Improvement of Route Cache in DSR Protocol by Predicting Effective Communication Distance between Nodes

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Abstract

Mobile Ad Hoc Network (MANET) is strongly affected by two factors: nodes mobility and environment changes due to obstacles, noise and channel fading. These factors cause high variability in the communication channel of nodes and should be considered when designing any MANET protocol like scheduling, routing or congestion control. Unfortunately, most of the proposed protocols in the literature are based on assumptions that do not reflect wireless environment.

In this paper, we present an approach for designing routing protocol based on a new metric namely the EFfective Communication Distance (EFCD). EFCD is derived from the prediction of link duration which is considered as a stability measure. The prediction algorithm is based on Kalman filtering and exploited available physical layer information such as mobility model, received power and SINR (Signal to Interference and Noise Ratio). Unlike other methods which propose nodes position and relative speed predictions, ours predicts the effective communication distance between nodes according to mobile environments. Moreover, slow fading is used to evaluate and improve nodes relative speed change.

Motivated by the opportunities offered by interaction between physical and upper layers, this paper investigates the effect of channel aware routing on DSR performances. We modified the route cache structure which selects a route according to two metrics: EFCD and hop count. Cross layer integration to DSR is presented and implemented in OPNET.

Introduction

A Mobile Ad Hoc Network is made of a collection of mobile nodes that can be interconnected by a multihop path and without any need of a wired infrastructure. Therefore, 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 support to the various Quality-of-Service (QoS) applications that will transit via the networks.

Recently, with the rising popularity of multimedia applications and potential commercial/military usage of MANET, better throughput and guaranteed QoS are demanding from the mobile Ad Hoc Networks. Throughput can be defined as the ratio of received data to the time necessary to transmit it [1]. QoS parameters can be: - end-to-end delay (time taken by a packet to be transmitted from the source to the destination), - packet loss – bandwidth requirements. However, satisfying these demands in mobile ad hoc networks is very challenging. 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 control information. Finally the performances of the protocols at different layer are interrelated in such a way that can affect the overall performance of the MANET system.

Most of the proposed routing protocols in the literature tend to use methods that are restricted to network or/and MAC layers in order to deal with the instability of the mobile ad hoc systems. However, their performance in providing better throughput is not satisfactory. According to [2], there are three reasons for that: 1) the sensitivity of algorithms to the degree of nodal mobility 2) the variability of nodes environment 3) the traffic load in mobile ad hoc networks. On the other hand, since Ad Hoc network doesn't rely on fixed infrastructure, achieving address resolution, services authentication and access control policies is very challenging. In order to minimize the effect of mobility on the mobile ad hoc networks performances especially at the network level two solutions are used: geographical location and nodes mobility prediction.

In geographical location based routing protocol the decision to forward packet is based on nodes locations information. One of the first protocols that introduced geographical location is the geographic routing protocol. In this protocol, positioning system like GPS (Geolocation Positioning System) is used to find nodes location and construct routing table. This protocol requires a distributed database at each node that can record the location of every destination node in the network.

Node mobility prediction addresses the issue of predicting the future movement and location of the nodes in a wireless mobile environment. Critical study of various mobility prediction schemes has shown mobility prediction to offer potential improvements to both the service-oriented where nodes cooperate to facilitate general communication e.g., routing, rate control [4] or resources reservation [5] and application-oriented where nodes come together for a particular purpose e.g., military operations aspects of ad hoc networks [3, 5, 6].

The purpose of our work is to develop a new mechanism for route selection that is based on predicted link stability. We predicted the stability of the link according to available physical layers parameters. We have also introduced a new metric EFCD for routing. This metric enables us to determine the amount of time two nodes A and B can really communicate with each others, considering their actual relative speed, signal strength and channel conditions. The reason of predicting the relative distance between nodes is that communication between nodes is affected by environment and received signal. Regarding this, the quality and duration of any link will strongly depend on the signal strength and environment. Consequently there is a correlation between the effective point to point communication distance and the relative distance of nodes. We have made the prediction at the MAC layer and its value to the routing protocol through cross layer architecture. It is important to mention that this predicted algorithm and cross layer architecture can be adapted to any reactive routing protocols.

In this paper, we explain and show the results obtained with the Dynamic Source Routing (DSR) protocol. DSR [7], protocol uses two mechanisms: route discovery and route maintenance. Route discovery is initiated whenever a node has a packet to send and it doesn't know the route to the destination. Route maintenance mechanism is used to monitor the link and in case of link failure, propagate route errors messages to source node. Route cache structure is used to avoid frequent route discovery. Route Discovery and Route Maintenance each operate entirely "on demand". Route maintenance is done only on active routes and Network topology changes not affecting active routes are ignored and do not cause reaction from the protocol. DSR works with low control overhead, compare to others routing protocols (e.g. AODV, DSDV).

In case of frequent nodes mobility, response to link failure in DSR may be slow because the stale information in the caches of inactive nodes is obsolete. Consequently, the route replies message generated while intermediate nodes are inactive can contain broken links and cause an initiation of route maintenance procedures. This could lead to an increase of delays in the network. Consequently, route cache mechanism that stores information related to existing routes to a specific destination cannot be used efficiently [8].

One method to support the node cache mechanism is the development of new metric which will be associated to each known route in order to have some knowledge about the duration of the selected path based on cross layer information. With this in mind, we decide to develop a model for predicting some important low layers parameters of the mobile network so as to exploit this prediction to improve the route selection and maintenance. Since mobility strongly affects systems performances, we choose to start with a model for predicting the relative distance and speed between nodes.

This paper describes how the proposed concept is implemented in OPNET as an enhancement to the existing DSR routing protocol. We integrate to the DSR route selection a new filtering algorithm based on Kalman filtering which aims at predicting the link connection status and the relative node speed for which the link is considered. We also address the issues of stable route selection and network throughput enforcement. At every packet reception, the path stability value is updated before its transmission to the nodes neighbors.

The contributions of our work are the following: To take into account the predicted link duration value, we modify the route discovery process in DSR. When an intermediate node received a route request and it doesn't have a path to the destination, before broadcasting the request, the node must collect from the MAC layer its predicted EFCD value. Based on this value, the node will update the so find path duration to the source which is located in the packet header. Another contribution of the article is the so called best route announcement procedure. This procedure works like the shortening method in the DSR protocol. It allows node originator to be informed of new route to their destination based on the path stability path. The difference with the shortening method used in the original DSR protocol is that the critter to qualify a path is not based on the minimum hop count method but primary on the predicted path stability. Source node can then switch to better stable routes.

The remainder of this article is organized as follows. Second section describes the node mobility prediction problem statement and existing solutions in the literature. Section 3 presents our proposed path stability solution and how cross layer architecture can be combined with it for routing decisions. In section 4, we present an implementation in OPNET by modifying the DSR routing protocol. Mechanisms like route discovery and route maintenance have been modified in order to integrate a path selection base on its stability prediction. Section 5 presents the conclusion and future work.

2. Problem statement and related works on mobility prediction

In high mobile MANET, the dynamic changes of topology impacts the performances of ad hoc routing protocols. In [10], the authors demonstrated the existence of a strong linear reciprocal relation between node mobility and networks parameters like throughput and overhead. The result described in their paper is a clear indication that mobility of nodes should be an important criterion to be considered while developing any MANET routing protocols.

For example in reactive on-demand routing protocols route cache information is used to avoid frequent route discovery. When a node **A** wants to send a packet to a node **B**, it can choose a path from its own cache or a path receive from its neighbor replies. Reference [11] showed that in DSR protocol, the number of replies coming from neighbor nodes is three times more than the number of replies from original node cache. It was also showed that the number of replies from the destination node is very small compare to the latter numbers. Although neighbor replies avoid the necessity for performing Route discovery at each packet sent, there is still a latency induced by the choice of non detected broken routes. To resolve this problem, one way is to frequently exchange “hello” messages to up date the stale information. But this can cause more overhead to the network. The motivation of our research is to develop a new path stability parameter to be used for efficient routing. Path stability is a very critical decision parameter in mobile and resource-constrained environments as frequent route discoveries can easily congest the network. The higher the stability of a route the lower is the probability that it will break. We define and predict the EFCD parameter which gives to the routing protocol an indication regarding its short term stability.

Our work is inspired by the work of *Jiang and al* [12]. In this paper, the authors estimated the probability $L(Tp)$ that a link can last from t_0 to $t_0 + T_p$. The value of T_p is the time the link between two nodes will last if the two nodes keep the current speed and direction. Their then used the mean path available time $T_p.L(T_p)$ for path selection. Although, the proposed model of path availability estimation gives better results, [13] affirms that for a given time period t different from T_p, *Jiang et al.* algorithm cannot compute the continuous path availability from t_0 to $t_0 + t$.

3. Prediction of effective communication distance between nodes

Given the signal strength available at each node, we want to develop a prediction analytical model for the effective distance between two nodes. This parameter, combine with number of hops and network environment will then be used to develop a model for qualifying routes according to their stability prediction. At each packet reception, route duration metric is calculated before it insertion in the route cache structure. The choice of path duration as a metric is essentially motivated by the work of [10] who demonstrated there exist a strong relationship between path duration availability and protocol performances.

Kalman filter is used to predict the effective distance between two nodes. The advantage of Kalman filter is its simplicity due to the recursive structure underlining the method. Moreover, Kalman filter provides a predicted value with minimum mean square error.

3.1 Model Assumptions

For simplicity reasons we made different assumptions regarding the mobility of the nodes.

1) We considered discrete time epoch. So for a given time interval (TI) which is fixed for all the simulation duration, the node velocity is considered to be constant.
2) The same considerations will hold for the nodes direction. This means that we consider the node direction to be variable but constant for the given epoch.
3) In case of high node mobility, we will also consider the value of the epoch to be small enough relatively to the node speed.
4) The physical canal is influenced by two factors: - the free space propagation model with measured power decreasing with distance, - slow fading which is represented by the Average Duration of Fade (**ADF**)

For the same reasons, we also assume that the initial relative distance between two mobile nodes is known as soon as their can exchange packet. The value of the relative distance between two nodes is obtained through the measure of the signal strength. All the nodes in the network have the same transmission power and radio coverage, which is represented by a circle with maximum radius *R*. The initial distance is less than *R*. since nodes are in communication. The links are supposed to be bi-directional.

3.2 Effective Distance Prediction

The effective distance D^{eff} represents the distance between two nodes that are in communication with each other at a given moment of the simulation. As the nodes are in movement, we want to predict the value of D^{eff} for a time t in the future. This time will be considered as the step of the prediction. Let D_k^{eff} be the effective distance between nodes at time k. Let V_k be the speed of the node at time *k*. The process state to be predicted by the Kalman filter is represented by $S_k = \begin{bmatrix} D_k^{eff} \\ V_k \end{bmatrix}$.The dynamics of the effective distance is modeled as:

$$D_{k+1}^{eff} = D_k^{eff} + V_{k+1}.T + \frac{1}{2}.T^2.A_k + W_D \quad (1)$$

The node speed at time *k+1*, can be expressed as:

$$V_{k+1} = V_k + TA_k + W_v \quad (2)$$

The linear system describing the state evolution can be written as:

$$S_{k+1} = AS_k + BA_k + W \quad (3)$$

Where

$$\mathbf{A} = \begin{vmatrix} \mathbf{1} & \mathbf{T} \\ \mathbf{0} & \mathbf{1} \end{vmatrix}; \quad \mathbf{B} = \begin{vmatrix} \frac{\mathbf{1}}{\mathbf{2}}\mathbf{T}^2 \\ \mathbf{T} \end{vmatrix} \quad (4)$$

The state process noise is represented by W which has the following covariance value:

$$S_W = \sigma \begin{bmatrix} \frac{1}{4}T^4 & \frac{1}{2}T^3 \\ \frac{1}{2}T^3 & T^2 \end{bmatrix} \quad (5)$$

Where σ is the standard deviation of the commanded vector A_k

The measurement equation is obtained from measured value of the Received Signal Strength Indication (RSSI). The RSSI is related to the effective distance by the following equation:

$$p_{A,B} = K_i - 10\gamma \log(D_{A,B}) + \psi_i \qquad (6)$$

K_i is a factor determined by the nodes antenna height, gain, transmitted power and wavelength, γ represents the attenuation factor (its value is 2 for highways and 4 inside cities), ψ_i represents the logarithm of shadowing component. Shadowing component is a zero mean stationary process with standard deviation σ_i varying from 4 to 8 db. W and ψ_i are uncorrelated processes.

For the calculation of measurement noise variance, we make the assumption that the measurement noise on the distance is linearly proportional to the measurement noise of RSSI. This means that from the RSSI value, we approximate the value of the distance between two nodes and acknowledge this measure distance to be different from the true distance value by a deviation equal to σ. Figure 1 shows the analytical result obtains from the Kalman filter prediction model.

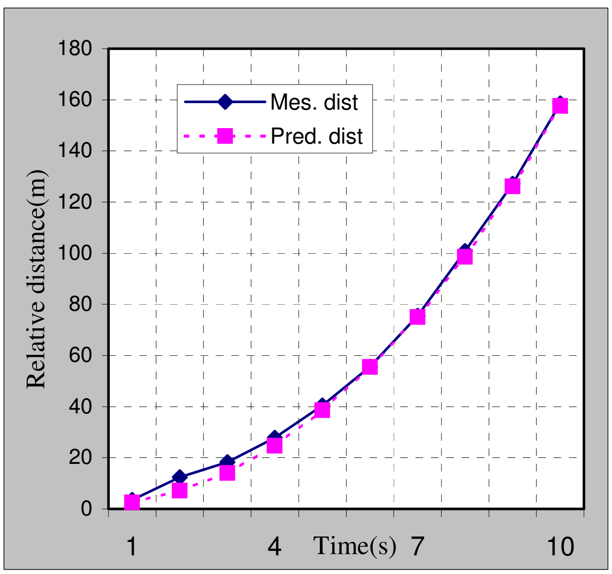

Figure 1. Distance Prediction

3.3 Path duration prediction

In our algorithm, all nodes can determine their predicted effective distance and relative speed with their neighbors. The link duration is determined as function of transmission radius R and the predicted relative speed between nodes V_{pred}. In order to consider the case when the node direction changes during the prediction time, we combine the measure signal strength RSSI to another physical layer parameter which is represented by the Average Duration of Fade (ADF). If the RSSI changes for more than the threshold value used in the ADF, then we concluded that the nodes depart (if positive change occurs) or approached (if negative change occurs).

4. Integration of link stability in DSR protocol

After verifying the accuracy of the effective distance prediction between nodes, we implemented it in OPNET simulation tools. We have chosen DSR as the routing protocol, and did modifications to Route Request procedure and Route Cache structure. As it has been described in the second section, DSR is a reactive routing protocol that chooses optimal routes according to the least number of hops. In case of high nodes mobility, the probability that the sending node chooses a broken path from his neighbors' cache table increase. This can lead to more latency and bandwidth utilization. By evaluating and predicting the effective distance and relative speed between mobiles nodes, we can associate to each funded link a time parameter which determines the probable disconnection time between two communicating nodes. When the packet is delivered among intermediate nodes, their calculated the time parameter and transmit it to the next hop. Path disconnection time is then the minimum of links that composed the specific path.

4.1 Cross layer architecture

Since our prediction algorithm is based on information from physical layer, we need to introduce cross layer architecture. The aim here is to allow dynamic cooperation between Physical, MAC and Network layers for real time effective distance prediction and routes optimization based on stability constraint and short path. This architecture is implemented as cooperation between the systems layers. Cooperation is done between Physical, wireless LAN MAC and Network layers in order to dynamically update cache information and choose a route with better stability. The link duration parameter is calculated at the MAC level at each reception of a new packet. We then predicted values of effective distance and relative speed.

We introduced a new module in the MAC layer that takes information from the physical layer and determines actual and predicted value of the link state information. The information is then stored in the Cross layer Interface (CLI). This way, each node in the network can collect information regarding his link status with the neighbors. Figure 2 illustrates the relationships between layers.

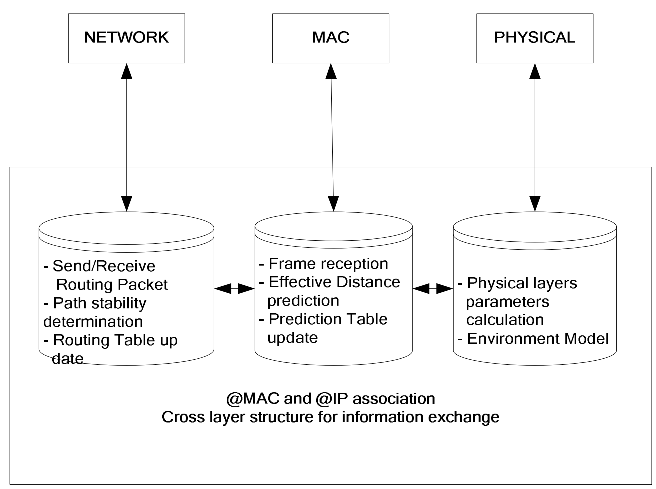

Figure 2. Cross layer architecture for routing cache update

The DSR protocol, works as follow. At each arrival of new packet, the node will determine the link stability status with its neighbors. This status is function of collected predicting information from MAC layer. The CLI serves as intermediate between Network, MAC and PHY layers.

4.2 Modification of DSR packet format

The format of our modified DSR protocol packet is slightly different from the original DSR in order to introduce the link duration field. A new stability field is also added to the cache route table. As was mentioned (section 2), in DSR protocol routes are dynamically constructed during packet exchange. There are saved in a route cache structure according to a shortest path algorithm which is based on the number of hops. The difference we introduced is the following. In addition to the number of hops, we introduced a new stability field, which represents the accumulated duration of the path. The later is defined as the minimum of all links composing the route and is dynamically calculated by the node.

At each intermediate node, the predicted link duration is compared to the path duration contained in the header of the received packet. If the new link duration is lower, then actual path duration is changed to the new link duration value. Otherwise, the path duration value doesn't change and the packet is treated according to the options mentioned in its header (Table 1).

Table 1. Pseudo code for packet processing

Packet arrived at MAC:
- Predict the link duration
- Registered the predicted link duration in a CLI
Packet arrived at DSR:
- Find the link Stability status from CLI in the network
- Find the path stability value
- Update node cache in DSR
- Treat packet according to its options

4.3 Optimization of RREQ flooding in DSR

In on demand routing protocols, route request messages are flood during the route discovery. For preventing the storm effect, only the first received request to a specific destination is broadcast. When using this mechanism in our case, the probability of finding the best quality routes in the network decreases since duplicate RREQ which arrived from different path are dropped and not rebroadcast.

In order to allow better route to be propagate to the network without causing the storm effect, we introduced the following route discovery modification. When an intermediate node receives a RREQ to a specific destination, it checks if a similar RREQ (according to the sequence number and source node of the RREQ) already exists. If yes, it calculates the path stability value from the MAC layer information, and compare this value to the one it has in record. If the new path stability value is greater, then the node will rebroadcast the new RREQ. Otherwise, the RREQ is dropped and no rebroadcast is performed. The algorithm is presented on Table 2.

Table 2. RREQ process algorithm in DSR

Received a new DSR packet
Case (RREQ Packet)
If *node IP address matches,*
- sent Route Reply
Else
If *RREQ table already has an entry with this request ID and from the same source*
For *all existing RREQ old with same ID in RREQ Table*
If *RREQ Packet Stability > RREQ old Stability*
- Rebroadcast RREQ Packet
End For
End if

5. Results and conclusion

The simulation concentrated on delay and routing traffic generated by the introduction of Effective distance prediction. We consider a network with 10 nodes each moving according to random waypoint mobility model. Each node can generate traffic to any random destination in the network. We then measure different network performances statistics. As we expected, the routing traffic with our EFCD algorithm is more than the original DSR algorithm. This is due to the fact that in our algorithm we rebroadcast route request if the stability of the last arrival request is better than the existing ones. On the other hand, the delay is much smaller since the chosen routes are more stable. The measured statistics are: routing traffic sent and wireless Lan delay. The results are presented on figure 3 and 4.

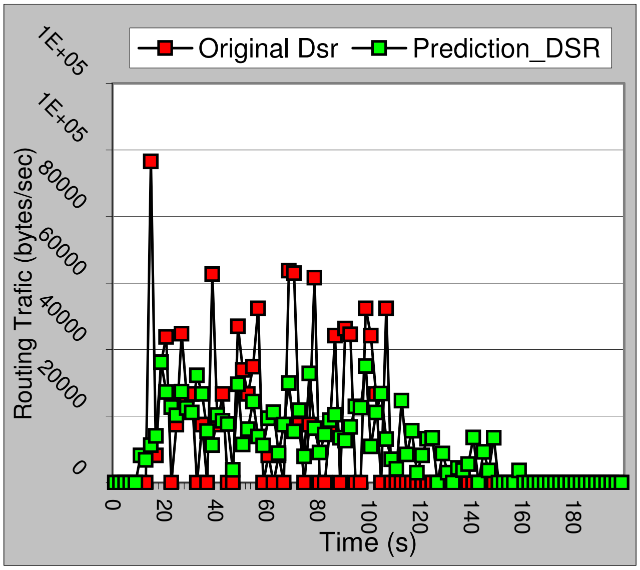

Figure 3. Routing Traffic

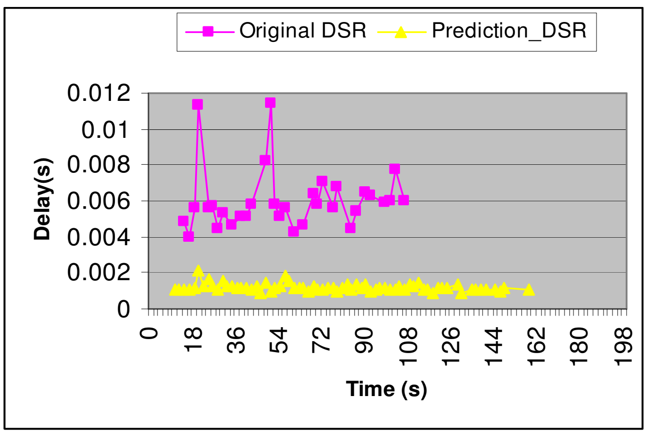

Figure 4. Wireless Lan delay

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