Challenges in Cross Layer Design for Multimedia Transmission over Wireless Networks

Christos Bouras, Apostolos Gkamas and Georgios Kioumourtzis

***Abstract*— Over the last years a number of new protocols have been developed for multimedia applications in the whole OSI layer's scale. In addition wireless communications and networking fast occupy centre stage in research and development activity in the area of communication networks. In order to support better wireless user the cross layer design paradigm has been proposed. This paper presents the challenges in design and implementation of cross layer adaptation schemes for multimedia transmission over wireless networks. In addition this paper presents the most important parameters and constrains that should be taken into consideration when attempting cross layer adaptation in wireless networks that involves different protocols in the overall protocol stack..**

***Index Terms*— cross layer design, multimedia transmission, wireless networks**

I. Introduction

MULTIMEDIA data transmission experience a number of constrains that result to low Quality of Service (QoS) that is offered to the end user. These constrains have mainly to do with the nature of multimedia applications, which are characterized by three main properties: the demand for high data transmission rate (bandwidth-consuming applications), the sensitiveness to packet delays (latency and jitter) and the tolerance to packet losses (packet-loss tolerant applications), when compared to other kind of applications.

This paper examines the issue of cross layer design for multimedia transmission over wireless networks. In wireless networks multimedia data transmission inherits also all the characteristics and constrains related to the propagation to the free space. One first striking difference between wired and wireless networks is the cause of packet losses. Packet losses in wired networks occur mainly due to congestion in the path between the sender and the receiver, while in wireless networks packet losses occur mainly due to corrupted packets as a result of the low Signal to Noise Ratio (SNR), the multi-path signal fading and the interference from neighboring transmissions. A second difference between wired and wireless networks is the "mobility factor". Mobility in wireless networks introduces a number of additional barriers in multimedia data transmission.

The above properties introduce new design challenges to the networking world as it is in fact difficult to combine guaranteed high bit rates and an acceptable packet loss ratio with low latency and jitter.

All the above factors have led both the research community and the industry to develop and propose a number of new protocols and optimization techniques targeting at mitigating delay and packet loss ratio during the transmission of multimedia data. Most of these efforts are based on the classic layered approach in which the various layers try to optimize its performance by adapting its behavior to constantly varying network parameters and provide its best services to upper layers. Under this layered approach, communication occurs between two adjacent layers without taking, however, into consideration the specific characteristics of multimedia applications. Although this layered approach has been the fundamental factor for the growth of the wired networks and the World Wide Web (WWW) it seems to pose serious constrains when attempting to adapt protocol's behavior to multimedia applications characteristics and to wireless network conditions.

For example packet losses in wireless networks occur mainly due to corrupted packets and any typical congestion control mechanism cannot function properly when it is not aware of the cause of packet losses (e.g. TCP has poor performance in wireless networks comparing with wired networks). A typical congestion avoidance mechanism at the transport layer would reduce the transmission rate to eliminate congestion and thus degrading further the performance of the application, although the cause of the packet loss was not a congested network. In this simple example, it is obvious that someone should employ different mechanisms in which all layers share knowledge with each other about the specific multimedia application characteristics and the instant network conditions.

This new approach lays in the way we view the various layers of the OSI model. Under the OSI model all protocols that function in the various layers communicate only with other protocols that belong to the same layer, while ignoring the existence of other protocols that function in different layers. When, however, looking at the OSI model from a different angle and from some distance we can vision it as a system. In an organized system the various system elements should develop a high level of cooperation through knowledge sharing so that the system as a whole can perform its tasks in a more effective and efficient way. Therefore, we could increase any system's performance if we developed such mechanisms that could increase the level of cooperation and communication amongst the various elements. Here is where the whole concept of cross-layer adaptation is encapsulated; to design those mechanisms without altering the layered model.

As wireless communications and networking fast occupy centre stage in research and development activity in the area of communication networks, the suitability of the layered protocol architecture is coming under close scrutiny from the research community.

Although layered protocol architectures have served well for wired networks, they are not suitable for wireless networks. To illustrate this point, researchers usually present what they call a cross-layer design proposal. Thus, there have been a large number of cross-layer design proposals in the literature recently [17], with some of them focusing to multimedia transmission [25], [8], [12].

Generally speaking, cross-layer design refers to protocol design done by actively exploiting the dependence between protocol layers to obtain performance gains. This is unlike layering, where the protocols at the different layers are designed independently.

This paper presents the challenges in designing and implementation of cross layer adaptation schemes for multimedia transmission over wireless networks. The remaining of this paper is structured as follows: The next section presents the international experience in the area of cross layer design for multimedia transmission over wireless networks. Section 4 presents the future trends in the area. Finally, Section 5 concludes this paper.

II. Related Work

Over the last years a number of new protocols have been developed for multimedia applications in the whole OSI layer's scale. The RTP and RTCP protocols [20], which operate on the transport layer usually on top of the UDP protocol, have been especially designed for multimedia data transmission. The RTSP [18] protocol offers control mechanisms over real time multimedia transmission whereas SIP [19] and H.323 are used in multimedia conferencing.

Apart from the above developments there have been a number of proposals for improving QoS in multimedia applications through cross layer adaptation strategies. In [25] the need of a cross-layer optimization is examined and an adaptation framework is proposed amongst the APP, the MAC and the Physical (PHY) layers.

The cross layered architecture available to the literature can be divided to the following categories [23]:

- Creation of new interfaces [7]: Several cross-layer designs require creation of new interfaces between the layers. The new interfaces are used for information sharing between the layers at runtime.
- Merging of adjacent layers [6]: Another way to do cross-layer design is to design two or more adjacent layers together such that the service provided by the new layer is the union of the services provided by the constituent layers.
- Design coupling without new interfaces [24]: Another category of cross-layer design involves coupling two or more layers at design time without creating any extra interfaces for information sharing at runtime.
- Vertical calibration across layers [14]: Adjusting parameters that span across layers.

Signaling issues between the layers for cross-layer optimization over wireless networks are examined in [29]. The authors propose a new signaling framework in which signaling can be done between two non-neighboring layers, through light-weighted messages and the use of a message control mechanism to avoid message dissemination overflow. Although this proposal avoids heavy ICMP messages for out-bound signaling between the layers that is proposed in [22], it introduces very high complexity. In [5] a joined adaptation scheme of the APP, MAC and PHY layers is presented. Packet transmission is made with a novel scheduling algorithm at the MAC layer whose function is based on the user and application priority levels. Priorities are assigned to users on the basis of paid services, in which users are classified into groups with different QoS levels.

In [26] a joined APP and MAC adaptation is proposed with the use of MPEG-4 and the latest Fine Granularity Scalability (FGS) extension. In this work, packets containing multimedia data are classified into different classes and in the light of poor network conditions only packets with high value are transmitted. The network conditions are jointly measured by combining the information obtained by the retransmission number of a lost MAC frames (ARQ) and the information provided by the RTCP protocol.

In [21] the issue of cross-layer design in wireless networks is addressed. The focus is on the way that higher layers share knowledge of the PHY and MAC layers conditions in order to provide efficient methods to allocate network resources over the Internet.

Finally, [3] outlines the need for new cross-layer architecture to address known problems of mobility, packet losses and delay that are observed in wireless networks. The main idea of a cross-layer manager is discussed in which all layers send notification messages to the manager who is responsible for intra layer co-ordination.

III. Challenges in Cross Layer Design for Multimedia Transmission over Wireless Networks

Cross layer adaptation is a very challenging process due to the numerous parameters involved in the whole procedure. This section outlines the most important parameters and constrains that should be taken into consideration when attempting cross layer adaptation in wireless networks that involves different protocols in the overall protocol stack.

A. *Network elements involved in the adaptation process*

In multimedia transmission three entities can be distinguished that take part in the information exchange procedure: the sender, the core network elements (links, routers) and the receiver. The term sender includes either a multimedia server or an individual host which participates in a multimedia data exchange with another remote host. There has been a detailed discussion whether or not all three elements should be involved in an adaptation scheme, targeting at improving the QoS offered to the end user. The most challenging and maybe the most beneficial approach would be the participation of all three elements in the adaptation mechanism especially when the multimedia data are transmitted among various network domains. However, even in the same network domain someone has to decide whether or not both the sender and the receiver should participate in the adaptation process. Someone should also consider that the complexity increases when inter-domain adaptation and policies are to be implemented.

Clearly, there are pros and cons in either approach. With both the sender and the receiver participate in the adaptation process better results are expected as this sender/receiver pair acts as an organized "team" by sharing information related to current network conditions and adapt their behaviors to these conditions. Logically, the total result would provide the highest QoS for given network conditions. On the other hand, by confining the adaptation process only in the sender or the receiver the level of independence is increased between the entities involved in the multimedia transmission.

Therefore, the cross layer adaptation scheme that is related to the participation of the entities involved in the multimedia transmission can fall into the next four categories:

- Sender based: The sender performs the cross layer adaptation. This approach has the advantage of easy deployment due to the fact that it does not require any support from the network or the receivers. On the other hand this approach has limited capabilities.
- Receiver based: The receiver performs the cross layer adaptation. This approach also has the advantage of easy deployment due to the fact that it does not require any support from the network or the sender. Again this approach has limited capabilities.
- Network supported: The network elements are involved in the cross layer adaptation. In a heterogeneous environment such as the Internet, agreements have to be set up amongst the various network domains to ensure any cross-layered implementation across the path between the sender and the receiver. In the same domain the administrator cab define their own policies-mechanisms.
- Hybrid: A combination of two or more of the above approaches. This approach is the most complicated to be implemented but has the potential to provide better performance.

B. Layers involved in the cross layer adaptation (Inter-layer optimization)

Most of the available bibliography focuses on a jointly PHY and MAC layers adaptation. This bibliography [6], [28], [4] has proven that PHY and MAC layers are very important especially in wireless networks and must be taken into account during cross layer adaptation and optimization. Moreover, the APP layer has been used in several cross layer adaptation schemes [16], [1].

While the above mentioned layers (PHY, MAC and APP) have been extensively researched in cross layer adaptation schemes there has been little work done in the whole protocol stack.

The transport/session layer can play important role in cross layer adaptation for wireless networks, as a number of adopting mechanisms in this layer (like TFRC [9] for example) have been extensively evaluated in wired networks, revealing adaptation opportunities in wireless networks.

Although, the network layer can not be used straightforward for cross layer adaptation it can be used for indirectly cross layer adaptation through QoS schemes implemented at the network layer [10].

C. Parameters involved in cross layer adaptation (Intra-layer optimization)

Each layer offers a number of different parameters through which adaptation can be achieved. The optimization of each layer parameters includes the selection of the applicable parameters which could lead to better results. At this point, we should mention that the adaptation of a parameter in one layer may and most likely, will influence the parameters in other layers. Therefore, the adaptation of the parameters in each layer should be done by taking into account the above mentioned assumption. By summarizing the above, any approach for optimal selection of the adaptation parameters should consider the following two actions:

- Optimization of the parameters that only affect the layer in which they appear
- Optimization of the parameters that affect two or more layers

The following table shows the various parameters that can be involved in cross layer adaptation.

TABLE I
PARAMETERS FOR CROSS LAYER ADAPTATION IN WIRELESS NETWORKS

Layer	Parameters [a]
PHY	Signal modulation
MAC	ARQ, FEC, QoS
Network	QoS (Diffserv, IntServ), IPv6
Transport / session	Adaptive Transmission Rates (TFRC, DCCP, other mechanisms [27])
Application	Encoding parameters (Layered Encoding, MPEG4)

D. Signaling amongst the various layers

The signaling amongst the various layers is another important aspect. A communication mechanism among the various layers must be available in order to implement a cross layer adaptation scheme. There are various approaches for cross layer signaling:

- Network Services: In this approach a separate network service is implemented and it is responsible for collecting parameters from the various layers. These parameters that are collected by the network service are available to APP (or other layer(s)) in order to perform cross layer adaptation.
- Local Profile: In this approach each layer stores important parameters to local profiles (file system) in the mobile device. Each layer accesses these profiles in order to obtain the information needed to perform cross layer adaptation.
- Existing protocols / Packet headers: Under this approach, the existing protocol headers can be used for signaling. One appealing approach is the use of IPv6 (network layer) and the extension header mechanism by defining one new type of extension header which will be used for cross layer parameters notification. A second approach is the exploitation of APP packets of the RTCP (transport layer) protocol, which is defined in Schulzrinne, 2003. The APP packets can carry application specific parameters that can be used for signaling in a cross layer adaptation scheme. However, the APP packets are exchanged between the receiving and the sending transmission layers. Therefore, there must be a mechanism in place in order to disseminate these parameters to other layers.
- ICMP messages: ICMP (Internet Control Message Protocol) is a widely deployed signaling protocol in IP-based networks. In this approach, desired parameters, measured by corresponding layers can be disseminated by ICMP messages. A new ICMP message is generated only when a parameter has been changed. However, as the ICMP message is always encapsulated in an IP packet, it has to pass by the Network Layer even when signaling is only desired between the MAC and the APP layer.

By summarizing the above mentioned approaches, the first approach stores parameters to a network server and the second approach stores parameters to mobile device. The third approach utilizes the already exchangeable packets as in-band signaling over the network. The forth approach makes use of extra packets as out-band signaling over the network.

E. Adaptation strategy

Another important issue is how the adaptation strategy could be realized [30]. There are various approaches in this field as following:

- Integrated approach: This approach is the most challenging because the adaptation strategy is decided jointly by all the layers.
- MAC-centric approach: In this approach the APP layer passes its traffic information and requirements to the MAC layer that decides which APP layer packets/flows should be transmitted and at what QoS level.
- Top-down approach: In this approach the APP layer informs the lower layers for the importance of each data packet and the lower layers treat each data set with a different way, based on QoS criteria. The higher layer protocols optimize the parameters and the strategies of the next lower layer.
- Bottom-up approach: In this approach the lower layers (PHY and MAC) provide the upper layers with optimal services by reducing the transmission errors (not efficient for multimedia transmission).

The above cross-layer approaches exhibit different advantages and drawbacks for wireless multimedia transmission, and the best solution depends on the application requirements, used protocols, algorithms at the various layers, complexity and limitations.

To summarize the above mentioned approaches, we can say that the most appealing approach is the integrated approach. However, this approach is difficult to be implemented due to the increased complexity as a direct result of the big number of possible strategies and the associated parameters involved.

F. Devices constrains

The decision on the above mention design issues must be done under the following constrains:

- Device constrains: Mobile devices have many limitations when compared to desktop systems. These include display limitations, CPU resources and power consumption.
- Network constrains: Network constrains include available bandwidth, delay, RTT and QoS support.
- Application constrains: Application constrains include maximum and acceptable delay, maximum and acceptable delay jitter (especially for interactive applications), maximum and acceptable packet loss ratio and finally bandwidth constrains.

In conclusion, the main objective of the optimization process is the optimal selection of the above described parameters in order to provide the best multimedia experience to the end user by taking into account the above described constrains.

TABLE II
PARAMETERS FOR CROSS LAYER ADAPTATION IN WIRELESS NETWORKS

Factors	Constrains
Mobile Device	CPU, display, power
Network	Bandwidth, delay, RTT, QoS support
Application	Maximum and acceptable delay, maximum and acceptable delay jitter (especially for interactive applications), maximum and acceptable packet loss, bandwidth constrains

IV. CONCLUSION

Nowadays we are moving from the static connectivity of the wired networks to the “anytime anywhere mobile applications”. In addition we are facing important increase in the usage of wireless access networks either in the form of PAN (Personal Area Networks e.g. Bluetooth), LAN

(Local Area Networks e.g. IEEE 802.11) and MAN (Metropolitan Area Networks e.g. IEEE 802.16) or in the form of current 3G and future 4G mobile networks and important increase of mobile multimedia applications like voice over IP, Video on Demand, videoconference, Media streaming, etc.

Cross layer design will facilitate the above important changes by providing a unify scheme which will allow the incessant usage of networked media by adapting the media transmission to the specifically needs of the wireless networks and the mobile terminal (e.g. laptop, PDA, mobile phone). In addition cross layer adaptation will allow smooth operation of mobile multimedia applications during the transition from one wireless network technology to other.

This paper presents the challenges in designing and implementing cross layer adaptation schemes for multimedia transmission over wireless networks. Cross layer adaptation for multimedia transmission will have important impact both in the research community and in the industry. More particularly, cross layer adaptation will allow better access to media content for users in a variety of locations, contexts and mobility scenarios.

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