Link Lifetime Based Route Selection in Mobile Ad-Hoc Networks

Merlinda Drini, Tarek Saadawi

Dept. of Electrical Engineering, City College and Graduate Center of City University of New York
New York, NY 10031, USA
{mdrini@gc.cuny.edu, saadawi@ccny.cuny.edu}

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

Keywords: wireless, ad-hoc, networks, cross-layer, Markov chain, channel.

1. Introduction

The layered networking architecture has been the key to the enormous success and widespread usage of the Internet, as well as the initial development of wireless systems. The success of the 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 is 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 indoor, it leads to many issues related to the strength of signal fading in this environment. Recently, 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.

Our focus is laid on the Physical layer which has a great impact on the performance of the system, being responsible for the nodes connectivity and overall network throughput. This is known as cross-layer design, which unlike the traditional architecture allows information exchange between OSI layers. The cross-layer design is very promising field of investigation. The use of physical (PHY) layer information in the routing decision, which we implemented in our work, is the result of the cross-layer dialogue between the PHY and the Network layers.

As an example we demonstrate the usefulness of the use of Link Lifetime as a metric in the selection of routes, thus modifying the Optimized Link State Routing (OLSR) protocol, [1]. In this paper we address the problem of link and route stability, focusing particularly on the multipoint relay (MPR) selection method, as well as that of determining the optimal path for any pair of nodes. Through actual simulation runs, we show that the modified OLSR protocol is more responsive to variations in network connectivity and can take preemptive actions in choosing stable and durable routes. The main contribution of this work is as follows: introduction of link-quality evaluation methodology based on SNR and link lifetime, for enhanced adaptability of ad-hoc routing in a dynamically changing topology.

The rest of this paper is organized as follows. Section 2 surveys related work. Section 3 examines the wireless communication channel model, and describes common radio channel impairments like multipath fading and path loss, while the impact of interference is explained in section 4. Section 5 elaborates the Finite State Markov Chain model of the channel. Section 6 presents the overview of OLSR protocol followed by analytical cross-layer framework based on signal quality and link lifetime route selection. Section 7 then presents simulation-based evaluation results. Finally, the paper finishes with concluding remarks of our work.

2. Related Work

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 to reduce 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. Reference [2] studies 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 both nodes are not moving (p = 0,) the link never breaks. But in wireless propagation environment 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 protocols design and performance. There has been some investigation into the estimation and predictability of link lifetimes. Reference [3] examines 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.

In [4] authors present a new design of the Movement Prediction based Routing concept (MOPR) [5], concept, which is more adapted to vehicular networks conditions. They consider that each vehicle in the network is supposed to have locally available all its neighbor's movement information (position, speed, and direction). By knowing the movement information of vehicles involved in the routes (including source and destination), MOPR can roughly predict their positions in the near future in order to predict the lifetime of the link between each pair of vehicles in the path. Both, [4] and [6] rely on information provided by a Global Positioning System (GPS) about the current positions and velocities of two neighboring nodes to predict the expiration time of a link. However communicating the movement information to all the neighbors through the control messages, increases the routing overhead in the network and our intention is to reduce it in order to achieve improvement in routing performance.

The Route-Lifetime Assessment-Based Routing (RABR) [7] 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 error prone.

In [8], authors propose a signal strength based service discovery (SS3D) framework as a solution by steering the service discovery over reliable links. They show improvement in service delivery success ratio based on link quality aware service. The link quality is typically measured as Signal to Noise Ratio (SNR).

Reference [9] presents a cross-layer ad-hoc routing approach based on link connectivity assessment in network topology and suggests a framework for proactive enhancements to the OLSR protocol. Authors deploy an IEEE 802.11b based vehicular network and demonstrate 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 values (SNR) to its neighbors. from the average rate of change of SNR, is estimated the affinity between two nodes. Yet, the affinity between two nodes is only a prediction of the lifetime of the link.

3. Wireless Channel Model

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 [10].

Large-scale fading is due to the distance loss and shadowing effects and changes relatively slowly. As the node moves over longer distance, the average signal strength gradually decreases. This way 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).

Slow fading can be caused by events such as shadowing, where a large obstruction such as a hill or large building obscures the main signal path between the transmitter and the receiver. The amplitude change caused by shadowing is often modeled using a log-normal distribution with a standard deviation according to the log-distance path loss model.

The simplest path loss model is well known free space model, which predicts the received power as a deterministic function of distance. The communication range with this model is represented as an ideal circle. But in reality, the received power at certain distance is a random variable due to multipath propagation effects. Since, the free space model predicts the mean received power at distance d, a more general model, so called the shadowing model has to be used.

The shadowing model extends the ideal circle model to a richer statistic model: nodes can only probabilistically communicate when near the edge of the communication range.

The more realistic physical layer includes a channel with both path loss and shadowing. This consists of two parts. The first one is known as path loss model, which also predicts the mean received power at distance d, denoted by Pr(d). It uses a close-in distance, do, as a reference. Pr(d) is computed relative to Pr(do) as follows:

\[
\frac{P_r(d)}{P_r(d_0)} = \left(\frac{d}{d_0}\right)^\beta
\]

where β is called the path loss exponent, and is usually empirically determined by field measurement. The value of β for free space propagation model is 2.

Since the path loss is usually measured in dB the previous eq. becomes

\[
\left[\frac{P_r(d)}{P_r(d_0)}\right]_{dB} = -10\beta \log\left(\frac{d}{d_0}\right)
\]

The second part of the propagation model reflects the variation of the received power at certain distance. It is a log-normal random variable, that is, it is of Gaussian distribution if measured in dB. The overall shadowing model is represented by

\[
\left[\frac{P_r(d)}{P_r(d_0)}\right]_{dB} = -10\beta \log\left(\frac{d}{d_0}\right) + \chi_{dB}
\]

where χ_{dB} is a Gaussian random variable with zero mean and standard deviation σ_{dB}, which is called the shadowing deviation, and is also obtained by measurement. Eqn.(3) is also known as a log-normal shadowing model.

4. Interference impact

In a wireless ad-hoc network, because nodes share a common channel, interference usually has a greater impact than noise. [11]. 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 we focus on the SINR, rather than the SNR, signal to noise ratio.

Computation of interference and noise at each receiver is a critical factor in wireless communication modeling, as this computation becomes the basis of SINR (Signal to Interference and Noise Ratio) or SNR (Signal to Noise Ratio) 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,[12]. Thus, a communication between two nodes u and v is successful if the SINR (Signal to Interference and Noise Ratio) at the 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 \( P_v(u) \), 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.

\[
\text{SINR} = \frac{P_v(u)}{N + \sum_{w \neq v} P_v(w)} \geq \delta \quad (4)
\]

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

Since in a realistic channel the interference can not be excluded, from now on, we will refer to SINR as SNR. Accordingly, \( N \) represents the background noise plus the total interference of all neighboring transmissions.

5. Finite State Markov modeling of the Channel

Previous research shows that fading channels have much larger impact on the performance of routing protocols, [13]. This view on fading channels encouraged us to characterize these channels more precisely for better identification and use of wireless channel.

In our work we consider Rayleigh fading channel, 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, received SNR, has also the Rayleigh distribution with probability density function:

\[
p(\gamma) = \frac{1}{\overline{\gamma}} \exp\left(-\frac{\gamma}{\overline{\gamma}}\right) \quad (5)
\]

where \( \gamma \) is the received SNR and \( \overline{\gamma} \) is the average SNR, which is physical layer depended. In one word 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. By establishing the FSMC, we show that the FSMC is accurate enough to evaluate the performance of the protocol with physical layer impact. Since Markov model is a natural way to approximate a channel, many people have considered finite state Markov modeling for describing a wireless communication channel. [14]

In order to build the FSMC, we assume 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 we may partition the range of the SNR into a finite number of intervals, with corresponding states. [15] The channel is said to be in the state \( k \), if SNR remains between two thresholds of average SNR: \( \{\Gamma_{k-1}, \Gamma_k\} \).

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

\[
0 = \Gamma_0 < \Gamma_1 < \Gamma_2 < \cdots < \Gamma_{K-1} < \Gamma_K = \infty \quad (6)
\]

Stady state probabilities can be calculated from the following expression:

\[
\pi_{sk} = \int_{\Gamma_{k-1}}^{\Gamma_k} p(\gamma) d\gamma = \exp\left(-\frac{\Gamma_k}{\overline{\gamma}}\right) - \exp\left(-\frac{\Gamma_{k-1}}{\overline{\gamma}}\right) \quad (7)
\]

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

\[
N(\Gamma_k) = \frac{2\pi f_m}{c} \int_{\Gamma_k}^{\overline{\gamma}} f_m \exp\left(-\frac{\Gamma_k}{\overline{\gamma}}\right) d\gamma \quad (8)
\]

\( f_m = \frac{f_c v}{c} \)

\( f_c \) 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 \( s_{k+1} \), \( P_{sk+1} \), can be expressed as a ratio of the level crossing rate at threshold \( \Gamma_{k+1} \), and the average number of signal segments per second staying in state \( s_k \).

The transition probabilities can be approximated as

\[
P_{s_{k+1}} = \frac{N(\Gamma_{k+1})}{\pi_{sk}}, \quad k = 1,2,\ldots,K-1 \quad (9)
\]

\[
P_{s_{k+1}} = \frac{N(\Gamma_{k+1})}{\pi_{sk}}, \quad k = 2,3,\ldots,K
\]
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

$$P_{kk} = \begin{cases} 1 - P_{k+1,k}, & 0 < k < K \\ 1 - P_{00}, & k = 0 \\ 1 - P_{k-1,k}, & k = K \end{cases}$$

(10)

and

$$P_c = [P_{k+1,k+1}]_{K+1 \times (K+1)}$$

(11)

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

### 5.1. Three State Markov Model

The two state Markov model, known as Gilbert-Elliot model, which was widely used in the research to evaluate the communication system, is not enough for modeling a real channel. By applying the higher order of Markov chains, it is possible to implement a more realistic channel. Even though the fading channels may change rapidly, increasing the number of states, increases the computational complexity during the protocol implementation. Consequently we used a three state Markov model of the wireless channel as a tradeoff between complexity and the performance. Three state Markov chain model is shown in Figure (2), where there are two good states: “Excellent” and “Fair”, and a single bad state, “Bad”. We consider the situation in which the success of a packet transmission in a given state is determined by comparing the received SNR to the thresholds in each state, each of which has certain packet error probability, PER [16].

![Figure 2. Three State Markov Model](image)

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

$$T = \frac{T_p}{1 - P_{GG}}$$

(12)

Where $T_p$ is the packet transmission time and

$$P_{GG} = P_{EE} + P_{FF}$$

(13)

### 6. Design of OLSR routing protocol with Cross-Layer Design

In ad-hoc networks routing protocols can be classified as reactive or proactive. Reactive protocols, such as Dynamic Source Route (DSR) protocol, start the route discovery procedure on demand only. In these protocols, because route information may not be available in the time the route request is received, the delay to determine a route can be significant. Moreover, the route discovery process of the reactive protocols generates significant control traffic.

On the other hand proactive routing protocols, such as Optimized Link State Routing (OLSR) protocol, attempt to monitor the topology of the network in order to have route information between source and destination available all the time. This is achieved through continuous routing updates. The advantage of the proactive routing protocols is that, once a route is needed, it is immediately available from the routing table. However, as the node mobility increases, the lifetime of the link decreases, because the period that the routing information will remain valid, decreases, as well. Hence, only the small amount of control traffic will be used.

To be able to use proactive protocols in a highly mobile environment, we employ a new parameter called Link Lifetime, and demonstrate our approach in a typical routing algorithm. We have chosen OLSR as an example of table driven proactive routing protocol.

#### 6.1. 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. So the topological changes cause the flooding of the topological information to all available hosts in the network. To reduce the possible overhead in the network protocol uses Multipoint Relays (MPR). The idea of MPR is to reduce flooding of broadcasts by reducing the same broadcast in some regions in the network. Another reduce is to provide the shortest path. The reducing the time interval for the control messages transmission can 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 the information about the link status and the host’s neighbors. With the HELLO message the Multipoint Relay (MPR) Selector set is constructed which describes which neighbors has chosen this host to act as MPR and 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 broadcasted throughout the entire network. TC messages are used for broadcasting information about own advertised neighbors which includes at least the MPR. The TC messages are broadcasted periodically and only the MPR hosts can forward the TC messages.

**Neighbor/Route Discovery:** Periodic HELLO messages are used to establish neighbor links and to distribute MultiPoint Relays (MPRs), determined by algorithm. MPR nodes are some selected nodes that have more connectivity to other nodes. These nodes have two main advantages:

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

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

**Routing Table Calculation:** Each node maintains a routing table which allows it to route data, destined for the other nodes in the network. The routing table is based on the information contained in the local link information base and the topology set. Therefore, if any of these sets are changed, the routing table is recalculated to update the route information about each destination in the network.

**Route Maintenance:** HELLO messages track link connectivity. Topology Control (TC) messages, distributed by MPRs, propagate link state information throughout the network, and are broadcast periodically as well as when there is a change to the topology.

Control traffic consists of periodic HELLOs and TC messages. Overhead is controlled by MPR broadcast and redistribution of TC messages throughout the network, rather than broadcasts of link state from each router.

### 6.2. OLSR with Cross Layer Design (CLD)

In this section, we propose the routing algorithm which selects the route that provisions a higher SNR along its hops to the destination. When a node is initially detected via a HELLO message it is entered in the neighbor table, but it is selected as MPR and broadcast to other nodes via HELLO messages only if the SNR to this neighbor is found to be above SNR threshold. Since we model the wireless channel with three state Markov model, we take into consideration two SNR thresholds. Thus, if 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 being selected as MPR according to the lifetime of the link. This neighbor is considered during routing table calculation.

The variations in signal strength, Figure (4), affect ad-hoc network protocols in a way that differs from other wired network architectures. For example, in regard to SNR value, a link may be considered “Excellent”, nevertheless, it may not be long living. 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 [17].

In our work we propose a solution to this problem by introducing special algorithm dedicated to Link-Lifetime (LLT) estimation, which is based on the use of the normalized mean sojourn time in calculation of the LLT. This value is normalized in regard of 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 new received SNR value: if the existing value is lower than the received one we say that the nodes are approaching each other. This mechanism is very efficient in calculating the stability of the link. Thus in our CLD mechanism we consider two constraints, which together characterize the new metric: stability.

The control packets HELLO and TC are generated in similar way. However, the HELLO packets, along with the neighbor sensing, now, are 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 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 criteria in computing the routes between a source and the destination pair.

Each node in the network periodically generates HELLO messages and transmits to all the one hop neighbors. However, in the HELLO message’s header are included two more fields: 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 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 it 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, to increase their stability.

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 MPR, which results in greatest stability, means maximum SNR and LLT.

- Each node in the network that is selected as MPR, by at least one of its neighbors, transmits a TC message periodically. The TC messages in our algorithm are also modified to include the link quality and LLT between the MPR node and its selectors. TC messages are forwarded thorough the network like usual broadcast messages from the MPRs. Since only the MPRs generate the TC messages that contain link stability information, 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 SNR and the 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 from the 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: highest SNR and LLT, process the control and overhead information.

Figure 3. Network Example.
Route selection in traditional OLSR
Route selection with SNR and LLT metrics

As an example, we will consider a network topology extended with the two metrics, which constitute the SNR and LL of the links. The letters indicate the link status and the number along the lines indicate the LL 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 2 hop neighbors have the maximum lifetime of a path through the MPRs to the current node.

Now, we show how node S selects its MPRs based on the network depicted in Figure 3. For source node, S, we have 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’s start with the route selection on link by link bases. 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 MPR. Then to reach 8, it selects 2 as MPR. By following the same procedure, to reach 5, 12 and 13, node 6 is selected as MPR. To reach 8, 9 or 10, 7 is selected as MPR. To reach 15, nodes 12 or 13 may be selected as MPRs. But it accomplishes the best route if it selects node 12 as MPR. Furthermore to reach 16, the node 11 or 15 may be selected as MPR. By the algorithm described above, the node 11 is selected as MPR. And to reach D, the node 17 is selected as MPR.

7. Simulation of OLSR Protocol under different radio propagation models

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 great impact on their performance. We first study the performance of traditional OLSR protocol in a specific network configuration comprising 100 nodes within an area of the size of 1000× 1000 meters. All other parameters of this scenario can be seen in the Table 1).

We will present results from two main propagation models:

a) Additive White Gaussian Noise (AWGN) and Free Space
b) Rayleigh fading with log normal shadowing model

The free space model with the Additive White Gaussian Noise, (AWGN), is used as a basic reference model and is also considered to be idealized propagation model. The AWGN is the noise in an ideal channel where no signal fading occurs. With this path loss model, even nodes far from the transmitter can receive packets, which can result in fewer hops to reach the final destination. Therefore, simulation results with the free space path loss model tend to be better than with other path loss models, such as log normal shadowing model.

Figure 4. SNR variations in time for a specific receiver-Node 70.

We show that OLSR routing protocol performs very well with the free space path loss model. Keeping all other parameters constant, and employing log-normal shadowing model, the transmission range of the nodes drops about 40%, in regard of free space path loss model. However, one way to improve the transmission range with log-normal shadowing model is to increase the transmission power of the nodes, Figure (5), but this does not yield that the free space path loss model perform better, due to increased interference. For the battery operated nodes, increased power yields in short network lifetime. If the power of each simultaneous transmission is increased, signal and interference power increase proportionally while thermal noise power remains constant. Thus, at some point thermal noise becomes approximately negligible, i.e., the network becomes interference-limited, and any further increase in transmission power provides essentially no benefit. [18].
Another way of increasing throughput is a cross-layer ad-hoc routing approach, explained in the previous section, based on link connectivity assessment, deploying the SNR, as a new metrics in route selection. Nodes will be selected as MPRs only if the links connected them are above some required threshold. The network throughput has almost the same enhancement with power adjustment. This can be seen in the Figure (6).

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 our proposed algorithm. From the Figure (7), it can be seen that the cross-layer use encourages transmission over more stable links, thus achieving higher throughput values. On the contrary transmission over the poor channel conditions with low LLT, leads to the transmission with errors, and the higher number of dropped packet, Figure (8). As expected, we see fewer losses in OLSR with CLD, as our metric favors minimum loss paths. In addition to this, the packet transmission time will be reduced, leading to a smaller average delay. 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, Figure (9).

**Figure 6.** Network Throughput vs. Simulation time with and without CLD

**Figure 7.** Network Throughput vs. Simulation time in Rayleigh fading channel

**Figure 8.** Average Number of Packets Dropped vs Mobility Speed

The ability of a routing protocol to scale networks is highly dependent on its ability to control routing traffic overhead. Routing traffic contains messages that a routing protocol needs to establish new routes through a network, maintain routes or repair broken routes. These can be simple HELLO messages which are sent periodically to allow neighboring nodes to learn about the presence of fellow nodes or they can be TC messages containing routing tables. As seen from Figure (10), the routing overhead of the protocol, which main part are TC messages, is decreased accordingly to the quality of the links. TC messages are sent only when the...
change in network is determined. When links are chosen with good quality and stability, less TC messages will be sent, which causes lower number of MPRs selected, Figure (11).

The main function of the Multi-Point Relay (MPR) of the Optimized Link State Routing protocol is to reduce the flooding overhead compared with classic flooding. When OLSR protocol has less MPRs, the coverage of the TC broadcast traffic is narrower and adjacent nodes will be receiving less routing traffic.

8. Conclusion
Using the above mentioned Rayleigh fading and shadowing model and considering the interference this paper makes the following contribution:

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

The paper shows also how network throughput behaves for different path loss models. Moreover our results indicate that the network throughput under the multipath fading and shadowing is far less than that under the free space path loss 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 our work 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.

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

Table I. Parameters values in the simulation

References


