PERFORMANCE IMPROVEMENT OF MANETS WITH LINK LIFETIME

Merlinda Drini, Queensborough Community College/CUNY; Tarek Saadawi, City College of New York

Abstract

There are many different factors in the physical layer that impact the performance evaluation of the routing protocols. Such factors consist of signal reception, path loss, fading and interference. With this in mind, a numerical approach based on Finite State Markov Chain channel model was adopted for this study in order to evaluate the performance of an ad hoc routing protocol under various radio propagation models. In this paper, the authors present a new cross-layer algorithm for joint physical and routing layers in wireless ad hoc networks by applying this to the Optimized Link State Routing (OLSR) protocol in order to demonstrate the effectiveness of the Link Lifetime (LLT) and channel quality measured by Signal to Interference and Noise Ratio (SINR) as a metric in the selection of routes. The problem of link and route stability, focusing primarily on the multipoint relay (MPR) selection method, was addressed in order to find the most optimal routes between any pair of nodes. The simulation results indicate that the network throughput is greatly improved and the delay is significantly decreased using this cross-layer mechanism when compared to the original OLSR.

Introduction

Layered networking architecture has been the key to the huge success and widespread use of the Internet, as well as the initial development of wireless systems. The success of layered architecture has been its ability to provide modularity and transparency between the layers. However, in order to support the revolution of new applications, a new era of network architectures has emerged. A major challenge has been to understand at a fundamental level how to best design and control these networks, referred to as “wireless ad hoc networks”.

Since human-operated devices will more likely be used indoors, that leads to many issues related to the strength of signal fading in this environment. It has been suggested that a possible interaction might exist between various parameters of the ad hoc networks and, more precisely, between the propagation model and the routing protocol. The focus in this study was on the physical layer, which has a great impact on the performance of the system and which is responsible for the node’s connectivity and overall network throughput. This is known as a cross-layer design which, unlike traditional architecture, allows for information exchange between Open System Interconnection (OSI) layers. The cross-layer design is a very promising field of investigation. The use of physical (PHY) layer information in the routing decision, which was implemented in this study, is the result of cross-layer dialogue between the PHY and the Network layers.

The quality of wireless channels among the mobile nodes is time varying, due to fading, shadowing and path loss. Given that the shortest-path metric does not take into account the physical channel variations of the wireless medium, it is desirable to select the routes with minimum cost based on some other metrics which take into account the wireless nature of the underlying physical channel. In Mobile Ad hoc Networks (MANETs) there are many other metrics to be considered: Power, Packet Loss, Maximum available bandwidth, etc. These metrics should come from a cross-layer approach in order to make the routing layer aware of the local issues of the underling layers.

The main contribution of this study is the introduction of link-quality evaluation methodology based on Signal to Interference and Noise Ratio (SINR) and Link Lifetime (LLT) enhanced adaptability of ad hoc routing in a dynamically changing topology. As an example of its applicability to various routing protocols, the usefulness of the Link Lifetime, as a new metric in the selection of routes, was demonstrated to the Optimized Link State Routing (OLSR) protocol [1]. The problem of link and route stability was addressed, focusing particularly on the multipoint relay (MPR) selection method as well as determining the optimal path for any pair of nodes in this protocol.

Related Work

Routing in MANETs (Mobile Ad Hoc Networks) is challenging due to the dynamic nature of network topology and resource constraints. To maximize the channel resource utilization and minimize the network transfer delay along the path, the shortest path with a minimum-hops scheme is often adopted.

DeCouto et al. [2] showed that routing in multi-hop wireless networks using the shortest-path metric is not a sufficient condition to construct good quality paths because minimum-hop-count routing often chooses routes that have significantly less capacity than the best paths that exist in the network. Specifically, the nodes near the center of the network carry high loads when the routing protocol uses a shortest-path route strategy.

Node mobility causes links between nodes to break frequently, thus terminating the lifetime of the routes containing those links. An alternative route has to be discovered once a link is detected as broken, incurring extra route discovery overhead and packet latency. A simple solution for reducing the frequency of this costly discovery procedure is to choose a long lifetime route carefully during the route discovery phase rather than a simple random shortest-path route scheme. Cheng & Heinzelman [3] studied the effect of node mobility in the link lifetime distribution, noting that the smaller the moving probability, p, the longer lifetime a link tends to have. When neither node is moving ($p = 0$), the link never breaks. But in wireless propagation environments, small-scale fading makes it difficult to recognize the node's moving tendency and cannot be simply ignored.

Link lifetime plays an important role in routing protocol design and performance. There has been some investigation into the estimation and predictability of link lifetimes. Bohacek et al. [4] examined many predictors in urban environments; however, such predictors would require knowledge of the location of the node, the path loss across the link and the age of the link.

Route-Lifetime Assessment–Based Routing (RABR) [5] uses an affinity parameter based on the measured rate of change of signal strength averaged over the last few samples in order to estimate the lifetime of a link. A metric combining the affinity parameter and the number of links in the route is then used to select routes for TCP traffic. However, shadow and multipath fading experienced by the received signal make the estimation of link lifetime prone to error.

Singh et al. [6] presented a cross-layer ad hoc routing approach based on link connectivity assessment in network topology and suggest a framework for proactive enhancements to the OLSR protocol. They then deployed an IEEE 802.11b-based vehicular network and demonstrated the effectiveness of link-quality assessment-based enhancements in improving the performance of inter-vehicle ad hoc routing. Every node in the network can maintain the history of averaged Signal to Noise Ratio (SNR) values to its neighbors; then, from the average rate of change of SNR, the affinity between the two nodes can be estimated. Yet, the affinity between two nodes is only a prediction of the lifetime of the link.

Interference Impact on Wireless Channels

The signal transmitted from a mobile node to others loses part of its power along the way. This happens because of the distance it travels and the terrain across which it travels. The radio wave (signal) propagation is generally modeled by the combination of large-scale and small-scale propagation models [7]. Large-scale fading is due to the distance loss and shadowing effects and changes relatively slowly. As the node moves over longer distances, the average signal strength gradually decreases. For this reason, large-scale fading is of interest because the movement tendency of the nodes enables us to discover routes which are more likely to fail. On the other hand, node movement over short distances may cause the rapid variation of the received signal strength, thus giving rise to small-scale fading. Small-scale fading can be modeled by Ricean fading (with line of sight) or Rayleigh fading (with no line of sight).

In a wireless ad hoc network, because nodes share a common channel, interference usually has a greater impact than noise [8]. In addition, thanks to in-band transmissions from nodes that are out of range but close enough to cause interference as well as crosstalk from near-band transmissions, the interference level can have large, rapidly changing values. Hence, the focus of this study was on SINR rather than SNR.

Computation of interference and noise at each receiver is a critical factor in wireless communication modeling, as this computation becomes the basis of SINR or SNR that has a strong correlation with PER (Packet Error Rate) on the channel. The power of interference and noise is calculated as the sum of all signals on the channel, other than the one being received by the radio, plus the thermal (receiver) noise. The resulting power is used as the base of SNR, which determines the probability of successful signal reception for a given packet [9].

Thus, communication between two nodes u and v is successful if the SINR at receiver v is above a certain threshold which depends on the desired transmission characteristics (e.g., channel, data rate, etc.). More formally, denoting the signal strength of a packet from node u (sender) at node v (receiver) by $Pv(u)$, a packet on the link (u,v) from node u to node v is correctly received if and only if SINR is above a certain threshold:

$$SINR = \frac{P_v(u)}{N + \Sigma_{w \in v'} P_v(w)} \geq \delta \tag{1}$$

where N is the background noise, v' is the set of nodes simultaneously transmitting, and δ is a constant which depends on the data rate, channel characteristics, modulation scheme, etc.

Since in a realistic channel the interference cannot be excluded, SINR will hereafter be referred to as SNR. Accordingly, N represents the background noise plus the total interference of all neighboring transmissions.

Modeling Wireless Channels with a Three-State Markov Model

In this study, the work by Rayleigh [10] on fading channel was considered; therefore, the received signal is the sum of signals with different phases caused by different paths, which can be modeled as a random variable. In a multipath propagation environment with additive Gaussian noise, the received SNR also has the Rayleigh distribution with the probability density function:

$$p(\gamma) = \frac{1}{\bar{\gamma}} \exp\left(-\frac{\gamma}{\bar{\gamma}} \right) \tag{2}$$

where γ is the received SNR and $\bar{\gamma}$ is the average SNR, which is physical layer dependent. Given the physical layer conditions, the average received SNR enables us to characterize the channel variation at the physical layer using the Finite State Markov Chain channel model, known as FSMC.

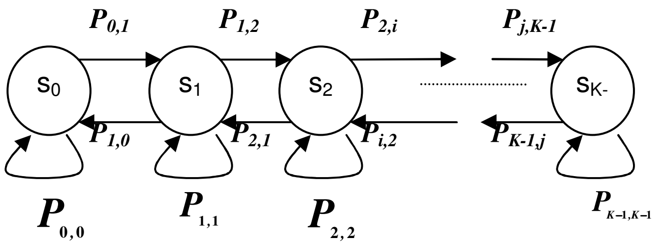

Figure 1. Graphical Representation of Finite-State Markov Chain (FSMC)

In order to build the FSMC, it was assumed that the received SNR remains at a certain level for the duration of a packet; therefore, a received packet completely falls in one state and the following packet only stays in the current state or one of the two neighboring states. As a result, the range of the SNR can be partitioned into a finite number of intervals with corresponding states [10]. The channel is said to be in state k, if SNR remains between two thresholds of average SNR: [Γk,Γk+1]. The state space of a stationary Markov chain with K states is denoted by S=s1,s2,…,sK. State space S is that of K different channel states with corresponding SNR thresholds, Γk, in increasing order [11].

$$0 = \Gamma_0 < \Gamma_1 < \Gamma_2 < \cdots < \Gamma_{K-1} < \Gamma_K = \infty \tag{3}$$

Steady-state probabilities can be calculated from the following expression:

$$\pi_{kk} = \int_{\Gamma_k}^{\Gamma_{k+1}} p(\gamma) d\gamma = \exp\left(-\frac{\Gamma_k}{\bar{\gamma}} \right) - \exp\left(-\frac{\Gamma_{k+1}}{\bar{\gamma}} \right) \tag{4}$$

Considering the mobility of the nodes, their motion of a certain speed causes the Doppler frequency, f_m, the number of times that the received signal crosses the given threshold, Γ_k, in the positive or negative direction only, is known as the level crossing rate of level Γ_k and is given by:

$$N(\Gamma_k) = \sqrt{\frac{2\pi\Gamma_k}{\bar{\gamma}}} f_m \exp\left(-\frac{\Gamma_k}{\bar{\gamma}} \right) \tag{5}$$

$$f_m = \frac{f_c v}{c} \tag{6}$$

where f_c is the carrier frequency, v speed of the node and c is the speed of light. Thus, the transition probabilities from state s_k to state s_{k+1}, $P_{k,k+1}$ can be expressed as a ratio of the level crossing rate at threshold Γ_{k+1} and the average number of signal segments per second staying in state s_k.

The transition probabilities can be approximated as

$$\begin{aligned} P_{k,k+1} &= \frac{N(\Gamma_{k+1}) T_p}{\pi_{kk}}, \quad k = 1,2,\ldots,K-1 \\ P_{k,k-1} &= \frac{N(\Gamma_k) T_p}{\pi_{kk}}, \quad k = 2,3,\ldots,K \end{aligned} \tag{7}$$

where T_p is the packet transmission time. Packet transmission time can be obtained as a ratio of the packet size and the effective network bandwidth. Consequently, knowing the transition probabilities, probabilities of staying in the same state, can be calculated as

$$P_{kk} = \begin{cases} 1 - P_{k,k+1} - P_{k,K-1}, & if \quad 0 < k < K \\ 1 - P_{01}, & if \quad k = 0 \\ 1 - P_{K,K-1}, & if \quad k = K \end{cases} \tag{8}$$

and

$$P_C = \lfloor P_{ij} \rfloor_{(K+1)x(K+1)} \tag{9}$$

where P_c is the transition matrix of the FSMC model for the wireless channel.

For simplicity, the approach taken in this study used a three-state Markov chain model (see Figure 2), where there are two good states: “Excellent” and “Fair”, and a single bad state, “Bad”. It was assumed that the situation in which the success of a packet transmission in a given state would be determined by comparing the received SNR to the thresholds in each state, each of which having a certain packet error probability (PER) [12]. The transition probabilities are given as a ratio of level crossing rate at a certain SNR threshold and the number of signal segments per second, staying at the next state.

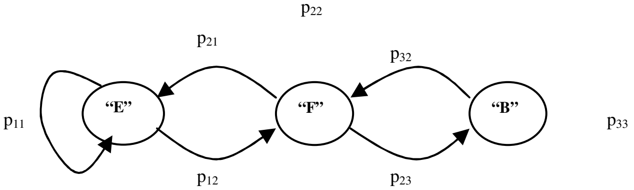

Figure 2. Three-State Markov Model

Hence, the transition probabilities, as given in Equations (7)-(9) are now given by the following matrix:

$$\boldsymbol{P} = \begin{bmatrix} \boldsymbol{p}_{11} & \boldsymbol{p}_{12} & \boldsymbol{p}_{13} \\ \boldsymbol{p}_{21} & \boldsymbol{p}_{22} & \boldsymbol{p}_{23} \\ \boldsymbol{p}_{31} & \boldsymbol{p}_{32} & \boldsymbol{p}_{33} \end{bmatrix} = \begin{bmatrix} p_{EE} & 1-p_{EE} & 0 \\ p_{FE} & p_{FF} & 1-p_{FE}-p_{EF} \\ 0 & 1-p_{BB} & p_{BB} \end{bmatrix} \quad (10)$$

Once these transition probabilities are determined, the mean sojourn time that the channel remains in either of the two good states, “Excellent” or “Fair”, can be calculated:

$$T = \frac{T_p}{1-P_{GG}} \quad (11)$$

where T_p is the packet transmission time and

$$P_{GG} = P_{EE} + P_{FF} \quad (12)$$

Design of an OLSR Routing Protocol with Cross-Layer Design

To demonstrate this approach, the authors applied it to a typical routing algorithm, choosing an Optimized Link State Routing protocol (OLSR) as an example of a table-driven proactive routing protocol.

Overview of Optimized Link State Routing Protocol (OLSR)

Optimized Link State Protocol (OLSR) [1] is a proactive routing protocol, so the routes are always immediately available when needed. OLSR is an optimization version of a pure link state protocol, where the topological changes cause the flooding of the topological information to all available hosts in the network. Using Multipoint Relays (MPR) can reduce the possible overhead in the network protocol. The idea of MPR is to reduce flooding of broadcasts by reducing the same broadcast in some regions in the network. MPRs can also provide the shortest path. Reducing the time interval for the control messages transmission can also bring more reactivity to the topological changes.

OLSR uses two kinds of the control messages: HELLO and Topology Control (TC). HELLO messages are used for finding information about the link status and the host’s neighbors. With the HELLO message, the MPR selector set is constructed which describes which neighbors have chosen this host to act as MPR; from this information, the host can calculate its own set of the MPRs. The HELLO messages are sent only one hop away but the TC messages are broadcast throughout the entire network.

TC messages are used for broadcasting information about their own advertised neighbors, which includes at least the MPR selector list. The TC messages are broadcast periodically and only the MPR hosts can forward the TC messages.

Neighbor/Route Discovery

A node sends a HELLO message to identify itself and to report a list of neighboring mobile nodes. From a HELLO message, the mobile node receives information about its immediate neighbors and 2-hop neighbors, and selects MPRs accordingly. A TC message originates at an MPR node announcing who has selected it as an MPR. Such messages are relayed by other MPRs throughout the entire network, enabling the remote nodes to discover the links between an MPR and its selectors. Periodic HELLO messages are used to establish neighbor links and to distribute MPRs determined by the algorithm. MPR nodes are selected nodes that have connectivity to other nodes. These nodes have two main advantages:

- Reduce the amount of flooded messages.
- Find the shortest path.

With the reduction in control messages, the OLSR can react quickly to topological changes.

OLSR with Cross-Layer Design (CLD)

In this section, the routing algorithm, which selects the route that provides a higher SNR along its hops to the destination, is presented. When a node is initially detected via a HELLO message, it is entered into the neighbor table, but it is selected as an MPR and broadcast to other nodes via HELLO messages only if the SNR to this neighbor is found to be above the SNR threshold. Since the wireless channel with a three-state Markov model was used in this study, two SNR thresholds were considered. Thus, if the SNR of the link is found to be higher than the first threshold, the link is considered “Excellent”; but, if its SNR is between two thresholds, that node is selected as the MPR according to the lifetime of the link. This neighbor is considered during routing table calculations.

The variations in signal strength (see Figure 3) affect ad hoc network protocols in a way that differs from other wired network architectures. For example, in regards to the SNR value, a link may be considered “Excellent”, though not long lived. In mobile ad hoc networks, the impact of mobility on the link and route lifetimes is of major importance for the design of efficient MAC and network layer protocols [13].

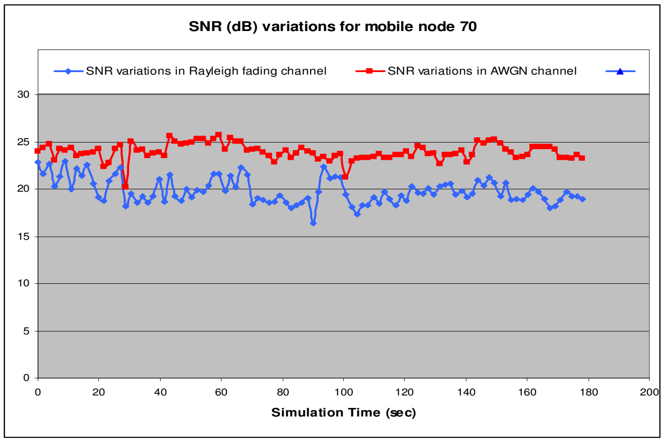

Figure 3. SNR Variations in Time for a Specific Receiver-Node 70. (NOTE: This figure was obtained from the OPNET simulator, which already has an upgraded program for calculating the SNR statistic)

In this study, a solution to this problem was proposed by introducing a special algorithm dedicated to Link-Lifetime (LLT) estimation, which is based on the use of the normalized mean sojourn time in the determination of the LLT. This value is normalized based on the maximum holding time of the routing table of the protocol. Besides this, the direction of the movement of the sending and receiving node can be determined by comparison of the previous SNR value already stored in the neighbor table and the newly received SNR values. If the existing value is lower than the one received, it can be said that the nodes are approaching each other. This mechanism is very efficient in calculating the stability of the link. Thus, in the CLD mechanism, the authors considered two constraints which together characterize the new metric: stability.

The control packets HELLO and TC are generated in a similar way. However, the HELLO packets, along with neighbor sensing, are now used to calculate the LLT based on the link SNR experienced during transmission from the neighbors. Using this information, MPRs are selected among the one-hop neighbors to reach all of the two-hop neighbors with the maximum LLT and SNR as a new metric. MPRs, in turn, transmit TC messages with link quality and LLT information to all the nodes in the network. This metric further is used as a criterion in computing the routes between a source and the destination pair.

Each node in the network periodically generates HELLO messages and transmits to all of the one-hop neighbors. However, in the HELLO message’s header, two more fields are included: SNR and the speed of the source node for calculating the LLT metric. When a HELLO packet is received by a node, the SNR value is stored in the neighbor table. Besides, according to the speed of the source node and the previous SNR, the LLT of the link is computed by each node. This information is treated as the stability of the link and is recorded in the neighbor table, too.

The criteria for MPR selection in OLSR with CLD protocol are to consider the SNR level of the one-hop nodes as a link quality metric, and to select maximum lifetime links in order to increase their stability.

The MPR selection algorithm can be described as follows:

- In the empty set of MPRs, first identify all two-hop neighbors of a node *u*, which have only one neighbor in the one-hop neighbor set, and add those nodes to the MPR set. If there are multiple neighbors from node *u*, select that neighbor as the MPR, which results in the greatest stability, or the maximum SNR and LLT.
- Each node in the network that is selected as an MPR, by at least one of its neighbors transmits a TC message periodically. The TC messages from the algorithm in this study were modified to include the link quality and LLT between the MPR node and its selectors. TC messages are forwarded through the network like typical broadcast messages from the MPRs. Since only the MPRs generate the TC messages that contain link stability infor-

mation, the overhead of the transmission is reduced significantly, in contrast to the traditional OLSR protocol.

- In the topology table of the nodes, each node maintains information about the SNR and LLT obtained from the TC messages. The routing table calculation is based on this information. The routing table of a node enables it to route packets for other destinations in the network. It consists of entries such as the destination address, next-hop address and the path lifetime from the source to the destination.
- The path lifetime, moreover, is calculated as the minimum lifetime of the consisting links.

This prevents calculation of routes passing through a weak link and this information being disseminated to other nodes in the network. Thus, only nodes which are connected to neighbors with high-quality links—the highest SNR and LLT—process the control and overhead information.

As an example, let us consider a network topology extended with the two metrics which constitute the SNR and LLT of the links. The letters indicate the link status and the number along the lines indicate the LLT of the links in a successful transmission from a node to a neighbor node. The idea behind this is to select the MPRs in a way such that all the two-hop neighbors have the maximum lifetime of a path through the MPRs to the current node.

Now, show how node S selects its MPRs based on the network depicted in Figure 4. For source node, S, there are two different routes: S-2-7-10-11-16-18-D and S-3-6-12-11-15-17-D. By the traditional method, the first route will be selected. But this is not the most stable route. Let us start with the route selection on a link-by-link basis. Node S has five possible routes: S-1-8, S-2-8, S-2-7, S-3-6, S-3-7 but it selects the highest SNR and maximum lifetime route, S-3-6. To reach 6, S selects 3 as its MPR. Then, to reach 8, it selects 2 as its MPR. By following the same procedure to reach 5, 12 and 13, node 6 is selected as its MPR. To reach 8, 9 or 10, 7 is selected as its MPR. To reach 15, nodes 12 or 13 may be selected as its MPRs. But it accomplishes the best route if it selects node 12 as its MPR. Furthermore, to reach 16, node 11 or 15 may be selected as its MPR. Using the algorithm described above, node 11 is selected as its MPR. And, to reach D, node17 is selected as its MPR.

Simulation of the OLSR Protocol

Presented here are the results using the scenario investigating the performance benefits of the OLSR with CLD in wireless mobile environments. All of the nodes in the network are configured to work under an ad hoc mode. In this study, the IEEE 802.11 Wireless LAN model with the ad hoc network configuration was used.

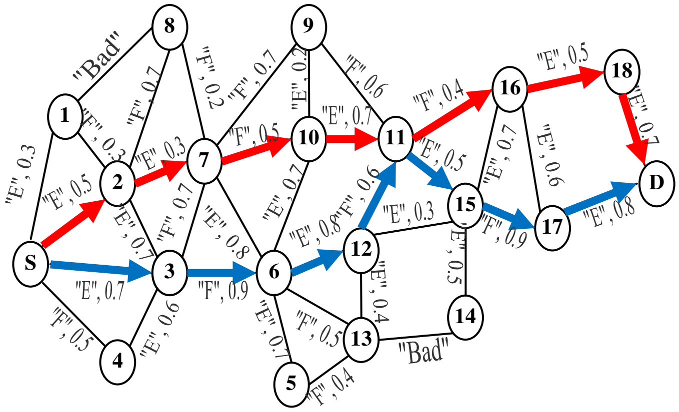

Figure 4. Route Selection in the OLSR with SNR Route Selection with SNR and LLT Metrics

A network of size 1000x1000 m^2 was chosen, but the size of the network is not restricted. The nodes in this current scenario were mobile but the position of the wireless nodes was arbitrarily chosen (see Figure 5). The mobility assigned to each node during simulation within OPNET is an important factor in the performance of the protocol. Each node is assigned a trajectory, which is generated from the traffic simulator. This will provide realistic node movement. Mobility of a mobile node generates a Doppler shift, which is a key parameter of fading channel.

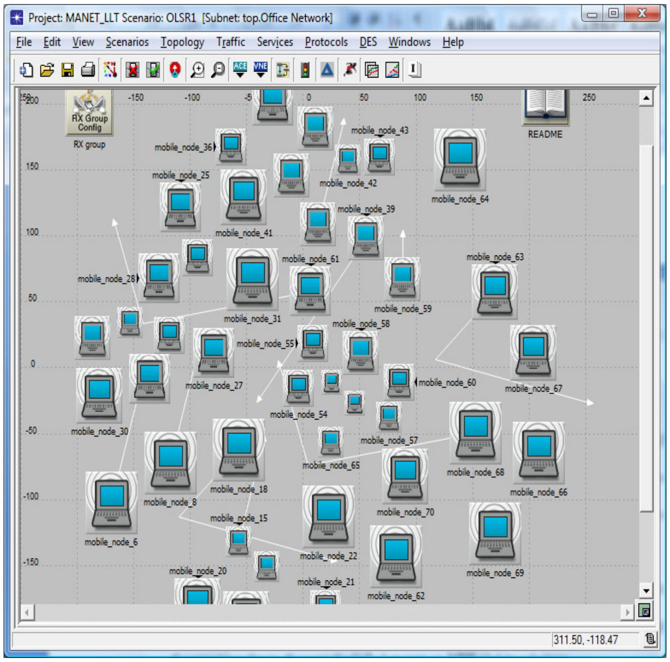

Figure 5. Simulation Scenario in OPNET

While propagation models such as fading, shadowing and path loss are not part of the radio models in simulators, they control the input given to the physical layer models and have a great impact on their performance. All other parameters of this scenario can be seen in Table 1.

Table 1. Parameter Values in the Simulations

Parameters	**Value**
Modulation Scheme	BPSK
Traffic rate	1 Mbps
Radio Tx Power	0.005 W
Mobility model	Random-Waypoint
Propagation model	Rayleigh fading
MAC protocol	802.11
Packet size	512 bytes
Routing protocol	OLSR
Carrier Frequency	2.4 GHz
Terrain dimensions	1000mx1000m
Simulation time	180 s
Nodes number	100
Traffic	CBR
SNR Thresholds	22[dB] / 17[dB]
Transmission Range	250 m
Speed	1-20 m/s

The simulation model in this study used OPNET Network simulation tools [14]. By default, OPNET assumes that a Gaussian channel model is being used and does not consider any fading. The Gaussian channel is a much more idealized environment for communication than a fading channel. For any SNIR of practical interest, the bit error rate (BER) in a fading channel is much higher than that of a Gaussian channel. Consequently, it is difficult to simulate some prominent wireless communication effects such as path loss, fading and shadowing in OPNET. To solve this problem, the authors added a Rayleigh fading channel model to OPNET and implemented the fading effect in the simulation by modifying the transceiver pipeline stages. Second, it was found that the OPNET Wireless Suite uses a fixed value of the path-loss exponent without considering that different environments have different path-loss exponents. In this study's enhanced wireless model, different path-loss exponents and the shadowing effect were added, again implemented as a function in pipeline stages.

Simulation results of the OLSR protocol performance (Figures 6-9) verify the physical-layer enhanced wireless models used in this study and display their application in the OPNET simulator. The remainder of this section focuses on the cross-layer enhancement of the routing protocol, taking into account only the simulation of the Rayleigh fading channel.

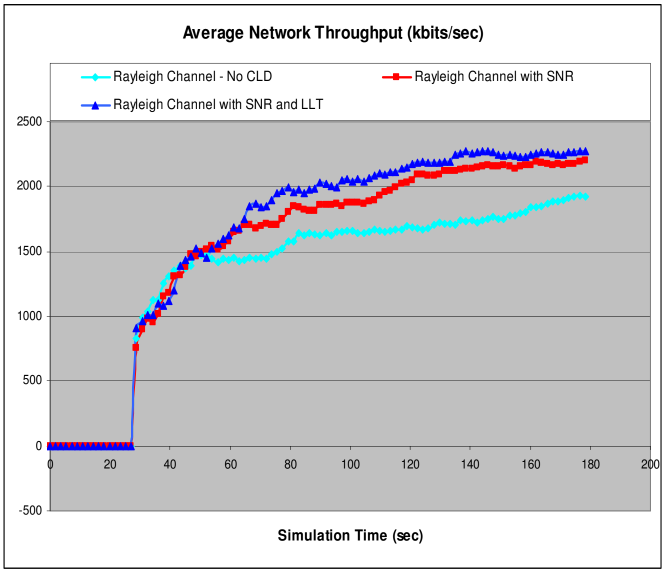

Figure 6. Network Throughput versus Simulation Time in the Rayleigh Fading Channel (NOTE: The simulation was done for a short period of time as the purpose was to see the impact of the physical layer in the higher layers; thus, this time is not enough to reach the stationary state)

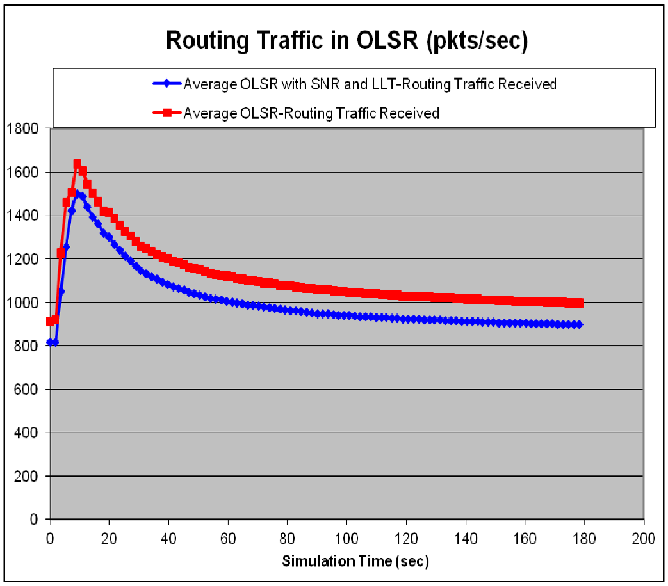

Figure 7. Routing Traffic in the OLSR and OLSR with SNR-LLT

Simulation results show that the OLSR protocol with CLD yields better performance compared to the best-effort OLSR protocol, and significantly improves throughput by using the algorithm proposed here. From Figure 6 it can be seen that the cross-layer use encourages transmission over more stable links, thereby achieving higher throughput values. On the contrary, transmission over the poor channel conditions with low LLT leads to transmissions with errors and higher routing traffic (see Figure 7). As expected, fewer losses in OLSR with CLD was seen as the metric proposed here favors minimum loss paths. In addition, the packet transmission time will be reduced, leading to a smaller average delay. The original OLSR protocol has frequent route changes, which has a negative impact on the delay performance because of the time needed for the nodes to update their routing tables (see Figure 8).

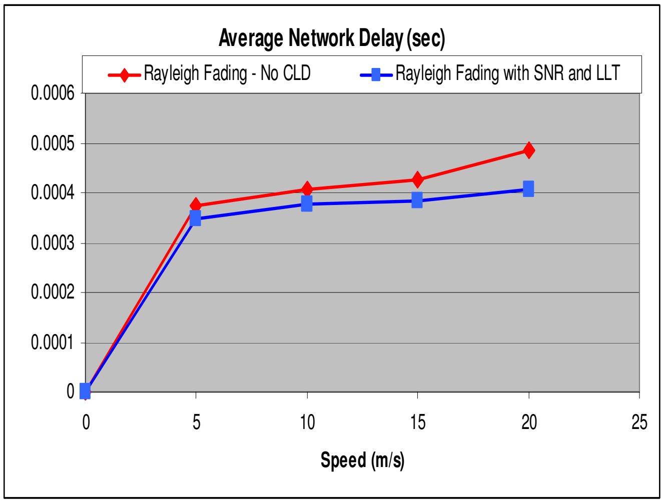

Figure 8. Average Network Delay in Seconds versus Mobility Speed (NOTE: As the delay cannot be zero, this value was not simulated for the static network)

The ability of a routing protocol to scale networks is highly dependent on its ability to control routing traffic overhead. When links are chosen with good quality and stability, fewer TC messages will be sent, which causes a lower number of MPRs to be selected (see Figure 9). The main function of the Multipoint Relay (MPR) of the Optimized Link State Routing protocol is to reduce the flooding overhead compared with classic flooding. When an OLSR protocol has fewer MPRs, the coverage of the TC broadcast traffic is narrower and adjacent nodes will be receiving less routing traffic.

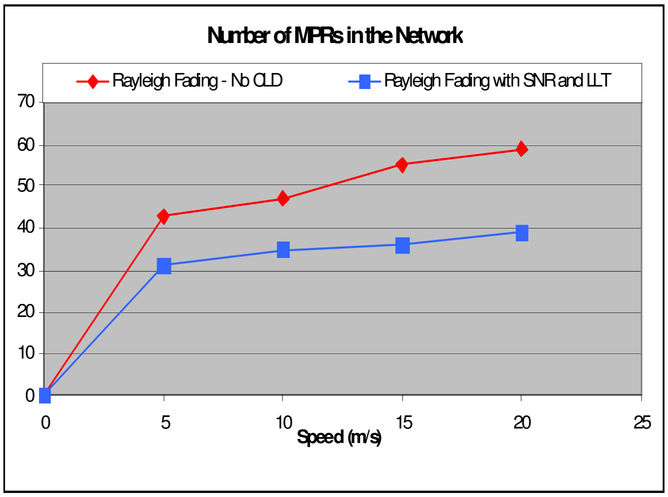

Figure 9. Number of MPRs in the Network versus Mobility Speed

Conclusion

Using the aforementioned Rayleigh fading and shadowing model, and considering interference, the authors make the following contributions:

A network architecture that supports QoS in wireless ad hoc networks using an algorithm which monitors the channel conditions during data transmission and feeds this information to the routing layer. The motivation for this study was to explore routing protocols with a cross-layer design and present the benefits of this approach with its impact on the transport layer and overall network.

This study also showed how network throughput behaves for different pathloss models. Moreover, the results indicate that the network throughput under the multipath fading and shadowing is far less than that under the free-space pathloss model, which is used in the majority of existing studies. But it can be greatly improved by using the cross-layer architecture. The goal of this study was not only to find a route from a source to a destination, but an optimal route that satisfies the end-to-end QoS requirement, in terms of quality and lifetime.

References

[1] Clausen, T., & Jacquet, P. (2003). Optimized Link State Routing Protocol. Retrieved from http://tools.ietf.org/html/draft-ietf-manet-olsr-1

[2] DeCouto, D. S. J., Aguayo, D., Chambers, B. A., & Morris, R. (2002). Performance of multi-hop wireless networks: Shortest path is not enough. *Proceedings*

of the First Workshop on Hot Topics in Networks, HotNets-I.

[3] Ishibashi, B., & Boutaba, R. (2005). Topology and Mobility Considerations in Mobile Ad Hoc Networks. *Ad Hoc Networks, 3,* 762-776.

[4] Cheng, Z., & Heinzelman, W. B. (2004). Exploring Long Lifetime Routing (LLR) in Ad Hoc Networks. *7th ACM International Symposium on Modeling, Analysis and Simulation of Wireless and Mobile Systems,* (pp. 203–210).

[5] Samar, P., & Wicker, S. B. (2006). Link Dynamics and Protocol Design in a Multihop Mobile Environment. *IEEE Transactions on Mobile Computing*, *5* (9), 1156-1172.

[6] Bohacek, S., Ilic, A., & Sridhara, V. (2005). On the Predictability of Link Lifetimes in Urban MANETs. *3rd International Symposium on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks*, (pp. 209-218). WiOpt.

[7] Agarwal, S., Ahuja, A., Singh, J. P., & Shorey, R. (2000). Route-Lifetime Assessment Based Routing (RABR) Protocol for Mobile Ad Hoc Networks, *Proceedings of the IEEE International Conference on Communications (ICC)*), *3*, 1697–1701.

[8] Singh, J. P., Bambos, N., Srinivasan, B., & Clawin, D. (2006). Cross-layer Multi-hop Wireless Routing for Inter-Vehicle Communication. *2nd International Conference on Testbeds & Research Infrastructures for the Development of Networks & Communities*, (pp. 100-101). TRIDENTCOM

[9] Rappaport, T. S. (2002). *Wireless Communications: Principles and Practice.* Prentice Hall. ISBN #0-13-042232-0.

[10] Avestimehr, A. S., Diggavi, S. N., & Tse, D. N. C. (2007). A Deterministic Model for Wireless Relay Networks and its Capacity. *Proceedings of Allerton Conference*, (pp. 6-11).

[11] Takai, M., Martin, J., & Bagrodia, R. (2001). Effects of Wireless Physical Layer Modeling in Mobile Ad Hoc Networks. *Proceedings of the 2nd ACM International Symposium on Mobile Ad Hoc Networking & Computing*, (pp. 87-94). Mobihoc

[12] Zhang, Q., & Kassam, S. A. (1999). Finite-State Markov Model for Rayleigh Fading Channels. *IEEE transactions on communications*, *47*(11), 1688-1692.

[13] Su, W., Lee, S. J., & Gerla, M. (2001). Mobility Prediction and Routing in Ad Hoc Wireless Networks. *International Journal of Network Management*, *11* (1), 3–30.

[14] Drini, M., & Saadawi, T. (2008). Modeling Wireless Channel for Ad Hoc Network Routing Protocol. *The IEEE symposium on Computers and Communications ISCC*, (pp. 549-555). Marakech Marocco.

[15] Ermel, E., & Muehlethaler, P. (2006). *Using OLSR Multipoint Relays (MPRs) to estimate node positions in a Wireless Mesh Network*. Research Report, INRIA.

[16] Villanueva-Pena, P. E., & Kunz, T. (2006). Extending Network Knowledge: Making OLSR A Quality Of Service Conducive Protocol. *Proceedings of the International Conference on Communications and Mobile Computing*, (pp. 103-108). IWCMC, Vancouver, Canada.

[17] Lenders, V., Wagner, J., & May, M. (2006). Analyzing the Impact of Mobility in Ad Hoc Networks. *International Symposium on Mobile Ad Hoc Networking & Computing*, (pp. 39–46).

[18] The OPNET simulator. (2010, April 10). Retrieved from www.opnet.com

Biographies

MERLINDA DRINI, Assistant Professor in Engineering Technology Department of Queensborough CC/ CUNY. She earned PhD in Electrical Engineering, The City University of New York, (June 2009), M. of Phil. (February 2007) and M. E. in Electrical Engineering Department, The City University of New York, City College (June 2004). Her research interests lie in the area of wireless networking, with emphasis on cross-layer design in ad-hoc networks, with focus on the interactions among PHY, MAC and Network Layers.

TAREK N. SAADAWI. Since 1980 Dr. Saadawi has been with the Electrical Engineering Department, The City University of New York, City College where he currently directs the Information Networking and Telecommunications group at CCNY. His current research interests are telecommunications networks, high-speed networks, multimedia networks, AD-HOC networks and packet radio networks. He has published extensively in the area of telecommunications networks. He is a Co-author of the book, "Fundamentals of Telecommunication Networks," John Wiley & Sons, 1994. Dr. Saadawi is a Former Chairman of IEEE Computer Society of New York City and received IEEE Region 1 Award.