OVERVIEW OF THE CROSS-LAYER PARADIGM EVOLVING TOWARDS FUTURE INTERNET

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Abstract: **The spectacular evolution of Internet services has requested significant improvements of the performances in communications networks. Cross-layering techniques have been selected as one of the most important issues in research, trying to change the classical OSI model and to define better mechanisms for scalability. In this paper we are investigating the main characteristics of this bi-directional vertical communication, breaking the claimed independence of physical, data link, network, transport, and application layers. Some deployment scenarios described herein could help the future Internet designers to follow a clean slate approach.**

Key words: *cross-layer, Future Internet, QoS*

I. INTRODUCTION

The Future Internet is expected to overpass the limitations of the existing networks, mainly due to suboptimal decisions, lack of security and scalability, difficulties in supporting nowadays innovations. The dream to offer access to data, voice or high quality video to the end user on the same infrastructure is not new. However the legacy solutions failure was compensated by introducing the concept of QoE (Quality of Experience), as well as specialized adaptive protocols. It seems that despite the huge research effort a new design of the whole Internet is needed, as a clean slate approach. We are investigating in this paper one of the new paradigms, i.e. the cross-layer exchange of information between different layers. The first part is focused on arguments related to the need of cross-layering, followed by already successful implementations. The third chapter describes the current design techniques, while the forth one is focussing mainly on the parameters that can be exchanged between protocols at different layers. The next section is dedicated to the taxonomy of existing cross-layer procedures, followed by a presentation of the disadvantages that some implementations can have. We will end the paper with a chapter dedicated to some conclusions and future work.

In the traditional network architecture (i.e. the one implementing the TCP/IP protocol stack), signaling between protocols is made through standardized interfaces between adjacent layers, using metadata included in the packet headers. Nowadays, when the real time services become more and more popular, the classical approach is not optimal anymore with respect to the QoS (Quality of Service) parameters. They have to be kept in a stringent domain in order for the user to receive a specific level of Quality of Experience

As a solution for this challenge, the cross-layer paradigm was proposed, bringing the possibility for protocols to exchange signaling with others, so that a global image over the network performance to be created and optimal decisions to be taken. This way, communication protocols from upper layers are able to adapt their behavior according to the variation of the traffic parameters from lower layers. In [1] cross-layer is defined as a method of adapting the protocols designed for wired networks, to the radio ones.

The main challenge is to find the essential information that should be signalled, because if we send too many parameters we might increase unnecessarily the overhead, but if the information exchanged is not enough, the receiver will not be able to take an optimal decision for a given situation.

An important field of research, where cross-layer signaling brings important improvement is energy saving. This domain is very important especially for mobile wireless devices, where implementing efficient energy management techniques, can be a way of improving the autonomy and also lowering the ICI (Inter Channel Interference). For example, if the application layer sends data that supports a higher level of BER (Bit Error Rate), it can inform the physical layer to decrease the transmitting power, while sending to the channel the specific frame.

Other cross-layer signaling could be exchanged between the Transport and Application layers, informing the second one about the percentage of lost packets, specific to a certain data flow. For example, in the case of VoIP (Voice over Internet Protocol) services, this information can be a valuable input to take into consideration if we want the application to adapt its behavior by changing the audio codec [2].

II. CROSS-LAYER DESIGN

Due to important research in the field of cross-layer techniques, several design proposals have been developed, being suited for a large domain of applications. An overview of the most important ones can be found in [4], while in Figure 1 we illustrate their synthesis.

Manuscript received April 12, 2009, reviewed June 15, 2009

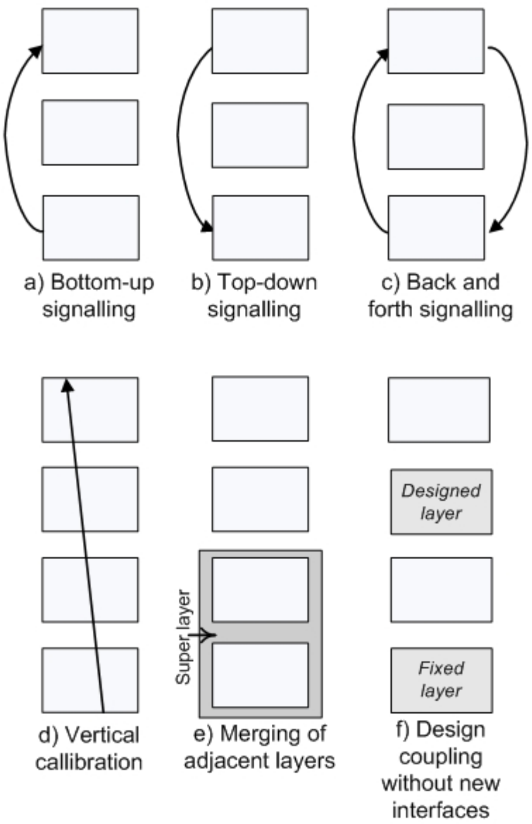

Figure 1. Cross-layer design [4]

The first type of signaling, illustrated in Figure 1a is *bottom-up signaling,* that can be used when a high level protocol is receiving information concerning parameters from a low level one (i.e. physical channel characteristics) during runtime. When using this type of information exchange, the parameters regarding the channel characteristics may be used by a high level application (i.e. audio/video encoder to modify the compression rate or the type of codec used). This approach can be a solution to achieve a better spectral efficiency or lower delay/jitter values, when transmitting real time traffic over wireless channels.

Top-down signalling, presented in Figure 1b, is usually implemented when there is a need to adjust the low level parameters, using information provided by the high level protocols. For example, an application can send information to the MAC (Medium Access Control) protocol, concerning required QoS parameters of a specific flow, so that the packets received from different applications, to be stored in queues with different sending priorities.

Back and forth signalling is a combination of the first two ones (bottom-up and top-down), and it is illustrated in Figure 1c. The main idea is that between two different protocols, information about each other's status can be exchanged, creating a closed control loop, where one entity can control another protocol's behaviour to achieve an overall improvement of the communication quality.

A vertical calibration across layers is a method of tuning the performance of a specific protocol, taking into account the parameters specific to the below layers. Implementing this kind of signalling is not an easy task to do, because adaptive protocols developed can change their behaviour, according to the information received. The time needed for the signalling information to travel from a specific protocol to another one and the time necessary for that protocol to react are also needed. In wireless communications, because the channel is varying fast, these parameters have to be as low as possible.

Another possibility to implement cross-layering techniques is by *merging two or more adjacent layers together* so that the service provided by the new super layer to be the union of the services provided by the constituent layers. This method does not require any new interfaces to be created, because the new layer will communicate with the rest of the stack using the interfaces that already exist [4].

The last type of cross-layer signaling, illustrated in Figure 1f, involves *coupling two or more layers at design time without creating any new interfaces*. Because there are no extra interfaces created, it may not be possible to replace one layer without making the necessary changes to the other one. For example if we consider a device whose Physical (PHY) layer is capable of multi packet reception (receiving more than one packet in the same time), the MAC layer has to be redesigned accordingly to support this enhancement.

After choosing the most suitable cross-layer design, the developer needs to make another decision with respect to the method used for implementing the solution.

In [4], three methods were found that can be recognized in many of the papers focused on studying cross-layer mechanism. The forth method presented herein was described in [5] and it is an interesting way of optimizing the communications using cross-layer signaling. A graphical representation of those proposals is illustrated in Figure 2.

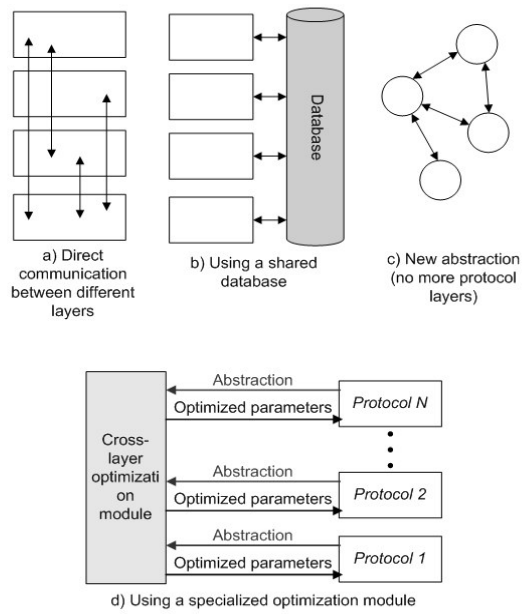

Figure 2. Cross-layer implementations [4], [5]

The easiest way of implementing cross-layer signalling is presented in Figure 2a, *using direct communication between different protocols*. This type of signalling can be achieved due to specialised messages exchanged on dedicated interfaces or due to special fields in the headers added to the data packets, as they go through different communications protocols. An example of a framework that implements direct cross-layer signalling is presented in [6] and it is called CLASS (Cross-Layer Signalling Shortcuts). This type of cross-layer communication method is recommended only when there is not that much information to be exchanged between layers.

The second type of methods for implementing cross-layer signalling, presented in Figure 2b, implies the usage of a shared database (dedicated for storing status information about the network) by all communication protocols. The steps performed when using this method are the following: an entity will publish specific information into the shared data base as frequently as it considers being necessary. A different entity/protocol will query from the same database, the needed information, in order to be able to make optimal decisions concerning the communication. The authors from [4] are considering that this approach is the optimal one when implementing vertical calibration cross-layering. This method can be improved by creating a new service specialized in cross-layering and offering predefined interfaces, used for sending and querying information to/from the database. The protocol layers can keep their independence to each other, being one of the biggest advantages [7].

The method illustrated in Figure 2c implies the usage of a new model for organising the communication protocols, other than the classical layering. This method is considered to be a cross-layer mechanism, because the communication between protocols can be done in many ways, permitting a high flexibility, both during design as well as during runtime.

Another proposal is presented in [5] and it is illustrated in Figure 2d. The most important part of this solution is the so called "*cross-layer optimization module*". This dedicated module works in three steps:

- **Abstraction** – the module extracts from each protocol the most representative set of parameters.
- **Optimization** – the received parameters are used as an input to specialized algorithms executed by the cross-layer optimization module.
- **Reconfiguration** – the module sends to the communication protocols a set of optimized parameters that have the purpose to improve the global performance of the network.

The rate, at which these three steps are repeated, depends on many factors such as the type of the physical channel used, or the type of applications running in the network. The parameters that are involved in this optimization process can be divided into three categories:

- **Direct tuneable** parameters that can be modified directly (e.g. time slot assignment in a TDMA system)
- **Indirect tuneable** parameters that can be influenced only by modifying the value of other ones which are direct tuneable (e.g. BER depends with the type of modulation used)
- **Descriptive** parameters can not be modified, but they could only be used to describe the performance of a certain protocol (e.g. estimated channel quality, the rate at which the video frames are received at the destination).

III. INFORMATION EXCHANGED BETWEEN LAYERS

In this chapter we present the parameters that are usually being exchanged between protocols running at different layers when implementing cross-layer signaling.

a) The information available at the **Physical Layer**, consist mainly of parameters like: transmitted power, BER, type of channel coding or modulation used. When exchanging cross-layer signaling with the *Application Layer*, the low level parameters can be an important input for the application to change its behavior for a better performance. Information from the physical layer can also be useful at the *Network Layer,* when a certain route can be characterized also by the BER which is a parameter that varies in time especially in wireless networks. Tests made in [8] show that performances of a MANET (Mobile Ad-hoc Network) can be improved when taking into account the Physical Layer parameters to calculate the metric of a specific communications path. If the length of the data frame, or the retransmission mechanism is modified by the *Data Link Layer* when taking into account the BER or the SNR (Signal to Noise Ratio) the performance of the transmission can be improved, with respect to the transfer rate or the consumed energy.

b) Because the main target of the **Data Link Layer** is to improve the communication performance using FEC (Forward Error Correction) mechanisms and ARQ (Automatic Repeat reQuest) methods, the most representative information consist of the following parameters: data frame length, the FEC method used, number of retransmitted frames. Between the data link layer and the *Application Layer*, information can be exchanged with respect to the type of the application from which a specific frame is received. This way data flows from applications, that request low level of delays, can be transmitted on the communication medium with a higher priority than the rest of the flows. The cross-layer information exchanged between the Data Link Layer and the *Network Layer* could also be important for wireless communications that uses the Mobile-IP protocol, because before detecting the changing of a subnetwork, the device senses first that the ID of the base station from its service area had changed, being an important input when trying to reconfigure the IP parameters faster.

c) Cross-layer signaling between the **Network Layer** and the *Application Layer* could be very important to implement algorithms for optimal routing. For example, if a device has multiple connections to the Internet, each one utilizing a different technology, depending on the requests of the application, with respect to the transmission quality that it can support, the network layer can chose a certain output interface. The *Transport Layer* could benefit from information exchanged with the layer below when for instance an IP hand-off takes place. If the TCP protocol is informed when this event happens, it can avoid misinterpreting the lost packets as being the effect of congestion in the network. This way the transfer rate will be kept constant and the network resources will be used optimally.

d) Between the **Transport Layer** and the *Application Layer*, exchanged information can be used by the TCP protocol to take into account the requested QoS parameters for a specific application, and on the other hand, the application can change its behavior based on the information containing the percentage of the lost packets, or the effective transfer rate between the source and the destination devices.

IV. TAXONOMY OF CROSS-LAYER IMPLEMENTATIONS

The research in the field of cross-layer mechanism and methods of implementations is very important, with many implementation proposals. Before choosing the best solution for a given scenario, we first need to know which the available possibilities are. In this chapter we present a couple of features that try to characterize any signalling technique, as it is described in [9].

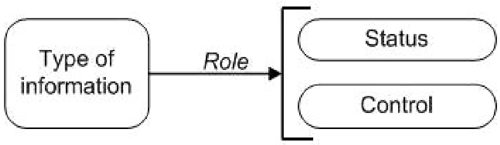

Figure 3. Cross-layer characteristics based on the type of information exchanged

For a better classification of a cross-layer implementation, the parameters are grouped in three categories. The first one describes an implementation, based on the type of information exchanged between protocols from different layers. As it can be seen in Figure 3, taking into account the role of the information we can have *status* information (describing the performance of a specific communication) or *control* information (useful when we want to impose a specific behavior to another protocol).

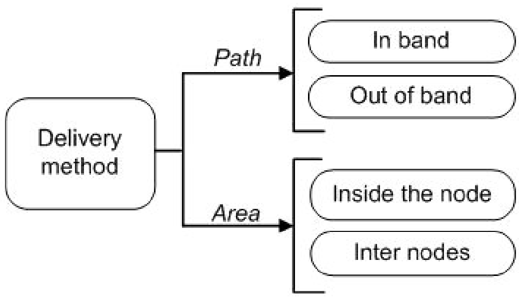

Figure 4. Cross-layer characteristics based on the delivery method used

In Figure 4 we have illustrated the second category of parameters that are characterizing a cross-layer implementation after the delivery method used. When observing the path that the information exchange follows, we can say that the signaling is made *in band* (the information uses the same path with the data) or *out of band* (the information exchanged between protocols uses a dedicated channel, different than the one for data). When taking into account the adaptation process of a specific implementation, we have two subcategories of attributes that can be observed in Figure 5.

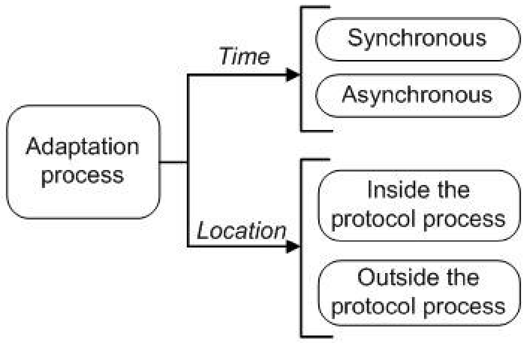

Figure 5. Cross-layer characteristics with respect to the adaptation process used

First one describes the process from the temporal perspective, specifying that we can have a *synchronous* (the adaptation process is synchronized with the reception or the transmission of a packet) or *asynchronous* (the timing of the adaptation task is not coordinated with any packet reception or transmission) cross-layer implementation. On the other hand, when observing the location where the adaptation process takes place, we can say that it can run *inside* or *outside* (the adaptation is not part of the packet processing flow) the protocol process.

The reason for allocating a whole chapter to the taxonomy of cross-layer implementation is mainly because any developer needs to see the complete picture with respect to the types of implementations from where he/she can choose, before starting to create a specific product. Without a clear synthesis of the work done in this field, the cross-layer paradigm will be hard to be imposed to the industrial manufacturers on the market.

Let us apply now these classification criteria to the next six relevant implementations analyzed.

Fast and optimal restoration of broken paths in multicast networks that transmits IPTV services over MPLS networks [3]. Due to the fact that both MPLS and PIM-SSM (Protocol Independent Multicast-Source Specific Multicast) implement their own path restoration mechanisms, congestion from traffic overlap can appear in the network. For eliminating this drawback, a cross-layer mechanism is proposed, where both protocols are communicating with each other, during path restoration process. Experiments showed that when implementing the proposed algorithm there is a 5-6% improvement with respect to packet lost during path restoration, but the major advantage is the mitigation of traffic overlaps in the network.

Opportunistic communication [11] uses cross-layer signalling when communicating over a wireless channel. This is a method of controlling the access to the communication medium, giving priority to the user that senses the best radio channel characteristics at a given moment. The access method is based on the assumption that in consecutive time slots, the same user will not have the best channel conditions, due to the fact that the parameters of a radio channel are varying in time. In order to prevent the situation when a radio device is not granted the access to the communication media, because of poor channel conditions, a specialized mechanism, that keeps track of the time passed since the last transmission of each device, is implemented. This medium access control algorithm, used for implementing opportunistic communications, is composed mainly of the next steps:

- The physical layer of each device sharing the same wireless channel will perform measurements on the pilot signal received.
- All the measurement results will be transmitted to the base station that will decide which device will be entitled to transmit data on the next timeslot.

The authors in [11] admit that this implementation can introduce some delay before granting the access to the channel to a specific device. Thus it may not be suited for real time communications, but important improvements are achieved when the traffic consists mainly on FTP or HTTP.

ECN (Explicit Congestion Notification) [15]: When using the TCP protocol in radio networks, the available resources are not utilized very efficiently, because when packets are lost due to high BER, the transport protocol interprets this event as being the effect of congestion in the network nodes and reduces the transfer rate. A well-known mechanism to eliminate this disadvantage is called ECN. This uses special bits from the IP header to inform when congestion appears in the network, so that the TCP protocol will apply the congestion avoidance mechanism only when it is needed.

Another method of improving the performance of TCP over wireless channels is described in [1] under the name of **LLE-TCP (Link Layer ARQ Exploitation TCP).** The main idea consists of using the confirmation messages received at the Data Link Layer to inform also the Transport layer that the segments transmitted were received at the destination. In this way the overhead in the channel will be mitigated, eliminating the TCP acknowledgement messages. The simulations with ns-2 showed that depending on the number of hops, between the source and the destination, the performance was from 5% to 20% better than in the classical approach. Due to the fact that this cross-layer mechanism was only implemented on the source and destination nodes, the overall performance improvement is smaller when the number of nodes is getting higher.

Multimedia Delivery over Wireless Internet [12]: For transmitting multimedia traffic over wireless channels, there is a need for a strong information exchange between the communication protocols at different layers. In [12] the proposal specifies that the audio/video codec from the application layer will modify its behavior according to the communications parameters from the network (delay, jitter, and throughput). The target is to achieve the best possible performance. During the communication over the radio media, the network parameters are varying fast. The mechanism must have the capability to predict future states of the channel, the decisions being according to status information, closed to the reality.

H.264 Video Streaming over IEEE 802.11e Devices by Cross-Layer Signaling [13]: A cross-layer signalling solution between the application and the MAC layers is implemented, in order to account for the different QoS characteristics of video and elastic traffic. In addition, network support for efficient multi-queue transmission is enabled in the Linux wireless card driver. Measurements also illustrate the effects of changing several H.264 and IEEE 802.11e parameters in the player and driver software.

Implementation	Crossed Layers	Type of information	Delivery method	Area of delivery with respect to the node	Timing of the adaptation process	Location with respect to protocol process
Fast and optimal restoration of broken paths in multicast networks that transmits IPTV services over MPLS networks [3].	Data Link <-> Network	status	in-band	inside	asynchronous	inside
Opportunistic communication [11]	Physical -> Data Link	status	in-band	outside	asynchronous	inside
ECN (Explicit Congestion Notification) [15]	Network -> Transport	status	in-band	outside	asynchronous	inside
LLE-TCP (Link Layer ARQ Exploitation TCP) [1]	Data Link -> Transport	status	out-of-band	inside	asynchronous	inside
Multimedia Delivery over Wireless Internet [12]	Physical -> Application	status	in-band	inside	synchronous	outside
H.264 Video Streaming over IEEE 802.11e Devices by Cross-Layer Signaling [13]	Application -> Data Link	control	in-band	inside	asynchronous	inside
Cross-Layer QoS for In-Network Management [14]	Substrate Network <-> Virtual Network	status/ control	in-band/ out-of-band	inside/ outside	asynchronous	inside/ outside

Table 1. Examples of cross-layer implementations

Cross Layer Quality of Service for In-Network Management [14]: Considering that the future network should be able to manage itself with minimum intervention from an administrator or a governor, while maintaining good performance, the cross-layer paradigm is implemented in FP7-4WARD project within a dedicated management Functional Component called QoS dmFC. It should be characterized by the next set of properties: self-descriptive, self-configuration, self-optimization, composability, governance, interoperability and extendibility. Work is under progress but preliminary details about implementation are given in [14]. Note that the concepts of layers were replaced in the sense that substrate network (i.e. former Physical and MAC Sub-Layer) could interact in top-down and bottom-up approach with virtual networks (i.e. former LLC Sub-Layer, Network, Transport and Application Layers).

Beside the good aspects a cross-layer approach has, we have to be aware also of the existing drawbacks. An interesting study that tries to capture these points is made in [10]. One of the main advantages when using the OSI reference model is the fact that protocols at different layers are running separate from each others and the only way of communicating is through standardize interfaces. However when deploying cross-layer architecture, these features are lost and the signaling information creates strong bounds between them. These aspects eliminate the possibility of designing a specific communication protocol isolated by the rest of the stack, attribute that was considered to be one of the reasons for the fast evolution that the Internet faced in the last years.

Due to the creation of multiple control loops, the possibility of destabilizing the whole system is another disadvantage. In order to avoid it, the developer has to be very careful when design a specific communications protocol or a cross-layer adaptation mechanism. Because of the high number of control loops the troubleshooting can also become very complicated compared with the one in classical networks.

V. CONCLUSIONS

This paper presented a survey of the cross-layer mechanism to be used in Future Internet. Because of the important work in this field, there are many proposals on how to implement cross-layer signalling. Having this overview a potential developer will be able to decide what architecture to implement in a specific application. Continuous information exchanged between layers will allow optimal decisions.

Even more, we can forget about layers and consider just the substrate network (i.e. hardware with legacy or future technologies) and virtual networks (with virtual links and nodes).

VI. ACKNOWLEDGEMENT

This work was partially funded by the FP7-ICT-2007-1-216041-4WARD project. The views expressed in this paper are solely those of the authors and do not necessarily represent the views of the 4WARD project.

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