Behaviors of Multi-hop Routing Protocols Based on Cross-Layer Approach

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***Abstract*—Most of the recent performance studies in MANETs (Mobile Ad Hoc Networks), consider the effects of multiple layer interactions. These interactions allow layers to exchange state information in order to obtain performance gains. For instance, the routing layer may use the channel state information such as interference and noise in the route discovery process, in order to dynamically select the most stable routes. In this paper, we present a behavior comparison of the routing protocols based on cross-layer approach among physical and network layers. The first protocol is a reactive protocol Ad Hoc On- demand Distance Vector (AODV), the second one is a proactive protocol Optimized Link State Routing (OLSR). Both of them are based on Signal to Interference and Noise Ratio (SINR) metric in their route discovery process. The behavior comparison of the routing protocols is implemented using NS2 simulator with mobile nodes in a shadowing environment qualified as an environment with important variations in the received signal power. Simulation results, using NS2, show that AODV based on SINR metric maximizes the packet delivery ratio and minimizes the overhead cost compared to OLSR based on SINR metric.**

***Index Terms*—cross-layer, SINR, AODV, OLSR, shadowing model**

I. Introduction

Mobile ad Hoc Networks (MANETs) can be defined as autonomous systems of mobile nodes connected via wireless links without using an existing network infrastructure. Wireless networks have specific properties such as limited bandwidth, dynamic topology, link interference and inherent broadcast nature. Small-scale channel variations due to fading, scattering and multipath can change the quality of a link within a few milliseconds. Variable link connectivity increases the number of dropped packet and has a direct impact on all the network protocols.

MANET behavior has to be adapted to efficiently handle user traffic needs, for sensitive real-time applications like Voice over Internet Protocol (VoIP). Consequently, the routing protocol that is responsible for route computation on the network has to be optimized to following requirements:

Knowledge of the parameters affecting the network state (channel condition, congestion, traffic demands, etc);

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Possibility for each protocol to adjust his behavior according to the current network state. For example, given the current channel state described with the Bit Error Rate value (BER), the routing layer may use the BER information in the route discovery process, in order to dynamically select the most stable routes [1].

The cross layer architectures have been proposed to guarantee protocols cooperation by sharing the network status information while still maintaining separation among the OSI model layers [2]. The routing metric widely used in the most popular routing protocols [3], [4] is the minimum number of hops. Therefore, in order to achieve the best quality of service (QoS), routing protocols should consider the cross-layer approach to extract QoS metrics such as current channel state as well as the quality of each link. In this work, we propose a solution of quality of service to improve the functionality of routing protocols. This solution is based on the cross-layer approach between physical and routing layer in order to increase the performance of the network. To do this, we use the SINR metric coming from physical layer to improve the AODV routing process. After that we compare our approach with the proactive protocols based on SINR metric.

The comparative study takes in consideration the effects of the simulation environment. It is implemented in shadowing model considered as a more complex compared to free space model. It considers the effect of obstructions and deviations on the received power.

The rest of the paper is organized as follow: Section 2 reviews some background and related works. Section 3 describes our solution, SINR-aware routing. Section IV is devoted to the evaluation of the comparative study of the protocols behavior. Section V concludes the work and presents future directions.

II. Related Work

In this section, we present some existing works in the literature related to our approach.

A. *Routing Metrics in Ad Hoc Networks*

Currently, there are two complementary classes of routing techniques for ad hoc networks. Proactive protocols attempt to maintain up-to-date routing information between each couple of nodes. They generally involve high overhead cost to keep all routing

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information. As a result, they are suitable for smaller networks with low mobility. Reactive routing protocols, also called on-demand routing, attempt to reduce the control overhead by discovering routes only when needed [5]. The on-demand routing dissemination provides lower overhead costs than the proactive protocols by eliminating the need for periodic updates. However, reactive protocols also experience a longer period in the route discovery process for each data transmission. Proactive routing includes OLSR [3] protocol, while AODV [4] is a reactive one.

Most of the routing protocols use the shortest path algorithm that prefers long hop and results in routes with weak links. Hence, route failures become frequent which lead to increased routing overhead due to frequent re-route discovery process.

B. Routing Mechanism Based on Physical Information Layer

Link quality assessment becomes a key feature of well performing routing protocols, in order to overcome numbers of issues rose by the wireless environment and the mobility nature of wireless equipments.

In [6], [7], the AODV protocol is extended by considering the bit error rate (BER) of each link in the route selection process. The resulting protocol named modified AODV (MAODV) leads to the selection of the route minimizing the end-to-end BER. The BER depends on the distance between the communicating nodes. This distance must be reduced to gain more performance.

Authors of [6], [7] argue that the interference problem is created when the distance between nodes is decreasing. To solve this problem, they incorporate a power control mechanism to reduce the interferences and to improve the MAODV protocol. The Fig. 1 shows the difference between the path chosen by AODV protocol and the one chosen by AOMDV protocol.

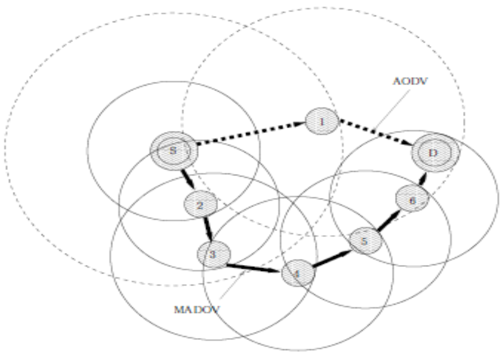

Figure 1. The difference between AODV and MAODV protocols

In [8] authors detail the significant impact of power control on the entire protocol stack above the physical layer. In addition, they summarize several studies that have been made to ensure the energy management throughout the protocol stack and demonstrate the impact of the power information on each layer. In [9] we have presented our first contribution designed by a cross-layer approach based on received signal strength (RSS) among physical and network layers. This approach permits to improve the AODV Protocol and to produce a new protocol named Aodv Power (AodvPw). In AodvPw protocol, the RSS parameter coming from the physical layer is used to compute the incurred path loss. AodvPw is based on RSS metric. It produces stable links with strong connectivity and offers the guarantee of the nearly totality delivery of the sent packets, in free space and shadowing model.

In [10] authors have carried out three cross-layer designs by sharing the Receive Signal Strength (RSS) information between physical, Mac and routing (network) layers. In the first proposal, the RSS parameter received from the physical layer is used by the network layer to compute the minimum and sufficient transmit power to obtain the energy conservation. In the second proposal, the RSS parameter is used to compute path loss incurred in order to identify and reject the unidirectional links which greatly affect the performance of AODV routing protocol in heterogeneously powered network. In the third proposal, RSS information is used to choose reliable links to form the stable routes by monitoring the signal quality to determine whether the neighbours approaching or departing. Authors of [10] have tested their approach just in the free space environment because the AODV protocol cannot give reliable results in a shodowing environment considered as a complex model.

In [11] we have presented another contribution where we have carried out a cross-layer design among physical, MAC and network layers, using RSS metric as a cross-layer interaction parameter. This proposal is based on AodvPw [9] which takes in its consideration the link quality in the route discovery process. In a first time, we integrate the minimum power in the received replay (RRep) packets of AodvPw protocol. This power will be stored in all routing tables of the nodes existing in the route chosen by AodvPw [9]. In a second time we transmit the minimum power stored in each routing table to the MAC layer in order to reduce the minimum transmission power of the Ready to Send/Clear to Send (RTS-CTS)-Data and Acknowledgment (ACK) packets. Due the environment impact on the signal strength, the simulations have been done in a shadowing propagation model. The Shadowing occurs when there are obstacles between the transmitter and the receiver. These obstacles have an impact on the received signal strength (RSS). The shadowing model extends the path loss with a probabilistic diminution based on the propagation model and the obstruction degree.

In [12], the authors improve the OLSR protocol by creating a QoS routing for ad hoc wireless networks using OLSR (QOLSR). QOLSR is QoS-aware and employs both bandwidth and delay metrics. In [13] authors develop Strongest Path OLSR (SP-OLSR) based on the SINR as routing metric to build a reliable topology graph and to improve significantly the VoIP application quality in the context of ad hoc network while maintaining a reasonable overhead cost.

III. Proposed Approach

In this work, we present a behavior comparison between the well-known reactive protocol AODV based on SINR metric named (AODV_SINR) and the proactive protocol OLSR based on SINR metric named (OLSR_SINR).

In OlSR_SINR protocol, we model the wireless network as a graph $G(N,E)$, where N is a set of nodes and E a set of links. Each link is associated with a cost, *sinr(i,j)*, the Signal to Interference and Noise Ratio, SINR, value of link (i, j). Every node calculates the SINR value of received Hello packets from its neighbors. The Hello messages are extended to include the links SINR values in addition to the list of symmetric neighbor addresses. The same extension is used for TC messages, instead of containing only the list of the MPR Selectors for SINR calculation, we adopt a similar approach to the one described in [14]. For each path (P) between the source and destination node we calculate the average SINR(P) as :

$$SINR(P) = \sum_{i,\, j \Xi P} SINR(i,\, j) \,/\, N \qquad (1)$$

The chosen Path from the source node to the destination node, is a path P that maximize the SINR(P) value.

In AODV_SINR protocol, the SINR parameter coming from the physical layer is added to packets AODV Route Request (RReq) and routing nodes table on the chosen path.

The average SINR parameter is deducted along the route from the source to the destination. The SINR calculation is indicated by equation 2. We conducted a performance evaluation by means of NS2-34 [15] simulations in a shadowing model. The new implementation of MAC (Mac802 11Ext and WirelessPhyExt) has been chosen. This model is integrated in the current version of the simulator as the complete replacement for the legacy model due to its accuracy and new features such as structure design of MAC functionality modules, cumulative SINR computation or multiple modulation scheme support. NS2-34 calculates the power of interference as the sum of all the signals on the channel other than the signal being received by the radio.It evaluates the SINR by the formula [14]:

$$SINR^{1} = \mathrm{Pr} / \,(getPowerLevel() - \mathrm{Pr}) \qquad (2)$$

where *getPowerLevel() is a function, it* represents the power of interference and noise. This function is expressed by the thermal noise at the receiver plus the sum of all the signals on the channel other than the signal being received by the radio.

Theoretically, in free space environment the value of the received signal power *Pr* of a signal is a decreasing function of the distance *d* between the transmitter node n_s and the receiver node n_r. If P_T is the transmission power, the received signal power can be modeled as:

$$P_r = P_T G_t G_r \lambda^2 \,/ (4\Pi d)^2 L \qquad (3)$$

[1] SINR is measured in WirelessPhy_Ext class added to NS2.34 version to extract physical parameters.

where. Gt and Gr are the antenna gains of the transmitter and the receiver respectively. L is the system loss, and λ is the wavelength. It is common to select Gt = Gr = 1 and L = 1 in *ns* simulations.

In reality, the received power at certain distance is a random variable due to multi-path propagation effects, which is also known as fading effects. In fact, the above model predicts the mean received power at the distance d. A more general and widely-used model is called the shadowing model. In this model P_R is experienced as :

$$\mathrm{Pr[dBm]} = \mathrm{Pr, Fs[dBm]} - 10\beta \log(d/d0) + \mathrm{XdB} \qquad (4)$$

β is called the path loss exponent, and is usually empirically determined by field measurements. Table I gives some typical values of β. Larger values correspond to more obstructions and hence faster decrease in average received power as the distance becomes larger.

TABLE I. SOME TYPICAL VALUE OF PATH LOSS EXPONENT B

Environment		β
Outdoor	Free Space	2
	Shadowed urban area	2.7 to 5
In building	Line -of -sight	1.6 to 1.8
	Obstructed	4 to 6

XdB is a Gaussian random variable with zero mean and standard deviation called σdB. σdB is called the shadowing deviation, and is also obtained by measurements. Table II shows some typical values of $\sigma_{dB.}$

TABLE II. SOME TYPICAL VALUES OF SHADOWING DEVIATION σdB

Environment	σ_{dB} (dB)
Outdoor	4 to 12
Office, hard partition	7
Office, soft partition	9.6
Factory, line of sight	3 to 6
Factory, obstructed	6.8

Pr,F s is Received power evaluated in the Free Space Model.

IV. SIMULATION AND RESULTS

A. *Simulation Scenarios*

In the behavior comparative study between the OLSR and AODV based on SINR metric, we analyze how the density and the mobility model impact the path selection process in term of packet delivery ratio and overhead. We consider two simulation scenarios:

- A simulation area of 900 × 700 $m2$ with 10, 20, 30, 40, 50 nodes randomly deployed with mobility of 10m/s.
- A simulation area of 900 × 700 $m2$ with 50 nodes randomly deployed and mobility of 2m/s, 4m/s, 6m/s, 8m/s and 10m/s.

For both scenarios, the nodes are mobile. We repeat the experiment for several seed values, in order to generate different simulation topologies (node deployment and communicating nodes). Thus, 30 different topologies are generated with the two scenarios. The parameters used in simulation are detailed in Table III.

TABLE III. SIMULATION PARAMETERS

Parameters	Value
Channel type	Wireless
Physical layer	WirelessPhy/WirelessPhyExt
Mac protocol	802.11/802_11Ext
Simulation Time	500s
Traffic Model	CBR
Packet Size	512 bytes
Mobility Model	Random way Point(Average pause time=2s)
Propagation Model	Shadowing (σdB[2] =6.8 / β[3]=2.8)
Routing Protocol	AODV, OLSR
Metric	SINR

B. *Simulation Results*

Fig. 2 indicates the impact of the node density on the performance of OLSR and AODV protocols based on SINR metric. We run the simulation by varying the node number (10, 20, 30, 40, and 50 nodes). The considered measurements have been evaluated for the random waypoint mobility model (Pause time=2 s, velocity=10 m/s) in a shadowing model.

When using AODV based on SINR metric, the Packet Delivery Ratio (PDR) increases. The AODV_SINR PDR increases from 66% with 10 nodes to 80% with 50 nodes because when there are just a few nodes, there may be not enough available paths based on SINR metric to send data. With the increment of the nodes, the chance to find an available path or even choose some best paths based on SINR metric becomes bigger. While when using the OLSR protocol based on SINR metric, The PDR decreases when the node density is increased. It varies from 63% with 10 nodes to 35% with 50 nodes. The increasing node number, involve more topology information especially with the rapid variation of the SINR. Therefore, more topology information will cost the channel source and reduces significantly the delivery ratio.

[2] The σdB value is matched to an obstructed environment as detailed in table II

[3] The β value is matched to a Shadowed urban area as detailed in table I

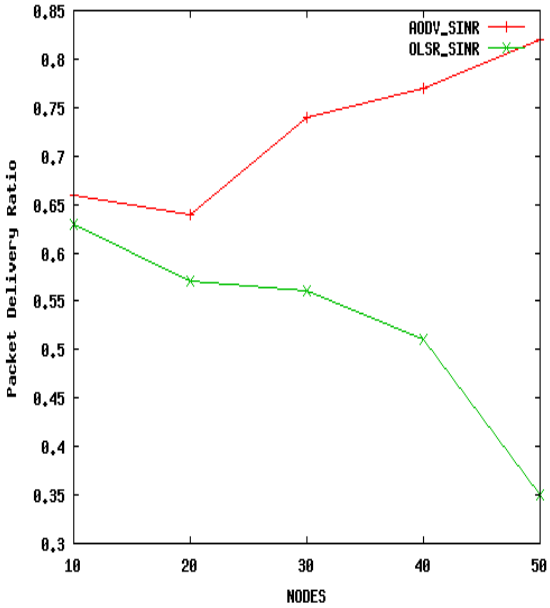

Figure 2. Impact of node density on packet delivery ratio

In Fig. 3, we plot the Packet Delivery Ratio for the Node mobility value; we can see that the increasing of maximum node mobility affects the two protocols. The PDR of the two protocols decreases when the mobility value is greater than 6M/s.

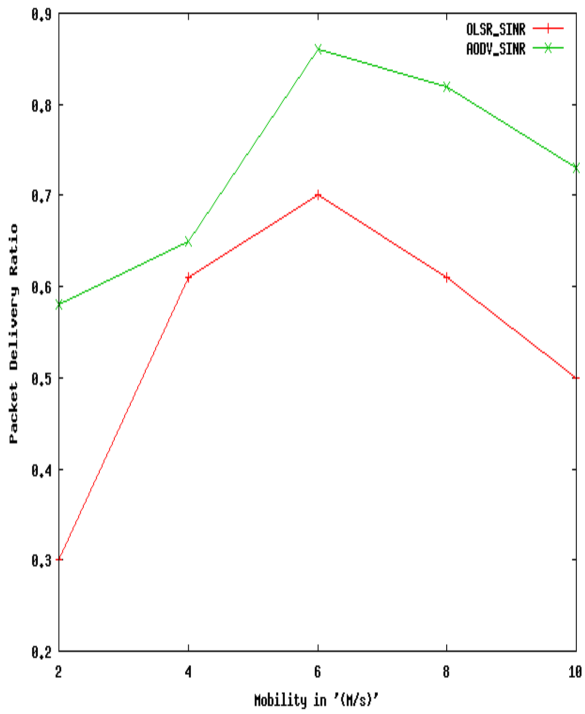

Figure 3. Impact of mobility on packet delivery ratio of the different protocol

Indeed the mobility impact, the AODV_SINR protocol reacts positively by giving the best PDR (0.70% down to 0.58%). In another case the OLSR_SINR protocol gives less PDR value compared to AODV_SINR when the mobility exceeds 6 m/s. The OLSR_SINR PDR varies (0.50% down to 0.30%).). In the shadowing model, the faster the speed is, the lower the delivery ratio is. This is understandable. When the nodes move faster and faster, the probability of breaking links becomes bigger and bigger. The nature of the environment and the mobility of the nodes have a big impact on the variation of the SINR considered as a metric of the routing process. Due to its proactive nature and to rapid variation of the SINR value, the OLSR_SINR protocol has to construct routes to all destinations in the network using new gathered topological information which impact the PDR ratio negatively compared to AODV_SINR protocol.

Finally, as illustrated in Table IV, AODV_SINR protocol has a lower routing overhead Compared to OLSR_ SINR Protocol, since links SINR values are added to the routing control messages. The highest Overhead value of AODV_SINR protocol is 4.9 Kbit and the highest overhead value of OLSR_SINR protocol is 3647.15 Kbits. Because of the rapid variation of the SINR value especially in the shadowing environment with wireless mobile nodes, OLSR_SINR involves high overhead cost to keep all routing information. It also needs quite large number of memories to keep the information. Because of the large difference of the overhead values between the two protocols, we present the overhead values on a table to illustrate the large gap between the two protocols in terms of control packets.

TABLE IV. AVERAGE ROUTING OVERHEAD FOR 500 SEC SIMULATION TIME

Nodes	Protocol Aodv_SINR(kbits)	Protocol Olsr_SINR(kbits)
10	3.11	259.22
20	1.3	764.31
30	1.8	1485,89
40	3.01	2448,64
50	4.9	3647.15

From the experiment above, we can see that AODV_SINR outperforms OLSR_SINR under different criteria like node density and mobility in terms of packet delivery ratio and overhead. AODV_SINR also shows its ability in dealing variable scenarios.

V. CONCLUSION AND FUTURE WORKS

In this paper, we have established a comparison of behavior of two protocols: OLSR_SINR and AODV_SINR protocols. We used a cross-layer approach to compute the SINR value and push it to the routing protocol. In our experiments, we extend the comparative study of the two protocols in two more criteria, mobility and node density. We have performed extensive simulations using NS-2, 34 simulator. From the results, we can see that AODV_SINR can efficiently improve the performance of the network delivery ratio in a shadowing model.

To summarize, there are two major contributions of this work: (i) We have proposed a new QoS routing metric for wireless multi-hop networks, where SINR is used to build a reliable topology, (ii) We have shown that in a shadowing environment using mobile nodes, the AODV_SINR protocol slightly outperforms OLSR_SINR protocol, with a lower routing overhead.

As part of future work, we will extend our SINR-aware routing protocol by adding other metrics that combine between the link quality provided by the physical layer and the quality of service required at the network

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