Cross-layer's Paradigm Features in MANET: benefits and challenges

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Abstract

Nowadays, the cross-layer design approach, is the most relevant concept in mobile ad-hoc networks which is adopted to solve several open issues. It aims to overcome MANET performance problems by allowing protocols belonging to different layers to cooperate and share network status informations while still maintaining separated layers. The central key of related research studies is what information can be shared and how it used in cross-layer architecture to provide QoS enhancement and enable an efficient resource utilization. In this work, we detail the most coupling features of introducing cross-layer models in mobile ad hoc networks. Then, we discuss the risks and the challenges facing this new architecture.

Keywords: mobile ad hoc networks, cross-layer design, quality of service.

1 Introduction

Ad hoc networks have many characteristics that meet a lot of node heterogeneity. A fundamental issue in such multihop wireless environments is that network performance can degrade rapidly as the number of hops increases. Major problems to transmit data over available radio channels exist in every layer of the protocol stuck. In one hand, adaptive rate selection, adaptive antenna pattern, adjust power control are issues of the physical layer. In the other hand, the link reliability, the admission control, and the access control to the shared channel are some issues of both routing and MAC layers. Moreover, there are several real-time application requirements that have to be respected in order to provide QoS support and achieve service differentiation.

In the past, a lot of research have been conducted to address these issues separately. One new research direction to optimize data transfer in ad hoc networks is the cross-layer design without respecting the original layered design approach in which each layer operates independently. The layered approach is simple, flexible, and scalable as the case in the Internet, but it led to poor performance in ad hoc network even with the optimization applied to the evolved protocols because they are no taking into account network and application constraints. For example, each layer have to react in route failures and collisions in its own way and there are no coupling of different layer informations to meet some parameters in order to address a good coordination of the efforts satisfying as well as possible the application requirements. Another example showing the importance of cross-layer design is when a MAC layer tries several times to transmit a packet to a destination which is out of its transmission range. In this case, if the network layer informs the MAC layer that the destination is unreachable, the useless frames retransmissions could be avoided.

As conclusion, the co-operation between layers to enable performance enhancement is very important and useful in wireless ad hoc networks. The global objective of such co-operation is to achieve a reliable communication-on-the-move in highly dynamic environments as well as QoS provisioning.

In this paper, we review the parameters that should be provided by each layer to other layers in order to improve the global performance. In some cases, specific processing should be done by intermediate layers to present the parameters to other layers in a comprehensive and understandable way. Lot of works have been presented in the open literature that introduce several coupling ways and solutions between different communication layers [10, 12, 17, 1, 15, 5]

The remainder of this paper is organized as follow: In Section 2, we discuss the problems of accommodating a good service for each layer in the layered approach going from the physical layer to the application layer. We also identify the most important parameters in each layer to be managed in a cross-layer architecture. Then, we review the most works that have been conducted to study the cross-layer design in mobile ad hoc networks in Section 3. In Section 4, we outline our observations that lead to fix the potential risk of cross-layer design in MANET. Then, we give our recommendations on how a cross-layer architecture should be designed in an efficient and scalable manner in Section 5. We conclude the paper in Section 6.

2 Limitations of Layered Approach in MANET

As it is well known, networks are organized as a series of layers, each one built upon the one below it. The goal of this architecture is to split the network into smaller modules with different functionalities and deal with more manageable design and implementation. The purpose of each layer is to offer certain services to the higher layers, shielding these layers from the details of how the services are implemented. So the advantage behind the layered protocol architecture is to reduce complexity by dividing and conquering approach. This simplicity ensure an easy way to standardize, and to deploy new flexible protocols (easy upgradeable). However, wireless networks don't come with links. The channel quality changes dynamically. The applications require a minimum of QoS that could not be achieved in such very dynamic capacity networks. Hereafter, we analyze the problems related to each layer and we give an overview of the characteristics and QoS metrics of each layer.

2.1 Limitations Related to Physical Layer's Characteristics

The wireless channel varies over time and space and has short-term (or small-scale) memory due to multipath. The channel variation meets the amount of contention, time-varying fading, multi-path, variation of the SNR. Indeed, these variations are caused either due to motion of the wireless device, or due to changes in the surrounding physical environment, and lead to detector errors. This causes bursts of errors to occur during which packets cannot be successfully transmitted on the link. Fast channel variations due to fading are such that states of different channels can asynchronously switch from good to bad within a few milliseconds and vice-versa. Furthermore, very strong forward error correction codes (i.e. very low rates) cannot be used to eliminate errors because this technique leads to reduced spectral efficiency. In addition to small-scale channel variations, there is also spatio-temporal variations on a much greater time-scale. Large-scale channel variation means that the average channel state condition depends on user locations and interference levels. Thus, due to small-scale and large-scale changes in the channel, some users may inherently demand more channel access time than others based on their location or mobile velocity, even if their data rate requirement is the same as or even less than other users. The techniques that may be used to adapt to rapid SNR changes in wireless links and mobility include: power control, multiuser detection, directional antenna, adaptive modulation and software radio. However, sharing these informations with high layers, has a big benefits on performance as shown in [2, 19, 8]. For example, characterizing the application requirements help to use the adaptive modulation, the knowledge of channel quality help to avoid useless MAC retransmission..etc.

2.2 Limitations Related to MAC layer's Characteristics

Due to the high difference between transmitted and received power levels, traditional random channel access mechanisms used in wired networks as CSMA/CD are not applicable in wireless networks. To deal with this problem, contention based random-access multiple access protocols have been commonly used since they are simple to implement. To further increase the efficiency of the operation, carrier sense based MAC algorithms are used, requiring the mobile terminal to first sense the channel to determine that it is idle and only then attempt its packet transmission. The latter attempts can still results in a collision event (when the intended receiver detects multiple transmissions at such power levels that it may not be able to correctly receive any of them). CSMA-based MAC protocols can yield an efficient operation (under proper loading levels) when the carrier sensing operation is spatially effective. Unfortunately, stations may be geographically located in a manner that induced blocking, leading to masked terminal scenarios. In this case, two major problems have been identified: hidden terminal and exposed terminal conditions. Despite of introducing RTS/CTS handshaking scheme, leading to the Multiple Access Collision Avoidance (MACA) protocol [18], the MAC layer still suffers from the problems of interference resolution, exposed terminal, efficient medium utilization. Indeed, the optimal strategies of resource sharing issue among different classes of users, still the main challenge also for the FDMA, TDMA techniques.

2.3 Limitations Related to Routing Layer's Characteristics

The functions of the network layer are to provide (IP) addresses to end hosts, and set up routes between sources and destinations. Routing protocols for ad hoc networks require to consider the reasons for link failure to improve its performance. Link failure stems from node mobility and lack of network resources. Therefore, it is essential to capture the aforesaid characteristics to identify the quality of links. Furthermore, the routing protocols that support QoS must be adaptive to cope with the time-varying topology and time-varying network resources. For instance, it is possible that a route that was earlier found to meet certain QoS requirements no longer does so due to the dynamic nature of the topology. In such a case, it is important that the network intelligently adapts the session to its new and changed conditions. So, the goal of QoS routing is to optimize the network resource utilization while satisfying application requirements. Indeed, it is not enough to find a shortest path but also with available resources as battery, bandwidth, and buffer. Note that the factors that can change the topology of an ad-hoc network are: the mobility of nodes, change of power, the MAC layer mechanism because different schedule for the contending nodes, results in different topology, the flow dynamics that flows come and go; if a node has nothing to transmit, its links are gone from the topology, and finally the mode of nodes: sleeping or active mode. If a node goes to a sleeping mode, its links are gone from the topology and hence it can't participate to route establishment and communication.

The network layer requires to identify the different routes parameters and shards it with the other neighbors. This helps to use efficiently the links and establish paths with an economic manner that takes into account the changes in the network topology and resources. However, efficiency and fast convergence rate are two conflicting objectives. It is hard to achieve the trade off between communication overhead and computation effort. The more routing information distributed, the less computation required at each node. So, there are three main functions of the network layer: provide (IP) addresses to end hosts, set up routes between sources and destinations, pro-actively (routes ready-to-use) or reactively (routes on-demand). To set up a route, we need route discovery; to make routes ready to use, we need route maintenance. Within these functions, there are several objectives that have to be achieved: the efficiency that consists in minimizing signal overhead in route discovery and route maintenance and minimizing convergence time. Furthermore, providing routes that support requested QoS is very important. Then, make sure if the protocol is scalable that's mean whether the network is able to provide an acceptable level of service to packets even in the presence of a large number of nodes in the network. Finally, introduce energy efficiency in route establishment.

2.4 Limitations Related to Transport Layer's Characteristics

TCP combines error control (ARQ), flow control that are not over-running the receiver buffer, and congestion control that is not clogging the network, and not overloading the capacity in the routers. Moreover, TCP enjoys simplicity of control and gains widest acceptance. However, this simplicity of control is at the cost of efficiency loss. TCP is not able to distinguish the presence of congestion in wired networks, mobility, collision in wireless links, and bit errors due to poor quality of wireless links. Single bit error could trigger congestion control mode (TCP getting into slow start phase); even fast retransmit/fast recovery is not effective in coping with packet/bit errors. So, TCP needs to handle delay (RTT) and packet loss statistics that are very different from those in wired networks.

2.5 Energy conservation

Some scenarios where an ad hoc network 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. In fact, in such scenarios, maximizing the network lifetime is a very important deft since recharging battery is very difficult (hard) to do in such conditions. Indeed, the network connectivity is strictly related to the possibility of routing between each node in the network. The goal behind is to minimize the energy consumption while maintaining the existing of routes between nodes.

Moreover, energy conservation is used in power control mechanism by reducing transmission range in order to decrease contention amount while allowing topology control [11, 17]. The energy exhaustion problem leads to network disconnection and resource unavailability problems.

2.6 Limitations Related to Application Layer's Characteristics

There are some application's requirements that should be considered in order to maintain as good as possible the performance and offer a minimum service delivery according to their constraints. Indeed, there are time-bounded applications that are sensitive to delay and others require high throughput and/or less packet loss rate. For example audio traffics should reach destinations at most up to 400 sec. The corresponding packets are almost short. They could have the highest priority: minimum waiting time in the queue, and so short medium access time (e.g. short contention window size). Moreover, they require short and less congested routes to reach destinations within a short delay. Throughput-constrained applications require less congested routes and available queue to enqueue packets. Hence, successful transmission should be assured and they are less sensitive to delay comparing to above described class. TCP traffics are very sensitive to both packet loss and delay. Background traffic should not be starved and so a minimum service has to be guaranteed.

The key question is how to adapt physical layer parameters, distribute fairly the access to the medium and achieve an efficient bandwidth sharing while providing service differentiation and application requirements with the less possible complexity?

In the next Section, we describe how these problems and information, related to each layer, are exchanged over the different protocols in the layered stack in order to address cross optimization and QoS provisioning. Hence, we discuss the most various cross-layer approaches that have been proposed in the literature.

3 Review and Discussion of Cross-Layer Proposals

Each layer of a stacked set of modules maintains an independent set of statistics for error conditions and performance metrics. When a problem occurs, it may manifest itself as aberrant statistic values in multiple layers in the system. In classical systems, there is no logic that correlates these aberrant statistic values across different system layers. This lets thinking about alternative solution as cross-layer design. The main feature of the proposed studies in the literature is the determination of what information could be shared and how is it used in a cross-layer architecture to provide QoS enhancement and enable an efficient resource utilization? Hereafter, we describe some examples of cross-layer integration for ad-hoc networks.

3.1 Physical layer + MAC

- Adaptive modulation and MAC

A cross layer networking system is described in [4]. The paper proposes a coordination between routing, MAC, and physical layers. Indeed, the scheme consists of considering three signal strength attenuation factors, namely, path loss, shadowing and multi-path fading. The authors suggest that for channel-adaptive protocols, a good time-varying channel model is needed for simulation. So, a correlated shadowing channel model is proposed. At MAC layer, a rate adaptation scheme is described. The RTS,CTS and ACK packets are sent at nominal rate. When a node receives the RTS packet, it estimates the SNR. Then, the transmission rate is mapped from the estimated SNR, and appended to the CTS packet. So, the sender transmits data at the adapted rate. An M-QAM scheme is used in which the constellation size changed with SNR. At routing layer, the source node considers the MAC delay of every RREP packets and chooses the route with min delay. The RREP packets are unicast packets to the source node using rate adaptation based on the SNR information along the route. However, no rate adaptation is used in RREQ packets. The routing decision is made based on three metrics. The first one is the bandwidth that represents the rate of link between node i and j. The second one is the interference duration that is the interval from the when the RTS packet is sent to when the data packet is received. The third one, is the congestion that is the queuing delay in the buffer of transmit node.

- Adaptive power control and MAC

There are several works that integrate adaptive modulation, MAC functions, and routing metrics to introduce cross-layer cooperation. Note that, adaptive modulation needs channel estimation: When channel is good (high SNR) that means higher order modulation and so, higher rate. The metric of channel estimation link gain is used in [2]. The proposed solution is based on MAC and physical layer cooperation. It estimates the channel using RTS packet and transmit the information using the CTS packet. Then, an adaptive power control mechanism is described according to the obtained information from MAC layer. The used system model considers n nodes in ad-hoc network. All nodes share the same frequency bands: TDMA or TDMA/CDMA, and one hop transmission (no routing) is considered. The interference is reduced by scheduling and power control. In the first step, the MAC layer scheme has to determine the optimum set of scheduled users. This decision changes according to the propriety of MAC layer: The simple TDMA eliminates self interference half duplex transmissions. This criteria is the same for TDMA/CDMA. Moreover, a node cannot receive from more than one neighbor simultaneously. Furthermore, a receiving node should be spatially separated from any other transmitter by at least a distance D that leads to spatial separation. Note that this later criteria doesn't mandatory for TDMA/CDMA. So, the D parameter greatly influences the amount of interference suppression: If we have low D, more users are selected in the valid set, but a lot of interference must be managed by the power control. The drawback is that power control may not be feasible. If we have high D, there are less users scheduled and so easier job for the power control. However, the scheme may be too conservative higher delays resulted from scheduling because of only these users can run the power control algorithm. In the second step, the power control mechanism optimizes the power allocation among different users. If we have few scheduled users, the MAC layer does not re-optimize its selection based on information from the physical layer ,the loop is not closing. Concluding this work, we mention that the main challenge is to select the optimum valid subset of users that gives the maximum number of users in a valid configuration. Indeed, the optimal solution presents an exponential complexity in the number of users that leads to a combinatorial optimization problem. The suboptimal solution selects the users sequentially and decides if they can be added or not to the valid subset. This solution could lead to deferring more transmissions than needed. Moreover, we have the same problem for the optimum admissible set: If power control is not convergent how to determine the optimal subset of users that leads to convergence? This is an exponential complexity NP hard problem. The suboptimal solution is to defer transmission for the user having the minimum SIR (or SINR signal to interference + noise ratio).

3.2 Physical layer + MAC + routing

- Adaptive beamforming + MAC + routing

The above discussed research works were not specifically consider routing. In general, MAC protocols differ based on: How RTS/CTS, is transmitted (omni, directional), transmission range of directional antennas, channel access schemes, and omni or directional NAVs. Furthermore, the antenna gains are different for omnidirectional (Go) and directional transmission (Gd): Gd > Go. Moreover, if an idle node listens omnidirectionally, it does not know who is going to transmit to it. The directional antennas provide a good spatial reuse, higher gains and better links. However, higher gains mean also high interference at distanced nodes. There are three types of links. The first type called Omnidirectional Omnidirectional (OO) which is characterized by smallest range. The second is Directional Omnidirectional (DO) links usually used in the protocols discussed up to now because the node listens omnidirectionally. The third type is Directional Directional (DD) which has the largest range and so the least number of hops. However, the problem is that the nodes listen omnidirectionally. In [19], the proposed mechanism describes a cooperation between adaptive beamforming, MAC, and routing. The scheme uses the same MAC for directional antennas, but transmits RTS over multiple hops (MMAC protocol). If source 1 (see Figure 1) wants to communicate with node 6. It transmits a forwarding RTS with the profile of node 6, using DO links. Then, when node 6 gets the RTS, it beamforms in the direction of 1, forming a DD link. Moreover, the transmission from 1 to 9 on DD links requires only 2 hops. The presented network performance results depend on the simulated network topology. There are several cases that were studied: Manhattan networks with aligned routes, Manhattan networks with random routes, and Random configuration. For all three cases, the numerical parameters chosen are: Antenna beamwidth equal to 45 Omnidirectional, transmission range equal to 250 m, Directional transmission range (DD link) equal to 900 m. The performance measure only average throughput. It shows that in general MMAC, better than DMAC, better than 802.11. However, when the routes are aligned, using MAC and directional antennas degrades the performance, compared to the case with omnidirectional antennas (802.11). For Manhattan networks, more directional interference occurs, due to the aligned paths. The gain is more if we can actually exploit the spatial reuse property of the directional antennas. If not, the performance will be worse because of the increased directional interference (higher gain for the directional antennas).

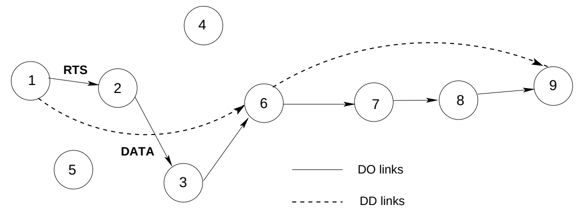

Figure 1: example for cross-layer scheme work

- Power control, scheduling, routing

The cross-layer approach introduced in [7], is presented at four levels: First, the proposed adaptive MAC protocol is sensitive to contention. Second, influence of network layer FIFO queuing on better bandwidth utilization. Third, importance of transmission scheduling. Fourth, routing and power control interactions.

Firstly, the authors study the effects of queue management, routing protocol, power control, and medium access mechanism on the capacity of the networks. Based on a novel frame format based loosely on the CSMA/CA protocol and TDMA, a contention slot is splitted into m mini-slot pairs (slotting is done at a much finer level). These contention intervals finally result in a *(src,dst)* pair agreeing to exchange data during the data slot portion of the frame. The duration of a mini-slot pair depends on several parameters, but as described in the paper it is equal to 80 micro-seconds. In the proposed Progressive Back Algorithm (PBOA) Protocol, nodes contend during every contention period. Unsuccessful nodes progressively backoff during progression of contention period. Successful nodes use remaining contention interval to discover minimum power needed to transmit their data. There are two benefits of this approach: the first that energy conservation is enhanced because of tuning transmission range as possible. The second benefit is that both interference and collisions are reduced thanks to the proposed backoff procedure. The PBOA performance is much better than CSMA/CA in throughput, power. But, in PBOA nodes can still waste contention time by transmitting an RTS to a node who has already sent a CTS to another originator.

The PBOA's authors proposed a second algorithm called Progressive Ramp Algorithm (PRUA). In PRUA, nodes monitor the channel for favorable conditions and send an RTS with some probability p at the beginning of the next RTS minislot. If the transmission succeeds, the node continues to send RTS packets to notify others to backoff, otherwise it backs off and tries again at a later RTS minislot. No transmitter power control mechanism was used. The benefits of this approach is that it does not obey to FIFO queuing, so that the best reachable destination has a high chance to receive its packets. PRUA employees carrier sense but it is tuned to detecting CTS and hence nodes will avoid extra RTS transmissions and unnecessary interference and collisions experienced by PBOA. The simulation results show that PRUA has better uniform capacity than PBOA as well as delay and throughput, but lack of power control costs more energy.

The performance of these interactions depends on several constraints. Indeed, The cost of packet control overhead and packet lost could be more significant than the performance improvement in an arbitrary mobile node in a particular scenario. The key observation is that the protocol performance looks worse than some optimal choices because these two protocols are distributed and hence require global knowledge to schedule their transmissions which is hard to achieve in a very high mobile and distributed networks.

3.3 MAC + Routing + network layer

- MAC utilization+Interface queue+reactive routing protocol

In *[20],* the authors propose a mechanism for detecting network congestion, in order to improve the performance of all types of traffic. Indeed, there are two metrics which are used to measure the congestion level. The first one, is the average MAC layer utilization around each node. Instantaneously, this metric can be equal to 1 or 0. It is equal to 1 if the MAC layer is utilized (there is at least one packet in the transmission queue, during backoff decrease period, inter-frame space, detection of physical carrier). The second metric, is the instantaneous interface queue length. This metric is used to avoid nodes that are congested even there is no contention. The proposed mechanisms aim to influence routing decisions that will follow other route discovery scheme either than the short hops count used traditionally. Indeed, it is unsuitable to establish routes over nodes that are already busy. However, if we avoid busy nodes in route establishment, there are some routes that cannot be established even they exist. The congestion information is also used when the medium utilization is high, to influence the setting of the Explicit Congestion Notification (ECN) bits in the IP header of packets at each node. ECN is used to prevent the loss of packets along that flow. At transport layer, the MAC layer utilization metrics measured around the node allow TCP sender to tune its parameters according to these metrics since they represent a recent level to the wireless medium utilization. At higher layer, these metrics can be used to decide or not data compression. Indeed, when the medium is busy the sender can decide to compress the data. However, the compression should represent a trade off between bandwidth consumption and the CPU time used for compression and decompression.

- topology information+Enhanced back-off +Proactive routing

In [21], a detailed discussion of cross-layering design has been presented in the context of research project called MobileMAN. This project investigates a local interaction among protocols in a manet node. For example, MAC layer exploits the topology information collected by network layer to achieve fair channel scheduling and fix the problem related to hidden and exposed terminals. An enhanced backoff scheme is introduced. At transport layer, the different events occurring at lower layers such as route failure, route changes and congestion, are analyzed in order to minimize the useless data retransmissions. Moreover, MobileMan considers routing according to the cross-layering principal. Indeed, a path per-formability index is computed using congestion, link quality, and other parameters that can influence system performance. Furthermore, the MobileMan transport protocol exploits information reported by the routing and Wi-Fi layers in the Network Status component to avoid useless data retransmission.The authors suppose that a node has a knowledge of the hole network topology and so a proactive routing protocol should be used. Hence, it seems that for some scenarios, it is very hard, costly, and not efficient to address this cross layer architecture regarding the dynamic traffic nature and the high mobile node speed. Any information has been provided to how compute the path per-formability index or other cross layer parameters considered in this project.

- Probability of successful transmission+route selection+energy conservation

In [3], tow cross-layer designs based on energy consumption are presented for wireless ad hoc and sensor network. The proposed schemes, namely, Energy-Constrained Path Selection (ECPS) and Energy-Efficient Load Assignment (E2LA), employ probabilistic dynamic programming (PDP) techniques and utilize cross-layer interactions between the network and MAC layers. They aim to enhance the operation of existing power-based multi-path routing protocols via cross-layer designs and optimal load assignments. The Energy-Constrained Path Selection (ECPS) consists of maximizing the probability of successful transmission in at most n retry. That is mean that the total n transmissions don't exceed a total amount of energy equal to γ. Furthermore, the authors developed four distinct reward schemes for which E2LA assigns routing loads accordingly. This objective is achieved by applying PDP techniques and assigning a unit reward if the favorable event (in this case, reaching the destination in n, or less transmissions) occurs, and assigns no reward otherwise. Hence, it can be shown that maximizing the expected reward is equivalent to maximizing the probability that the packet reaches the destination in at most n transmissions. In ECPS mechanism, the MAC sublayer provides the network layer with information pertaining to successfully receiving a CTS or an ACK frame, or failure to receive one. ECPS, in turn, chooses the route that will minimize the probability of error or, equivalently, maximize the expected reward.

The proposed medium access control (MAC)-based performance studies, revealed that battery capacity may not be efficient for achieving energy-based fairness and system longevity for wireless mobile multi-hop ad hoc and sensor networks. However, energy conservation may be attained only if valuable MAC (and PHY) input is passed to the network layer. In addition, illustrative examples of E2LA were presented, and its diverse properties were introduced and validated.

- power control + topology information

In [1], a study of cross-layer design based on power conservation, and congestion informations in ad hoc network have been presented. The authors describe a power control based cross layer architecture. Indeed, they detail the significant impact of power control on all protocol stack above the physical layer. Furthermore, they summarize several works that have been done to address power saving in the protocol stack and show how the power information could be considered at each layer. Moreover, the work claims that, exchanging the topology information between different layers through their interfaces, is very important to support QoS such as geometric location, channel, link conditions. A proposed mechanism, that uses the number of neighbors around the node to adjust transmission power, has been presented.

3.4 Physical layer + MAC + Application

- SNR information +MAC retransmission+ adaptive FEC

Real-time applications, such as audio and video streaming over wireless links, suffer from bandwidth variation, packet losses, and heterogeneity of the receivers. To overcome, bit error problem, many works have addressed adaptive error-control strategies at the application layer. However, in existing WLAN environments, different protection strategies exist at the various layers of the protocol stack and, hence, a joint cross-layer consideration is desirable in order to provide an optimal overall performance for the transmission of video [14, 9, 11]. In [14], the authors propose to exploit the mechanisms available at the lower layers of the protocol stack in order to address an adaptive cross-layer protection strategies for robust scalable video transmission. This mechanism uses a multipath channel model to simulate the wireless indoor channel. This channel model provides the bit error rate (BER) of the link for the eight different PHY modes of 802.11a under different channel signal-to-noise ratio (SNR) conditions. Then, the authors analytically derive the packet loss ratios and throughput efficiency at various channel conditions, considering a given packet size, a given number of retransmissions at MAC layer, and an application layer FEC. These parameters are dynamically adapted according to an end-to-end distortion model in order to achieve an efficient transmission of video streams. The presented algorithm presents a good performance for video streaming. However, it is only centralized.

In the next section, we discuss the constraints of introducing cross layer architecture and the recommendations to achieve a good and optimized solution.

4 The Implementation Cost of a Cross-Layer Architecture

The advantages of cross layer design is to exploit the interactions between layers in order to improve QoS support and optimize resource utilization. Moreover, this new architecture promotes adaptability at all layers based on the exchanged information and tight their interdependence. However, understanding and exploiting the interactions between different layers is the core of the cross-layer design concept. For example, the cross layer models introduced in [20] and in [21], require respectively the congestion information and hole topology information to build routes using layer cooperation mechanisms. Hence, if we consider high variable scenario in term of mobility and traffic load, the collected metrics will be inaccurate and so become inefficient and very costly. Indeed, it is hard to characterize the best and efficient interactions between protocols at different layers. Moreover, joint optimization across layers may lead to complex algorithms. Note that complexity consumes more resources for computing and introduce a new problem of scalability. So, we have to answer the following question: is cross-layer design suitable for all types of wireless networks and all types of applications?

If yes, that means that we have to throw away the OSI reference model and we don't need to consider a network architecture anymore? This is clearly impractical and disaster in terms of implementation, debugging, upgrading and standardization.

The solution is to maintain the layered approach, while accounting for interactions between various protocols at different layers.

5 Achieving a good trade-off between complexity and enhancement in cross-layer architectures

While cross-layer model could enhance the performance of the applications and achieve better QoS support, there is a lot of proposed models that have to be compared and optimized. In the most cases, we have to take into account the benefits of each model that provides 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 are 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. So, 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, traffic, and capacity.

We believe that cross-layer a QoS model is a somewhat "danger". In one hand, the modification that we have to add in the protocol stack and the complexity in introducing a new parameters and new algorithms to provide a "good" layer cooperation are usually introduce a high complexity risk. In 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 route" between sources and destinations in a way to achieve a global load balancing, and in other cases have knowledge about neighbor density and "quality" to adapt transmission rate and to use scheduling strategies in an efficient manner.

So, if we recapitulate, cross-layer is a promised solution to address QoS support and service differentiation in mobile ad hoc networks, but it is affected by mobility and so the "lifetime" of the availability of the accurate available informations. We recommend the following requirements to efficiently design a QoS cross-layer model which leads to the architecture shown in Figure :

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 2, 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.

As a conclusion, the decision to use a cross-layer model is very coupled with the nature of the user application and the evolution of the network behavior. 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.

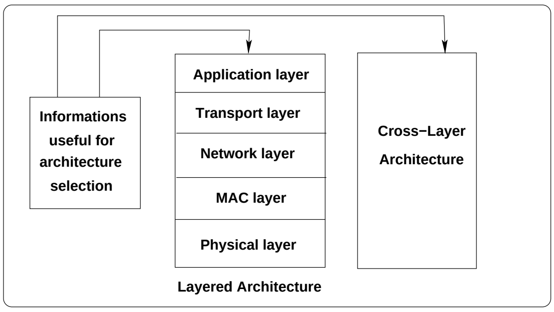

Figure 2: New architecture design

6 Conclusion

Many subsystems of appliance operating systems are implemented as stacked modules. For example, the TCP/IP subsystem consists of the link layer, the network layer (IP), the transport layer (TCP and UDP) and the application layer organized as a protocol stack.

In this paper, we discussed the most important features based on cross-layer exchanged information, introduced for mobile ad hoc networks. Despite of the performance improvement that this new design can achieve, there are some risks into changing the legacy layered architecture. Indeed, several issues need to be talcked before these interactions can be successfully exploited such as implementation, debugging, upgrading and standardization. We have to specify and explain whether cross-layer paradigm is suitable for all types of wireless networks and applications or not. Even if the answer is yes, it is necessary to maintain the layered approach, while enabling interactions between various protocols at different layers.

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