An Optimal Path Stability Achieved By a Cross-Layer Proposal for Wireless Networks

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***Abstract*—This article presents an adaptive cross-layer solution for wireless networks. The main objective is to estimate the impact that different physical layer variations and approaches can have on the network layer. The data loss probability obtained directly from physical layer will provide the routing protocol enough information to choose routes with the highest successful transmission probabilities. This proposal was evaluated under simulations and the obtained results point to a more stable network with fewer route recalculations and smaller number of packets lost.**

I. Introduction

The great interest in multi-hop wireless networks such as ad hoc and wireless mesh networks (WMNs) comes from their low implementation cost, the independence of a fixed infrastructure and also their increased coverage speed and capacity. WMNs are dynamic self-organizing and self-configuring networks which nodes automatically form an ad hoc network with mesh connectivity [1].

The layer concept was originally designed for use on wired networks. However, wireless networks present quite dynamic characteristics, with routes and topologies changing frequently, loss of connections and dynamic time-varying channel transmission conditions [2]. Thus, while the rigid separation into layers can be easily applied to a fixed wired network, the dynamic nature of a wireless network brings the need for a model with greater flexibility. It is then proposed in this article the use of a cross-layer approach, which allows information to be shared between different layers in order to improve network performance, enabling better and faster responses to variations experienced by the network.

Using appropriate metrics, it is possible to find the routes that provide the best connections between nodes or with the least failure probability. The use of the physical layer information allows the routing protocol to respond in a dynamic and preventive way to changes that wireless transmission channel may suffer, providing fewer losses in the network data transmission, besides targeting an optimization in the routes calculation.

II. Adaptive cross-layer approach

The adaptive cross-layer proposal is mainly a set of changes in physical and network layers, in order to allow information exchange with the objective of obtaining the best routes with lower loss probabilities and a better allocation of network resources. The proposed model will be investigated under simulation.

Therefore, the simulation model needs to be reliable and to reflect the changes the transmission wireless channel may suffer. In addition, the network layer has to be prepared to receive the information obtained from the physical layer and to use them to perform an optimal route calculation.

At the network layer, the OLSR (Optimized Link State Protocol) was the chosen protocol, which is a proactive protocol optimized for use on mobile ad hoc networks. OLSR is defined by RFC 3626 [3], and uses the concept of MPRs (multipoint relays) to make an optimal onward transmission of messages, thus reducing the signaling message traffic in the network. The protocol uses Hello and TC (Topology Control) messages to obtain the network topology and information about connections states.

In order to establish the routes with the lowest transmission failure probability, our proposal uses the OLSR protocol to collect information from all network nodes. In the proposed model, the value of the frame error rate (FER) is the physical layer information to be used by the network layer to set the routing tables. FER value is obtained by analyzing the effects that transmission channel has on a data packet and accounting the packet lost rate.

Equation 1 is used to consider previous channel states in order to avoid instantaneous and abrupt FER values variation. For example, if channel has good transmission conditions (a low FER value) and a high FER value is obtained (a bad channel condition), FER weighted mean allows a smoother transition from a low to a high FER channel value. This FER_{wm} is inserted as an additional field in Hello and TC messages and then transmitted to the entire network by these messages exchanges to be used by routing protocol.

$$FER_{wm} = (\alpha \times FER_{hist}) + ((1-\alpha) \times FER_{inst}) \qquad (1)$$

where FER_{wm} is the FER weighted mean, FER_{hist} represents previous FER_{wm} values calculated, FER_{inst} is the instantaneous FER value obtained from received packet and α is a value from 0 to 1 that balances FER_{hist} and FER_{inst} values.

Upon receiving the FER value from each connection, the routing protocol may through this additional information, obtain a better knowledge of the network and be able to make a differentiated routes calculation, optimizing them and avoiding connections that have a higher packet loss probability.

Then, based on FER supplied values, it is necessary to introduce a metric that allows the routing algorithm to optimize the route choosing process. So, as in equation 2 we can consider for each route the failure probability [4] as been:

$$P_f(x) = 1 - (1 - (P_f(a,b)) \times ... \times (1 - P_f(b,c))) \quad (2)$$

where $x = (a, b, ..., c)$ is the path to be analyzed, $P_f(x)$ is the failure probability metric of a transmission by this route and $P_f(a,b)$ is the loss probability (the FER value) of the connection between nodes a and b.

Then, this measurement can be represented into a multiplicative metric as shown in equation 3.

$$P_s(x) = (P_s(a,b) \times ... \times P_s(b,c)) \quad (3)$$

where $P_s(x)$ is the metric of successful transmission probability by this route and $P_s(a,b)$ is the successful transmission probability between nodes a and b, or just $1 - P_f(a,b)$.

Analyzing the OLSR protocol, it should be noted that this proposed model does not require extremely deep and complex changes. It is not necessary to create new signaling messages or new messages, only the information dissemination mechanism provided by the protocol is used. There is, however, the need to adapt the algorithm to consider the FER information for route calculation.

III. Related works

Authors in [11] propose a work whose scenario and Quality of Service (QoS) metrics are different from our proposal. In their scenario, nodes are organized into MAC clusters with radio communication resource allocation occurring centrally in each cluster individually, as opposed to the proposal of this article, in which each node is considered an independent entity. Moreover, they use two different QoS metrics to establish two different sets of QoS routes: routes with optimized delay and routes with minimized losses. The required information is acquired from the access layer for each cluster, our proposal, however, focuses on information obtained directly from the physical layer, without changes in the access layer.

The authors in [12] focus on the optimization of MPR nodes selection, resulting in a better choice of routes to be used. This article aims to perform the optimization of routes directly, initially without interference on the selection of MPR node. FER based MPR selection was implemented in our model and results are planned to be presented in coming articles. The metrics used are also different. While [12] uses the available bandwidth and connections delay, our proposal focuses on the transmission quality of the channel at the transmission time.

The authors in [13] also present an OLSR cross-layer modification proposal. However, they take topology information from network layer to be used in access layer in order to get a distributed scheme for transmission scheduling of nodes and obtain a higher overall throughput in the network. Similarly to our proposal, the authors also take advantage of OLSR message exchange mechanism and use signaling messages to transport and propagate metric information.

The work in [14] presents a cross-layer approach in wireless multi-hop networks which nodes have a software controlled radio that is able to use several modulation and coding schemes at different data rates. A distributed algorithm is introduced and used by each network node to control its transmission rate and select the neighbor which a packet will be forwarded to. So the node can select the proper physical layer transmission characteristics and neighbor to meet QoS requirements like end-to-end throughput and delay.

IV. Performance Evaluation

The proposal implementation and the simulations results were conducted using the current version (2.34) of Network Simulator (NS-2) [5]. The typical implementation of the IEEE 802.11 physical layer in NS-2 however, is incomplete and some adjustments were necessary to correct their deficiencies and to obtain results with a greater realism degree. Then, another model implementation of physical and access layers was used. The chosen model was proposed by [6], which includes the implementation of cumulative signal to interference-plus-noise ratio (SINR) and corrections in the collisions handling.

By analyzing in details the implementation of NS-2 current physical layer, it can be noticed that the failure or success data reception at a node is directly related to the value of the received power signal by this node. If the received power is above a certain threshold value, it is considered that the data was successfully received. The model of [6] used in our proposal, however, is more complete and considers the noise and interference that the signal may have undergone and takes the value of SINR to be compared to another threshold value. They consider, however, as a point of improvement the implementation of bit error rate (BER) calculation at the data reception.

This improvement was implemented in our model, and besides considering the effects of channel variation on large-scale (calculation of the received power), the effects of small-scale variation of the channel are also obtained, thus computing the rapid changes in signal strength that can occur in short periods of time, that may cause bursts of errors during the transmission [7]. Then, from SINR values we obtain the BER values the frame error rate (FER) for each transmission performed.

FER values are calculated in a two steps simulation model: data is generated to be transmitted and data is recovered in reception. In first step, a random bit sequence to be transmitted is generated. This sequence is exposed to noise effects and to interference from small scale channel models. In the second step of this process, received data is analyzed. Values obtained in reception are compared to transmitted data. The number of bits that did not match is obtained to get bit error rate caused by simulated channel effects. This process is performed to each data packet received by a node and considers data size. If there is any bit mismatch in packet received, the frame is considered as lost, increasing frame error rate.

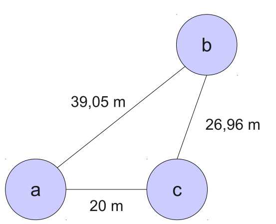
So, FER values obtained from established connections between two nodes are then inserted into an additional field created in the Hello and TC messages that should be diffused among all other network nodes. Thus, each node will have the knowledge of network topology information and also the transmission loss probability information between two nodes in the network.

Our OLSR model implementation was based on UM-OLSR implemented by [8]. UM-OLSR is an OLSR implementation for NS-2 that is RFC 3626 compliant.

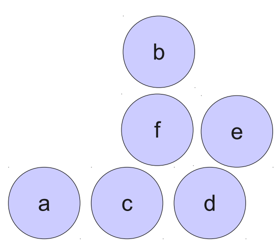
According to the RFC 3626, the standard OLSR protocol should choose the shortest path (with fewer hops between nodes) to perform the routes calculation. However, this is not often an optimal choice because by using only this metric, factors such as distance and conditions of the communication channels between nodes are not considered. By taking the FER as a metric, however, both factors are considered, giving greater flexibility and dynamism to the algorithm.

V. Results and Analysis

A simple simulation scenario that illustrates the differences in results obtained with the standard OLSR protocol and our proposal can be seen in figure 1a.



(a) Simple scenario that shows the differences between proposed model and standard OLSR



(b) Scenario with greater nodes density

Fig. 1. Simulated testing scenarios.

In this scenario, the three nodes are fixed (not mobile) and they have the same transmission power and hardware characteristics. Node *a* starts a CBR (constant bit rate) over UDP traffic transmission 15 seconds after simulation beginning to node *b*. This traffic simulation data is collected for 20 seconds, ending the simulation.

By analyzing the amount of packets lost in CBR traffic during the scenario simulation, the first result is that in our proposal (OLSR + FER) no packet is lost, whereas in the scenario using only the OLSR protocol 8 packets were lost.

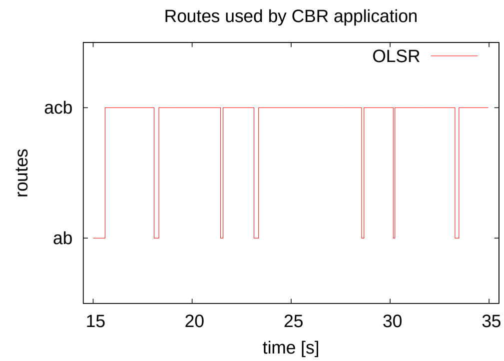


Fig. 2. Chosen routes using OLSR protocol only.

Figure 2 illustrates the chosen routes variation for the CBR traffic transmission from node *a* to node *b* by their transmission times. Note that in the initial traffic simulation time, in 15 seconds, the route *ab*, which is the route with the least number of hops, was chosen. However, soon after this the routing protocol chooses an alternative route between nodes *a* and *b* (route *acb*) due to the unavailability of the preferred route (route *ab*). The following route exchange, from route *acb* to route *ab*, is due to a routing table recalculation initiated by the reception of an OLSR protocol signaling message (Hello message).

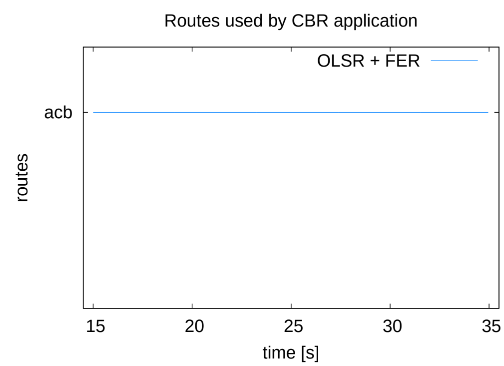


Fig. 3. Chosen routes using proposed model.

Figure 3 shows the great routes stability provided by our proposed model. When performing the route calculation between nodes *a* and *b*, the modified OLSR protocol uses the FER values of connections between all nodes provided by physical layer and calculates the odds of successful transmission of all routes between nodes *a* and *b*, according to equation 3. The route that has the highest transmission success probability is then chosen, regardless the amount of required hops. At the opening of CBR transmission, for example, the values of routes *ab* and *acb* successful transmission probabilities were respectively 0.602161 (60.2161%) and

0.79946 (79.946%), so route *acb* was chosen, providing a lossless data traffic with no routes exchanges in simulated time.

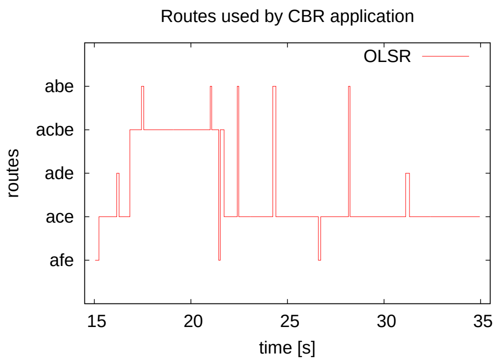


Fig. 4. Great routes variation in a higher nodes density scenario using OLSR protocol only.

A scenario according to figure 1b was then simulated for 20 seconds and CBR traffic was also initiated 15 seconds after simulation start. The objective is to analyze routing algorithms behavior in an environment with greater variety of routes available to be chosen.

Figure 4 illustrates the great route exchanges that occurs when using the standard OLSR protocol for route recalculation. In this scenario 42 CBR data packages were lost. It can be noted that there is no route convergence in this scenario. Routes are continuously changing due to lost packets and received signaling packets, which force a new route calculation.

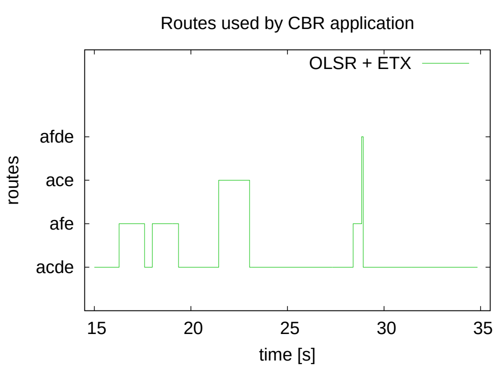


Fig. 5. Routes variation in the same higher nodes density scenario using OLSR protocol using ETX metric.

Figure 5 presents chosen routes to transport CBR application for the same testing scenario but using an OLSR protocol variant based on the ETX (Estimated Transmission Count) metric proposed by [9]. ETX is an additive metric that represents the number of data transmissions and retransmissions expected over a link. The model was implemented by [10] and is also based on the same UM-OLSR implementation used in our implemented model. Results obtained by using ETX metric point to 9 lost packets and show greater stability in routes choosing (if compared to the minimum hop-count metric used by standard OLSR protocol) due to its capacity of calculating routes with high throughput, despite losses.

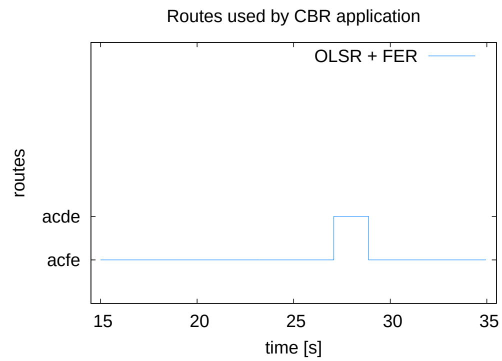


Fig. 6. Stability in routes choice in a higher nodes density scenario using OLSR protocol associated to FER.

Figure 6 shows the greatest routes stability obtained using OLSR protocol combined with physical layer measurements if compared to figures 4 and 5, in this scenario there were no packet losses when transmitting CBR traffic. The change from route *acfe* to route *acde* is observed because the route *acde* temporarily had better transmission conditions than route *acfe*, ie, with higher successful transmission probability.

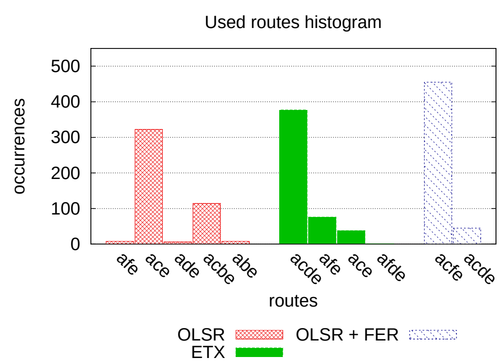


Fig. 7. Total number of each route occurrences during the simulation.

Figure 7 quantifies the total number of times each route was chosen to carry the CBR traffic. Note that using only the OLSR protocol although at some times routes with more hops (*acbe*) are chosen, shorter routes with 2 hops are preferred. Using ETX metric 3 hops routes are preferred (*afe* and mainly *acde*), however 2 hops routes are also chosen. While using our proposed model, only routes with 3 hops, but with greater reliability were used.

In order to measure and analyze the impact that the choice of routes with more hops has on network delay and jitter, the same scenario from figure 1b was simulated

TABLE I
AVERAGE DELAY AND JITTER MEASURED IN MILLISECONDS.

	OLSR	ETX	OLSR + FER
Delay sample mean	2.9050127	2.9935503	3.1603265
Delay standard deviation	1.6790655	1.2898063	1.0433821
Jitter sample mean	1.2288212	0.9719440	0.7794436
Jitter standard deviation	1.7441478	1.4799310	1.1796044

with four different RNG seeds for standard OLSR, ETX and OLSR combined with FER. Table I presents average delay and standard deviation values measured for each pair of packet transmission and reception during simulations. Higher delay values obtained for ETX and our proposed model exposes the disadvantages of more hops routes. As packets will be handled and processed by more nodes, delay is inserted in these packet transmission. Although ETX and our proposed model have similar average delay, their delay standard deviation values are quite different, which is reflected to different jitter values. As our proposed model had lower delay standard deviation values, lower jitter values were obtained.

VI. CONCLUSION

Presented results show the gain in stability obtained by using routing protocol OLSR associated to information obtained directly from the physical layer. Comparing the standard OLSR protocol and ETX metric, it is possible to observe changes in routes associated to packet loss and metric calculations. Meanwhile when our proposal is used, the route variations observed are directly linked to searches for routes with lower error probability. If standard OLSR and our proposed model are compared, simulations show that using FER values, route changes can be seen as preventive measures, while in the original OLSR model route recalculations can be seen as a packet loss consequence.

It can also be noticed that in the scenario that has more nodes, the choice of routes for established CBR traffic does not converge in standard OLSR. There is variation and routes exchanges due to lost packets and signaling messages reception, which causes routes recalculation, that will always prefer routes with fewer hops. In contrast to this behavior observed, using ETX and our proposed model the convergence occurs in the process of routes calculation, resulting in the choice optimization, although the use of OLSR associated to FER values presented a more stable network with fewer routes recalculations.

The negative impact of ETX and OLSR + FER metrics in simulated scenarios is evidenced by delay values obtained. As standard OLSR prefers routes with minimum hops number, packet will be processed and relayed by less nodes and consequently measured delay in network transmission will be lower if compared to ETX and OLSR associated to FER.

Simulation scenarios and performance metrics can still be greatly explored. Network size, topology and nodes density could be better explored. Simulation scenarios could be expanded, with greater areas and more nodes with random nodes positions in order to verify proposed model scalability and behavior in several different scenarios. Simulation duration could be expanded and different applications could be also simulated, instead of just one CBR application. The impact of transport protocol could also be explored. In presented simulations, CBR over UDP traffic was simulated. As UDP does not have retransmissions, TCP transport protocol could point to differences in network throughput. Another possible point of analysis and study could be the impact of increased overhead caused by the insertion of new FER info in signaling OLSR messages. Although it is just one additional field, as there are many signaling messages to be sent and received in the network, overhead could affect overall network performance.

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