CrossAid (XAid): Towards a New Scalable Cross-Layer Architecture for MANETs

Lamia Romdhani and Christian Bonnet
Institut Eurecom,
Mobile Communications Department
lamia.romdhani,christian.bonnet@eurecom.fr

ABSTRACT

Nowadays, the cross-layer design approach, is the most relevant concept in mobile ad-hoc networks. It is obvious that designing this architecture for MANETs could be used for more than one objective such as QoS provisioning, security, and multicast transfer. In this work, we discuss trends and challenges on designing cross-layer communication protocols for mobile wireless networks. Our analysis are based on the comparison of several cross-layer mechanisms that we have introduced to improve application performance under specific scenario characteristics. Indeed, we study the simulation output obtained with and without considering layer interconnections. These results show that the performance of the inter-layer cooperation paradigm depends on the network characteristics and the application constraints. Our remarks lead to a description of a new cross-layer architecture "XAid", that aims to provide a mapping between the set of QoS requirements, network characteristics, and the appropriate basic or cross-layer protocol.

Categories and Subject Descriptors

C.2.1 [**Computer Communication Network**]: Network Architecture and Design—*network topology, wireless communication, distributed networks*

General Terms

Algorithms, Design, Performance, Reliability

Keywords

Architecture, cross-layer model, routing, quality of service, MANETs

1. INTRODUCTION

Current layered design paradigm is inflexible and suboptimal for wireless networks. A good network planning is required in order to meet the performance expectations especially when IEEE 802.11 is used with real-time applications [7]. Indeed, multimedia processing and transmission are delay sensitive that require considerable battery power as well as network bandwidth. Furthermore, the routing, mac, and physical protocols that support QoS must be adaptive and cooperative to cope with the time-varying topology and time-varying network resources.

The cooperation between layers to enable performance enhancement is very important and useful in wireless adhoc networks. The global objective of such cooperation is to achieve a reliable communication-on-the-move in highly dynamic environments as well as QoS provisioning. Numerous works have been presented in the open literature that introduce several coupling ways and solutions between different communication layers as we discussed in [4]. In this paper, we discuss the challenges of introducing cross-layer mechanisms. To this end, we compare the performance of our four inter-layer cooperation mechanisms described in [1, 2, 3, 5]. We study the impact of traffic load and network varying characteristics. Then, we address the trade off between the improvements achieved thanks to our proposals and the complexity to implement them and to exchange useful information between wireless devices. We also expose XAid (CrossAid), a novel framework for cross-layer QoS provisioning in multihop wireless networks. It includes all the cross-layer proposals. We provide a guideline for mapping user applications to the "optimal" cross-layer routing scheme according to their QoS requirements. The main feature of this new concept is that, basic layered mechanisms could be selected depending on the network characteristics.

The remainder of this paper is organized as follows. We devote section 2 for reviewing our cross-layer proposals. In Section 3, we compare the performance of the different cross-layer mechanisms and we provide a deeper analysis of the main obtained simulation results. Our new XAid architecture will be described in Section 4. Section 5 summarizes the paper and outlines the future works.

2. SHORT OVERVIEW OF OUR CROSS-LAYER MECHANISMS

We designed four cross-layer mechanisms that aim to overcome the issue of routing in MANETs while enhancing important QoS metrics (path stability, energy consumption, end-to-end delay, etc.). To this end, we extract the adequate parameters from both MAC and network layers and adapt them to provide QoS enhancement based on new inter-layer

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cooperation algorithms. As an example, we mainly focus on the enhancement of the AODV reactive routing protocol (Ad-hoc On-demand Distance Vector) and the IEEE 802.11e MAC protocol by adding the support of our proposed mechanisms [6, 9].

- **F-AODV: A cross-layer approach for efficient data Forwarding in MANETs**

F-AODV is a cross-layer forwarding strategy, which is based on the cooperation between MAC and routing protocol [2]. The proposal aims to minimize the number of Forwarding Nodes (FN) by hop, in the network. By this way, we decrease the contention amount and we improve the medium utilization. The selection of FN is based on maximum battery level and queue occupancy. These information are injected into routing requests and replies crossing nodes in the network. Then, each node is able to select the FN that will participate in path establishment. In order to maintain a fair node capability, the forwarding procedure is dynamically distributed and assigned to nodes in the network. Moreover, different weights are assigned to each node i in the network according to its load. This parameter is used to tune and adapt MAC layer parameter values, as Contention Window (CW) and TXOP duration. This leads to high medium access probability for FNs. The proposed cross-layer mechanism demonstrates a good performance, specially in term of throughput, that can be significantly improved. Moreover, it achieves a high degree of fairness among applications.

- **E-AODV: An energy consumption rate-based cross-layer routing mechanism for MANETs**

In [5], we proposed a new approach that aims to incorporate energy-related metrics in the decision of determining the optimal route between each pair of wireless devices. We described a new framework to compute a novel metric called energy-consumption rate which reflects how fast a node is consuming its remaining energy. This metric takes into account by nature the traffic load in the node and its contribution on the data forwarding process in the network. We also proposed the required modifications of the AODV routing protocol in order to make it energy-aware by considering the metric we design. As the optimal path is decided at the source side and intermediate nodes help only on providing the updated measurement of the energy metric, this scheme can be classified as source-initiated and network assisted technique.

- **D-AODV: A cross-layer routing mechanism for delay-sensitive applications**

In [1], we addressed an adaptive service differentiation based on buffer management and route establishment strategy. This proposal aims to find the best path according to application requirements in terms of delay. Each node periodically estimates the average transmission delay for each class of service. This information is injected into routing requests and replies crossing each node. The sender is then able to select the best path which ts its delay requirement. Furthermore, in order to overcome transit network characteristics due to new communications set up and mobility, we develop a new buffer management scheme for the audio class of service that aims to discriminate audio packets according to their tolerated end-to-end transfer delay and their current experienced delay.

- **S-AODV : A stability-based cross-layer routing mechanism for MANETs**

Selecting the stable path is a major challenge in MANETs. Hence, we tackle this problem by developing a new "cross-layer metric" for measuring the stability of links in MANETs [3]. We use an entropy-based technique to measure the neighborhood stability value. This metric is updated based on the measurements done in both network and MAC layers. We develop a distributed algorithm allowing to compute this metric and maintaining it up-to-date in each wireless node in the network. Incorporating this metric on routing protocols such as AODV allowing to optimize the selecting of nodes composing a path between each pair of nodes.

3. SIMULATIONS AND PERFORMANCE ANALYSIS

We implemented our proposals in the ns-2 network simulator [8]. We have extended the AODV protocol and the EDCA (Enhanced Distributed Coordination Access) scheme [6] to support our cross-layer algorithms. We compare the performance of the different inter-layer interaction mechanisms with various scenarios and network mobility patterns and we provide an analysis of the obtained results. In the first set of simulations we compare F-AODV and E-AODV mechanisms since they are based on energy and congestion parameters. In the second set of simulations, we present a comparison results of S-AODV and D-AODV. Finally, we provide a quantitative comparison of all the proposed mechanisms.

3.1 Performance Comparison of F-AODV and E-AODV Mechanisms

The objective of the next set of simulations is to compare the performance of F-AODV, E-AODV, presented in the previous section, and the basic AODV protocol. We aim to evaluate the benefits of considering inter-layer cooperation and adaptation using several network scenarios. Recall that E-AODV considers only energy rate consumption metric in route establishment scheme. However, F-AODV ensures further, MAC layer adaptation for congested nodes. We consider squared area of 1000m x 1000m. The different simulation parameters are summarized in Table 1. Each plotted point is the average of 10 simulation iterations, while the error bars represent a 95% confidence interval. We measured several significant metrics for MANETs: Packet Delivery Ratio (PDR), Routing Overhead (RO), and Average Delay (AD). We study the effect of the node density, the influence of the speed variation and the data traffic rate on the performance of the E-AODV, F-AODV, and the basic AODV protocols.

- **Impact of network density**

We illustrate, on the first set of simulations, the influence of node density (in terms of average number of neighbors per node) computed as shown in Table 1, on E-AODV, F-AODV, and the basic AODV performance.

Figure 1, shows the obtained PDR results. The general trend of all curves is a decrease in PDR with high node density. This is mainly due to higher probability of collisions and channel contention. We observe that F-AODV outperforms both AODV, and E-AODV especially at high node

Simulation time	$900s$
traffic	CBR, $4pkt/s$
Packet size	512 bytes
Mac rate	2 Mbps
Initial speed	$Sp_{min} = 5m/s$, $Sp_{max} = 25m/s$
Speed	Uniform
Density	#nodes $* \frac{\Pi * range^2}{X_{dim} * Y_{dim}}$
Range	$250m$
Simulation area	$1000*1000m$
#nodes	40, 50, 60, 70, 80
Confidence Interval	95%

Table 1: Simulation parameters

density. The improvement achieved by F-AODV, compared to AODV, is about 9% at low node density and about 14% when the node density increases. E-AODV and F-AODV exhibit similar trends at low node density. However, the obtained performance by F-AODV becomes higher than E-AODV when the node density increases. This behavior is explained by the fact that F-AODV minimizes the number of nodes that participate in communications used by F-AODV which in turn causes a low probability of contention. Thus, F-AODV can accommodate more packet delivery in this case by reducing the number of collisions using a low number of FNs. Moreover, this is a direct consequence of adapting the MAC layer parameters incorporated in F-AODV. Indeed, giving more access ability to FNs by allowing them more transmission opportunity duration (high TXOP length) and assigning them minimum CWmin and CWmax to increase the access probability to the channel.

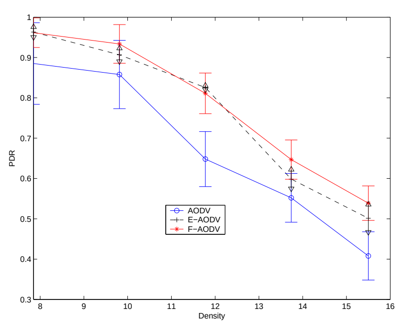

Figure 1: The effect of increasing the node density on the Packet Delivery Ratio (PDR)

Figure 2 depicts the variation of the average delay as a function of node density. The delay increases with load for all protocols. With a low node density, the lower delay is incurred by AODV protocol. However, when the node density increases, E-AODV performs slightly better than F-AODV. It is important to note that E-AODV and F-AODV still show significantly lower delay compared to AODV at high congested network.

Figure 3 illustrates the routing overhead incurred by different routing protocols. Routing overhead is an important metric to compare these protocols, since it has a direct impact on network utilization efficiency. In Figure 3, we observe that both F-AODV and E-AODV have a lower overhead in terms of bytes compared to AODV protocol. Once again, this is due to high reactiveness of F-AODV and

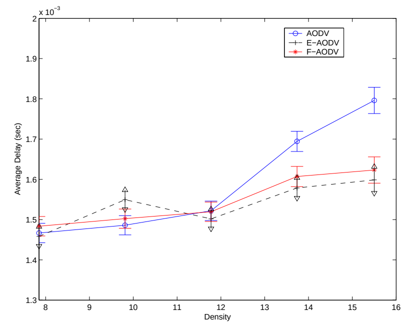

Figure 2: The effect of increasing the node density on the average delay

EAODV to link changes compared to AODV, induced by congestion and energy exhaustion. Although F-AODV provides better PDR than E-AODV, E-AODV has minimum routing overhead. In F-AODV, a large amount of packets are used for the role rotation of the forwarding process, which allows a distributed selection of the FNs and increase overhead. Moreover, F-AODV carries new parameters in control packets and hence packet size is higher.

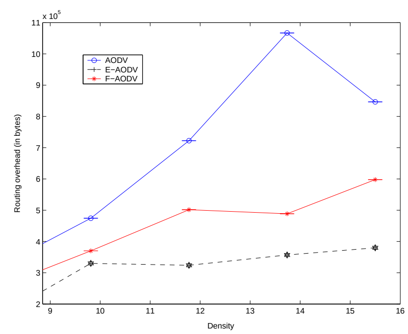

Figure 3: The effect of increasing the node density on RO

- **Impact of traffic Load**

In this set of simulations, we investigate the influence of data traffic rate on the performance of the studied protocols. We fix the number of nodes to 40 and we increase the inter-packet arrival time.

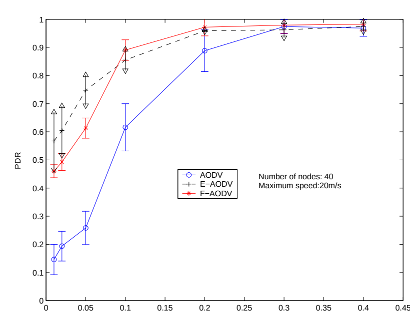

Figure 4: The effect of increasing the data rate on the PDR

Figure 4 illustrates the PDR results. With low inter-packet arrival time, which corresponds to high data rate, E-AODV and F-AODV perform better than AODV. Indeed, the improvement is about 40% for E-AODV and 30% for F-AODV, compared to AODV.

F-AODV provides the minimum delay at high data rate compared to AODV and E-AODV. Its performance becomes similar to AODV when we increase the inter-packet arrival time. Contrarily, E-AODV has a high delay as shown in Figure 5.

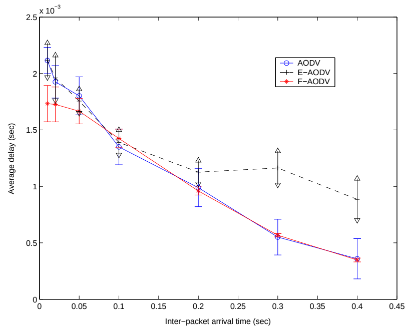

Figure 5: The effect of increasing the data rate on the average delay

The RO results shown in Figure 6, remain quite similar to those presented for the effect of node density.

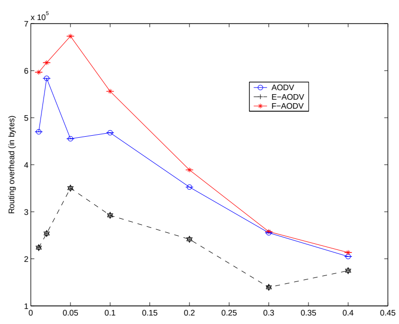

Figure 6: The effect of increasing the data rate on the routing overhead

- **Impact of node speed**

In this set of simulations, we investigate the influence of node mobility on the performance of the studied protocols. Thus, we varied the initial speed. Indeed, the increase of initial speed leads to an increase on the average speed. In return, the mobility of the network becomes high. As nodes become highly mobile, the probability of link failure increases. Consequently, the route error rate also increases. However, due to the consideration of energy metric and node load in route establishment scheme, E-AODV and F-AODV have the minimum route error rate compared to AODV. In Figure 7, we illustrate the results of routing overhead. E-AODV has the minimum routing overhead compared to F-AODV and AODV. Figure 8 shows that E-AODV and F-AODV have higher packet delivery ratio as a consequence of load balancing effect triggered by both node mobility and the use of the adaptive cross-layer mechanisms. Indeed, route failure due to power exhaustion and node congestion are avoided using our proposals. We observe that F-AODV has the higher PDR compared to E-AODV and AODV. This is due to the fact that F-AODV employs FNL, allowing nodes to use other route possibilities in case of routing failure. In return, this avoids re-starting the route discovery process.

Another interesting observation is that for the most protocols the end-to-end average delay uniformly increases from low mobility rate to medium mobility rate (see Figure 9).

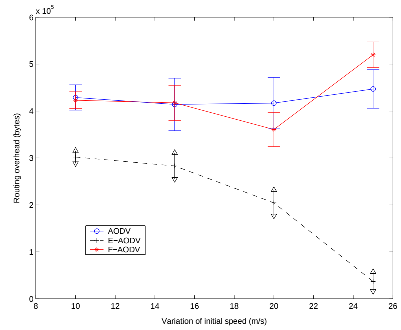

Figure 7: The effect of increasing the initial speed on the routing overhead

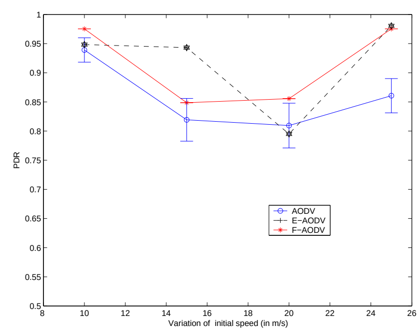

Figure 8: The effect of increasing the initial speed on the PDR

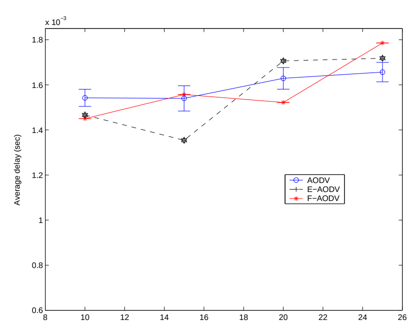

Figure 9: The effect of increasing the initial speed on the average delay

Summary

Overall, we can conclude that we have to take into account the application QoS requirements as well as the network characteristics in order to select the appropriate routing scheme that leads to better performance. Moreover, our proposals enable nodes with better characteristics (nodes that are less congested and have high energy level) to participate in the data forwarding process. Consequently, the probability of route breaks is reduced and the routing overhead is minimized. It is notable that the results in terms of average delay as function of node mobility, for the three protocols, are almost similar. One can also learn from the simulation results that in some cases (for example at low data rate), it is inefficient to count on the inter-layer parameters in route establishment scheme. Thus, we have to consider the accuracy level of the inter-layer parameters used in route establishment in order to achieve the overall performance enhancement objectives.

3.2 Performance Comparison of S-AODV and D-AODV Mechanisms

To quantify the importance of taking into account the network characteristics and the target metrics to optimize when selecting a routing protocol, we provide in this section a simulation-based analysis of the results obtained for S-AODV and D-AODV mechanisms. We evaluate the performances of these protocols under various network scenarios. The simulated scenarios consist of 50 nodes located in a uniform distribution within an area of 1500x300m forming a multi-hop network. These scenarios are generated by the enhanced random way-point mobility model [10]. The sources are CBR and generate UDP at 4 packets/second, each packet being 512 bytes. Note that the number of source nodes is 30 sources. In our simulation wireless nodes move at an average speed of 15m=s. We provide simulations for several pause time values. We compare the performance of D-AODV and S-AODV protocols using the following metrics: packet delivery ratio, routing overhead, and average end-to-end delay.

In Figure 10, we plot the mean delay of the two mechanisms. It's obvious from the curves that the mean delay is improved well when using D-AODV for the case where there is no mobility (pause time=900). Indeed, the model enables packets routing over less congested nodes. However, this good performance decreases when the node mobility increases. Hence, the S-AODV mechanism performs better in such scenario with frequent changes. D-AODV allows re-routing and refresh routes including new nodes that have better quality than in the old routes which improves the end to end delay. Moreover, we remark that the improvement on delay increases with high network mobility. Furthermore, we can also observe this difference on performance in Figure 11 and 12. Indeed, for the D-AODV scheme, the packet delivery ratio increases when the nodes are more stable. The routing overhead results obtained with this mechanism decreases when considering low mobility. These results demonstrate the importance of the adequate selection of cross-layer parameters regarding both network metrics and application requirements. On one hand, the efficiency of S-AODV is shown with high link changes. This mechanism is able to select stable routes even with mobile nodes but they follow the same movement direction. On the other hand, with D-AODV the performance improvement is obtained only when considering stable nodes.

By this comparative study, we demonstrate that cross-layer routing mechanisms could not be efficient when network characteristics change frequently given that the estimation of the QoS metrics may not be accurate.

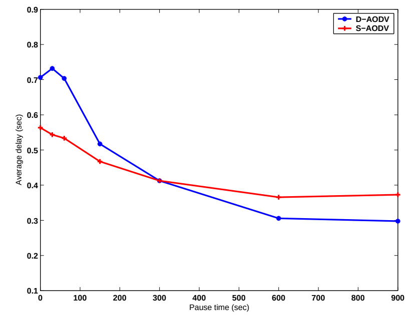

Figure 10: Results of the average end-to-end delay

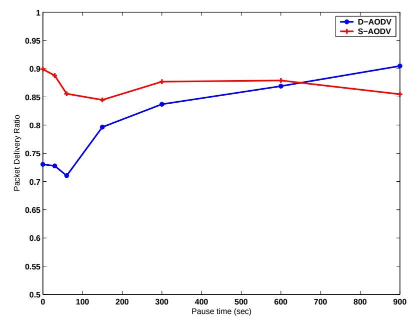

Figure 11: The results of the packet delivery ratio

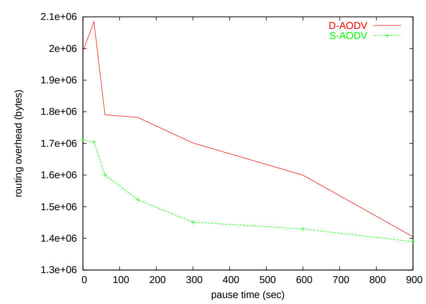

Figure 12: Results of the routing overhead

3.3 Cross-layer design: trends and challenges

In this subsection, we provide quantitative comparisons of the different proposed mechanisms described in the previous sections, regarding the basic protocols (AODV, EDCA). We summarize the results that we have extensively described in the previous subsections. Thus, we recall how much the performance of the different proposals is enhanced. Moreover, we illustrate the scenarios where inter-layer interaction is useful for routing in MANETs. Furthermore, we identify the scenarios where each routing scheme among those we have proposed (E-AODV, F-AODV, S-AODV, D-AODV) is the best to use. We define the notations that we use in our comparison in Table 2. Due to the limited space, we only present a summary of PDR and delay results.

+	minor enhancement
≃	similar performance
+ +	good enhancement
+ + +	significant enhancement
-	minor performance degradation
- -	performance degradation

Table 2: Notations used for the comparison of the proposed cross-layer routing mechanisms

Summary of the obtained Packet Delivery Ratio results

We illustrate the comparison results in terms of the Packet Delivery Ratio (PDR) for low and high traffic load scenarios in Tables 3 and 4, respectively.

Cross-layer protocols	Low mobility	Medium mobility	High mobility
E-AODV	-	≃	+
F-AODV	+ +	+ +	+
S-AODV	≃	+	+ +
D-AODV	+	-	-

Table 3: Results of the PDR for low loaded networks and with different mobility levels

Cross-layer protocols	Low mobility	Medium mobility	High mobility
E-AODV	+ +	+ +	+ +
F-AODV	+ + +	+ + +	+ +
S-AODV	≃	+ +	+ + +
D-AODV	+	-	- -

Table 4: Results of the PDR for highly loaded networks and with different mobility levels

Table 3 summarizes the PDR results of our proposals with low traffic load. A good performance improvement is observed with F-AODV at both low and medium mobility. Moreover, there is an enhancement with S-AODV at high mobility. However, there is a degradation of the performance with E-AODV at low mobility. Furthermore, the same remark is observed with D-AODV at both medium and high mobility.

As we can see in Table 4 a significant performance enhancement in terms of PDR is achieved by F-AODV especially at low and medium mobility level. At high mobility scenarios, although D-AODV performs poorly, the S-AODV protocol provides a significant PDR improvement while it maintains a similar performance as the basic AODV when considering a stable network. Moreover, E-AODV provides a good performance enhancement at all different mobility levels.

Summary of the obtained average delay results

The average end-to-end delay is only enhanced by D-AODV mechanism as shown in Table 5. A minor enhancement is observed with S-AODV and F-AODV at high mobility.

At highly loaded conditions, all the proposed protocols improve the average end-to-end delay metric (see Table 6). A significant average end-to-end delay performance enhancement is observed with D-AODV at low mobility level. A minor enhancement is achieved with the S-AODV proposal.

Cross-layer protocols	Low mobility	Medium mobility	High mobility
E-AODV	≃	-	-
F-AODV	-	-	+
S-AODV	-	-	+
D-AODV	+ +	+ +	+

Table 5: Results of the average delay for low loaded network and with different mobility levels

Cross-layer protocols	Low mobility	Medium mobility	High mobility
E-AODV	+ +	+ +	+ +
F-AODV	+	+ +	+ +
S-AODV	+	+	+ +
D-AODV	+ + +	+ +	+

Table 6: Results of the average delay for highly loaded networks and with different mobility levels

The results that we got, showed that the performance of the inter-layer cooperation paradigm depends on the network and application characteristics. Indeed, the network characteristics (as mobility pattern, congestion, lack of resources (energy)..etc.,) and the application requirements (delay, bandwidth) have to be described in order to efficiently select the appropriate cross-layer algorithm or just apply basic protocols. As an example, when considering low loaded network and stable nodes, the basic AODV protocol performs better than the inter-layer schemes. Moreover, it is not necessary to apply QoS mechanisms, when we have only communications with low priority applications.

Having proposing several cross-layer approaches for QoS-based routing in MANETs and extensively studying their performance under various scenarios, we designed a new cross-layer architecture called XAid (CrossAid). It is a cross-layer architecture for 802.11-based MANETs that incorporates all our proposals. Moreover, it may include other cross-layer mechanisms.

4. THE CROSSAID (XAID) ARCHITECTURE

Cross-layer models are mainly introduced to enhance the performance of real time applications and achieve better QoS support. However, the proposed cooperative algorithms and parameters have to be rigorously selected, compared, and optimized. In the most cases, we have to take into account the benefits of each model that provides inter-layer cooperation comparing to its complexity. Indeed, there are some proposals that compute global or local metrics which are used to make decisions for route establishment, scheduling, tuning transmission rate, etc. However, using these metrics in a cross-layer model could be not efficient because they have sometimes inaccurate values which do not reflect the real situation around a given node. Moreover, since a node moves with an arbitrary speed and toward an arbitrary destination, the computed metrics (according to the participation of the node in communication and the traffic load level around it) could change during the time. Consequently, other nodes that consider the metrics of that node, to build routes for example, could have an inaccurate information since this later change according to mobility patterns, traffic load, and links capacity. We believe that developing a cross-layer model for QoS support in MANETs has many challenges. On one hand, the modifications, which have to be added in the protocol stack and the complexity in introducing a new parameters and new algorithms to provide a good inter-layer cooperation, could introduce a high complexity risk. On the other hand, this could be very interesting given that it captures the characteristics of the capacity, the expected behavior of node load to choose the best routes between sources and destinations in a way to achieve a global traffic load balancing.

We recommend the following requirements to efciently design a QoS cross-layer model:

1. **Choosing the metrics:** choosing of a very useful and efficient metrics such as battery level, available bandwidth, and mobility rate.

2. **Computing the metrics:** the way of computing these metrics regarding one path (energy, lifetime of nodes, throughput, delay, etc.) have to be decided. The well-known approach is to minimize a cost function for a given link in the path between a source and a destination then consider the different costs computed for all links in the path. Depending on the nature of the metric, the cumulative value could be additive, concave and multiplicative. Other techniques could be also used such are variance and max-min. Computation and complexity costs should always be taken into account.

3. **Adapting metrics' values:** an adaptive method should be used to update the measured metrics: They could be updated even more when mobility increases and less in a stable network while taking into account traffic load variation and application requirements.

4. **Deciding to use or not the metrics:** As shown in Figure 13, considering the information useful for model selection, the more efficient model has to be chosen according to the two following parameters:

   (a) **Regarding to the network behavior:** in some cases, when the traffic load and its characteristics change rapidly (high mobility), it is very difficult to compute accurate values of the metrics that can be used to address QoS. Hence, the complexity of the cross-layer model becomes too high comparing to the expected performance enhancement and it is recommended in this case to use the legacy layered approach.

   (b) **Regarding to the user application:** each layer of the protocol stack responding to local variations and informations from other layers. We have to evaluate the benefits and the disadvantages of the cross layer model for each specific user application.

The XAid architecture shown in Figure 13 considers the challenges illustrated above. Each cross-layer routing scheme is used regarding the network characteristics and application requirements. The decision is made based on the analysis of the collected measurement from the network and that is stored in the bloc named information useful for architecture selection in Figure 13). This architecture is introduced not only to make a choice between layered or cross-layer architectures, but it contains implicitly the required information that we should consider to select the adequate cross-layer mechanism to use. Furthermore, XAid could consider other interaction parameters that involve other layer cooperation schemes from physical, transport and application layers.

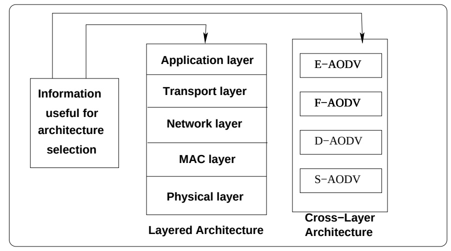

Figure 13: XAid: proposed new architecture design

5. CONCLUSION AND FUTURE WORKS

In this paper, we compared four cross-layer routing mechanisms under several performance metrics. Then, we describe a new cross-layer architecture called XAid, which implements basic protocols, inter-layer approaches and models to select the appropriate architecture for communication set-up in MANET. We believe that the decision to use which cross-layer routing mechanism is very coupled with the nature of the user application and the evolution of the network behavior.

The design of the XAid architecture is derived from an extensive simulation-based (quantitative) analysis of our cross-layer routing schemes. We believe that we could extend this analysis by a qualitative study similar to what the authors of [11] have conducted for the GRACE (Global Resource Adaptation through CoopEration) cross-layer architecture. GRACE addresses the whole device and its resources using inter-layer cooperation. Every application that wants to make use of the GRACE framework must include some kind of cost model and should allow for multiple operation points. The cost model permits to predict resource consumption over time of the running application.

6. REFERENCES

[1] Lamia Romdhani and Christian Bonnet, A Cross-Layer On-Demand Routing Protocol for Delay-Sensitive Applications", PIMRC 2005, Berlin, September 12-15.

[2] L. Romdhani and C. Bonnet, A cross-layer feature for an efcient forwarding strategy in wireless ad hoc networks, AINA 2006, 20th IEEE, Vienna, Austria.

[3] L. Romdhani and C. Bonnet, A cross-layer stability-based on-demand routing protocol for mobile ad-hoc networks, IWWAN 2005, May 23-26, London, U.K.

[4] L. Romdhani and C. Bonnet, Cross-layer's paradigm features in MANET: benets and challenges, PWC 2005, August 25-27, Colmar, France.

[5] L. Romdhani and C. Bonnet, Energy consumption speed-based routing for mobile ad hoc networks, WWAN 2004, March 23-26, Tokyo, Japan.

[6] IEEE 802.11e WG. MAC Enhancements for Quality of Service (QoS), IEEE Std 802.11e/D9.0. August 2004.

[7] IEEE 802.11.Standard 802.11: Wireless LAN MAC and PHY Speci cations. 1999.

[8] Network Simulator-2. www.isi.edu/nsnam/ns/.

[9] Perkins, Ad hoc on demand distance vector (AODV) routing, IETF, RFC 3561.

[10] RandomTrip: http://icawww1.ep.ch/RandomTrip/.

[11] S. V. Adve et al., The Illinois GRACE Project: Global Resource Adaptation through CoopEration, SHAMAN workshop, June 2002.