Energy-based routing optimization in MANET: Cross-layer benefits

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Abstract

Obviously, the energy is one of the important metrics to consider when designing communication protocols for Mobile Ad hoc NETworks (MANETs). In this paper, we *demonstrate the importance of considering energy saving in MANETs. Our analysis are based on the comparison of two energy-based mechanisms called E-AODV, an energy consumption rate-based routing protocol, and F-AODV, a cross-layer-based routing protocol. We investigate the trends and the challenges on designing cross-layer communication protocols for MANETs. Indeed, we study the simulation output obtained with and without considering layer interconnections. These results show that the performance of the layer cooperation paradigm depends on the network characteristics and the application constraints. Our remarks lead to a description of a guideline and recommendations for addressing layer interaction in MANETs.*

***Keywords**: mobile ad hoc networks, energy consumption, cross-layer design, and quality of service.*

1 Introduction

Some scenarios where MANET could be used are business associates sharing information during a meeting, military personnel relaying tactical and other types of information in a battlefield, and emergency disaster relief personnel coordinating efforts after a natural disaster such as a hurricane, earthquake or flooding. Mobile nodes rely on batteries for proper operation. The depletion of batteries in these nodes will have a great influence on overall network performance. In such scenarios, maximizing the network lifetime by using the nodes with the maximum residual energy (lifetime) is a very important challenge since recharging battery is very difficult (hard) to do in such conditions. Therefore, one of the most important routing protocol design factors is related to device energy conservation.

The cooperation between layers to enable performance enhancement is very important and useful in wireless ad-hoc 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 [2].

In this paper, we discuss trends and challenges of introducing cross-layer mechanisms. Indeed, we describe and compare the performance of two energy-based routing protocols for MANET. The first algorithm called **E-AODV,** includes only new features to the routing selection procedure [3]. It is an energy consumption rate-based mechanism that aims to maximize the network lifetime and enhance the performance obtained by the basic AODV (Ad hoc On-demand Distance Vector) routing algorithm [7]. The main goal of E-AODV mechanism is routing the packets through the nodes which we expect to have the better residual lifetime among all possibilities. However, the second mechanism called **F-AODV**, suggests to collaborate the routing and the MAC modules in order to optimize the data forwarding in MANETs [1].

The extensive set of simulations that we have done with various network characteristics to compare E-AODV and F-AODV to the basic AODV routing protocol, show that a good network planning is required in order to meet the performance expectations especially when IEEE 802.11 is used with real-time applications [5]. Indeed, multimedia processing and transmission are delay sensitive that require considerable battery power as well as network bandwidth. Furthermore, the routing and the MAC protocols that support QoS must be adaptive and cooperative to cope with the time-varying topology and time-varying network resources.

The remainder of this paper is organized as follows. We devote section 2 for reviewing our routing proposals. In Section 3, we compare their performance and we provide a deeper analysis of the main obtained simulation results. Section 4 gives a list of recommendations on using cross-layer based routing protocols. Section 5 summarizes the paper.

2 Short overview of our energy-based routing mechanisms

We designed two energy-based 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.). As an example, we mainly focus on the enhancement of the AODV reactive routing protocol and the IEEE 802.11e MAC protocol by adding the support of our proposed mechanisms [4, 7].

Due to the limited space, we only give the main features of the proposals. More detailed descriptions are presented in [1, 3].

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

In [3], 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.

2.2 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 [1]. 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 w_i 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 Transmission Opportunity ($TXOP$) 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.

A ns2 simulation-based comparison of the described proposals is given in the next section. We aim to identify the scenarios where sharing useful parameters between different layers is quite recommended to enhance the routing of packets.

3 Simulations and performance analysis

We implemented our proposals in the ns-2 network simulator [6]. We have extended the AODV protocol and the EDCA (Enhanced Distributed Coordination Access) scheme [4] to support our cross-layer algorithms. We compare the performance of F-AODV and E-AODV mechanisms with various scenarios and network mobility patterns and we provide an analysis of the obtained results.

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), Average Delay (AD), and Route Error Rate (RER).

We study the effect of the node density, the influence of the initial 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. The corresponding results are presented in Figures 1, 3, 2, and 4.

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

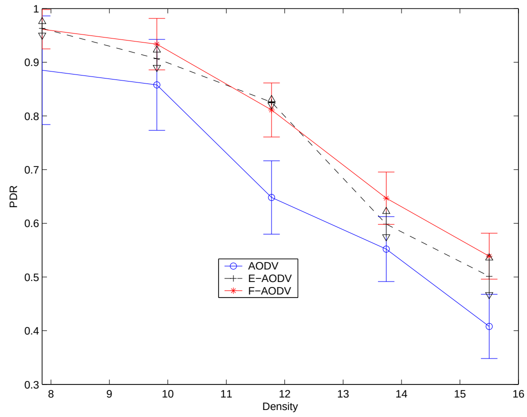

Figure 1: The effect of increasing the node density on the PDR

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 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. Furthermore, due to load balancing effect triggered by the features of the algorithms that use E-AODV and F-AODV, their associated performance remain significantly high compared to the basic AODV protocol. This indicates the robust nature of the protocols and their ability to adapt themselves to increasing load. The AODV protocol uses minimum hop count as metric. These results are an inherent bias toward the same routes involving to congestion.

A similar observation can be done in Figure 2, where we depict the Route Error Rate (RER) results. We observe that F-AODV has the minimum RER compared to AODV and E-AODV.

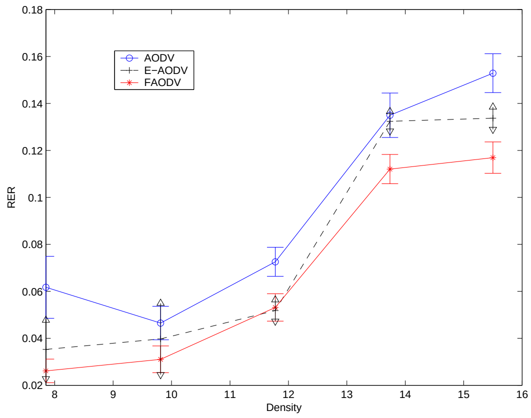

Figure 2: The effect of increasing the node density on the RER

In 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 E-AODV 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.

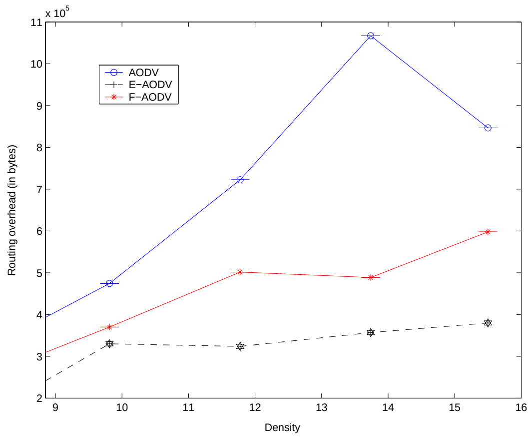

Figure 3: The effect of increasing the node density on RO

The average end-to-end delay includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at the MAC, propagation, and transfer times. Generally, there are three factors affecting end-to-end delay of a packet: first the route discovery time, which causes packets waiting in the queue before a route is found, second congestion state of the network, which causes packets waiting in the queue before they can be sent, and finally the path length. The more number of hops a packet has to go through, the longest time it takes to reach its destination.

Figure 4 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

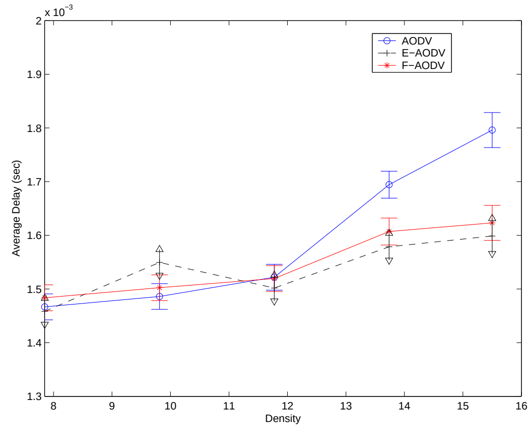

Figure 4: The effect of increasing the node density on the AD

E-AODV and F-AODV still show significantly lower delay compared to AODV at high congested network.

- **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.

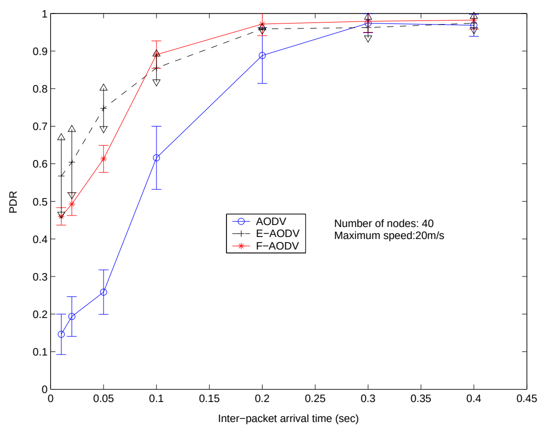

Figure 5: The effect of increasing the data rate on the PDR

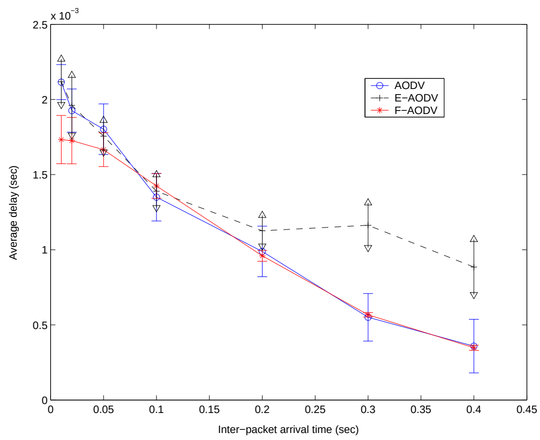

Figure 6: The effect of increasing the data rate on the AD

Figure 5 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

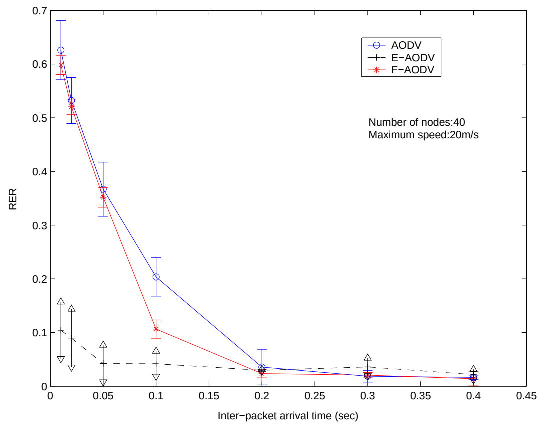

Figure 7: The effect of increasing the data rate on the RER

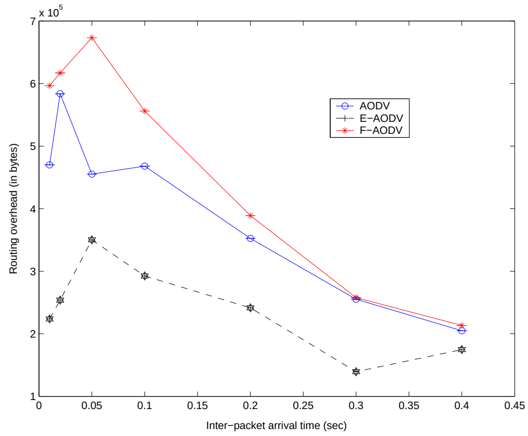

Figure 8: The effect of increasing the data rate on the RO

AODV. When we decrease the data rate, the three protocols have approximately the same performance. However, 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.

Figure 7 depicts the RER results. At high load, E-AODV has the lower RER compared to F-AODV and AODV. However, the results on RER of the three protocols are similar when we increase the inter-packet arrival time. The RO results shown in Figure 8, remain quite similar to those presented for the effect of node density.

- **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 [8].

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 as shown in Figure 9. In Figure 11, we illustrate the results of routing overhead. E-AODV has the minimum routing overhead compared to F-AODV and AODV. Figure 10 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

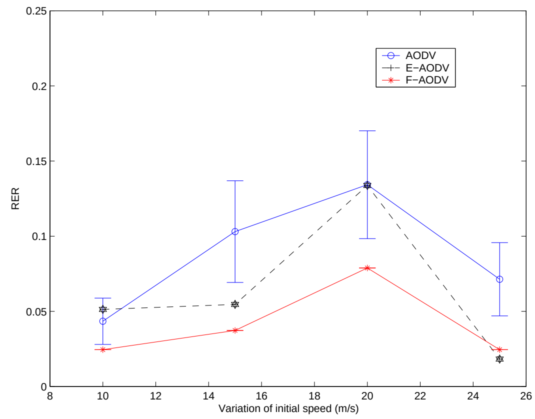

Figure 9: The effect of increasing the initial speed on the RER

exhaustion and node congestion are avoided using our proposals. We observe that F-AODV has the lower RER and the higher PDR compared to E-AODV and AODV. This is due to the fact that F-AODV employs FNL(FN List) [1], allowing nodes to use other route possibilities in case of routing failure. In return, this avoids re-starting the route discovery process.

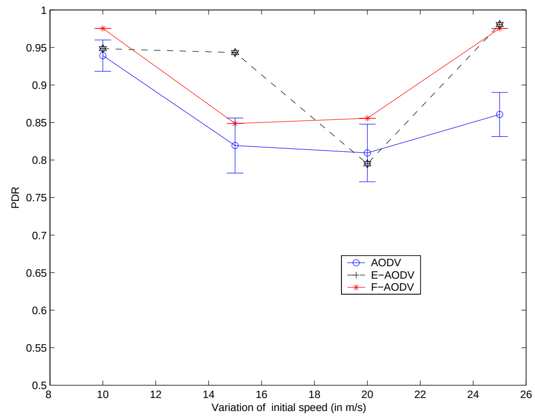

Figure 10: The effect of increasing the initial speed on the PDR

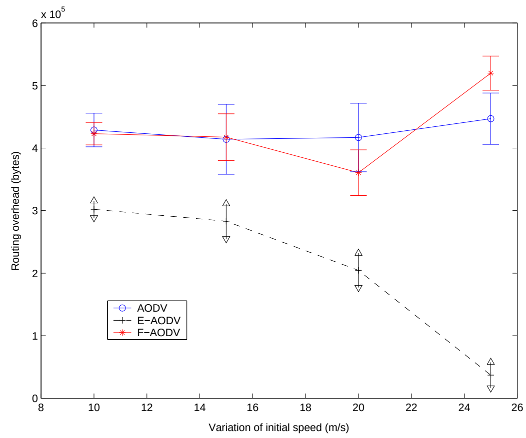

Figure 11: The effect of increasing the initial speed on the RO

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 12).

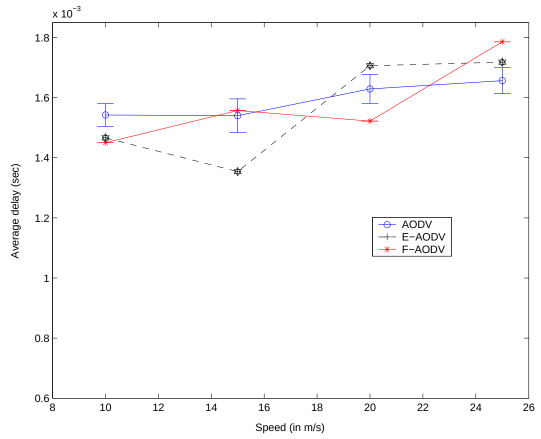

Figure 12: The effect of increasing the initial speed on the AD

4 Discussion

The immediate remark that we can observe from the analysis presented above, is that both E-AODV and F-AODV which is based on MAC and network layers' cooperation provide a QoS enhancement in terms of packet delivery ratio (PDR) especially at high node density compared to the basic AODV routing protocol. On the other hand, the MAC layer adaptation scheme used by F-AODV enables a higher improvement of the PDR compared to E-AODV. Furthermore, we see a significant enhancement in terms of the average end-to-end delay at high node density. However, a slight improvement of this metric is observed at high data rate. However, the E-AODV mechanism has the higher average delay compared to the basic AODV and F-AODV at low data rate.

Although the mobility causes frequent link failure, it allows diversity and load balancing. 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 also notable that the results in terms of average delay as function of node mobility, for the three protocols, are almost similar.

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. Indeed, we can learn from the simulation results that in some cases it is inefficient to count on the inter-layer parameters in route establishment scheme. As an example, when considering low loaded network and stable nodes, the basic AODV protocol performs better than the E-AODV and F-AODV mechanisms. Moreover, it is not necessary to apply QoS mechanisms when we have only communications with low priority applications.

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.

5 Conclusion

In this paper, we compared two energy-based routing mechanisms under several performance metrics. We investigate the impact of using cross-layer adaptation . The simulation results demonstrate the benefits of layer interaction and adaptation on the application performance. Indeed, this cooperation 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. However, 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, usually introduce a high complexity risk. On the other hand, this may be useful to have knowledge about neighbor density and "quality" to adapt transmission rate and to use scheduling strategies in an efficient manner.

Thus, we have to establish whether cross-layer paradigm is suitable for all types of wireless networks and applications or not. Hence, 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. Thus, the very promising cross-layer design model consists in maintaining the layer isolation in the protocol stack while enabling a cross-layer interaction according to network and traffic characteristics. Unless, the complexity of the new architecture could be expensive and inefficient regarding to minor performance enhancements as we have shown in the compared examples that we evoked in this paper.

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