the GMM. First the node density and the behavior of the DSR protocol with the change of direction at the border of the network region. We observe the following. With the GMM, the nodes movements are not concentrate at the center. Each node has approximately a stable mean value of neighboring nodes during all the simulation time. Figure shows the routing control traffic sent.

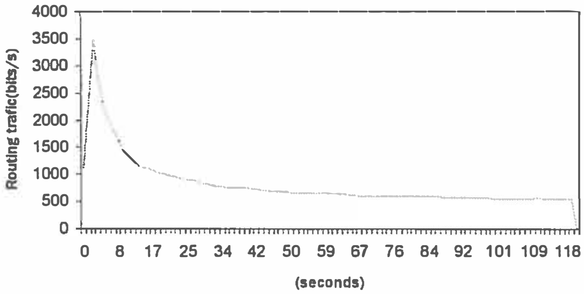

Figure 2: Routing control traffic sent by node in GMM

Link state prediction

Here, we derive some expressions for the link state prediction.

To determine the quality of a link connecting two nodes, we use the probability that the distance between the two nodes is less than the transmission range of the nodes denoting by R.

We made the following assumptions:

1. The nodes are equipped with unidirectional antenna and all have the same transmission range. The free space transmission is used with all the nodes having the same attenuation factor;
2. The link is bidirectional. This means that a link that satisfies the quality in one direction is also qualified for the opposite direction;
3. The distribution of the speed is given by the equation (3).
4. The actual distance between two nodes is known from the measured received power.

The probability is:

$$P_{link}(d) = prob\{D < R\} = prob\{d + VT < R\} \quad \textbf{(4)}$$

Where T is the time for which the prediction is done. This time can be equal to the time between two updates or is equal to k times the update time t ($T = kt, k \succ 0$), d is the actual distance between the nodes and R is the transmission range (we suppose that R= 250m).

Replacing V by its expression in (2), we get

$$P_{link}(d) = prob\left\{\max(v(t) + dV, V_{\min}) > \frac{R-d}{T}\right\}$$
$$= 1 - prob\left\{\max(v(t) + dV, V_{\min}) < \frac{R-d}{T}\right\} \quad \textbf{(5)}$$

Now,

$$P_{link}(d) = prob\left\{\max(v(t) + dV, V_{\min}) < \frac{R-d}{T}\right\}$$
$$= \int_{-\infty}^{\frac{R-d}{T}-V_a} \frac{1}{2.V_{\max}} dv = \frac{1}{2.V_{\max}}\left[\frac{R-d}{T} - V_a + V_{\max}\right] \quad \textbf{(6)}$$

V_a is the speed of the node at time t.

Extended DSR protocol: The purpose of the computational expression (6) is to find a predicted value of the link state. This prediction is then used dynamically by the routing protocol in order to avoid instable links and therefore assure some quality of services for applications.

We chose to use the DSR protocol of OpNET Modeler environment to do our test on the performances obtained from the link state prediction. The dynamic Source Routing protocol (DSR) is an efficient protocol designed to be use in a multi-hop environment. It has been implemented in many platforms and is in a way of becoming a standard routing protocol by RFC.

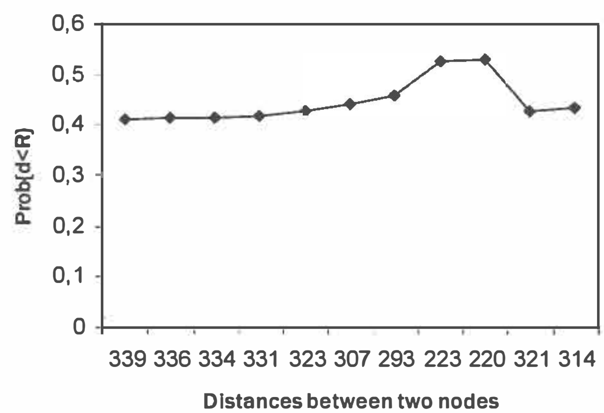

Figure 3: Link quality between two nodes moving with the GMM model

The protocol is composed of two main parts: route discovery and route maintenance. All information concerning the path to any specific destination is obtained on demand by the source. This information is then placed into the packet. This allows the DSR protocol to be more scalable since less control overhead messages are used for the routing. One of the main reasons why we choose the DSR protocol is that it can maintain more than one route to the destination, thus allowing the source to select the best route and possibly control the routing strategy to adopt in case of link breakage during the communication.

In order to evaluate the performances of the link prediction algorithm we made some modifications to the route discovery algorithm of the DSR protocol. In the future work, we are planning to develop a new protocol stack for the cross-layer approach.

Route Discovery: The route discovery is the mechanism by which the node finds a new route to a destination. When a node needs to find a route to specific destination, it generates a route request packet that is broadcasts to its neighbors. At a reception the neighbor will look in its cache to see if it already has a path to this destination. If not, it rebroadcasts the request. For the purpose of our algorithm, we introduced the following conditions:
When a node doesn't have in it cache a route to a destination, it only forwards to the neighbors nodes for which the link quality is more than a threshold value. This means that only the nodes that have $P_{link}(d)>Threshold$ will receive the broadcast.

Cross layer approach: In order to make available to the routing protocol information concerning the distance between nodes, their speeds and power strengths. This information is transmitted to the interface shown in Figure. The interface is also responsible of translating the characteristics of the physical layer into metric in a time scale that is relevant to the routing function.

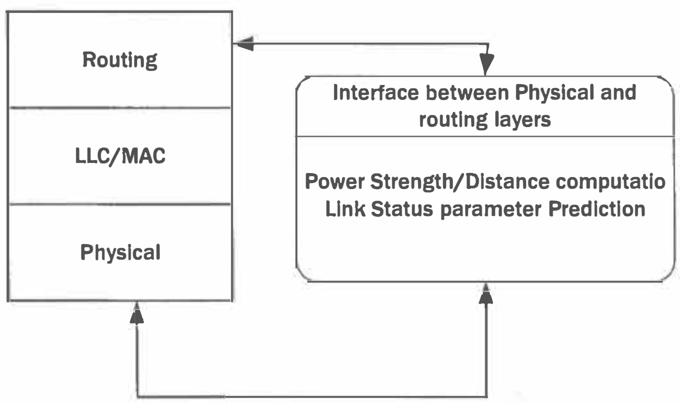

Figure 4: Interface between Physical and routing layers

Conclusion

In this work, we implemented the Gauss Markov Mobility model in OpNET and based on it, we developed an expression for the link state prediction. The node spatial distribution of the GMM was analyzed and the result showed that the node density is stable during the simulation time.

We also proposed a way to share relevant information between physical and routing layers since the physical layer has better understanding of the channel state.

We are presently continuing the modification of the DSR protocol in order to prove that the link state prediction algorithm can lead to better performances of routing protocol.

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