Video-streaming Transmission with QoS over Cross-Layered Ad hoc Networks

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Abstract: End-to-end Quality of Service (QoS) provision to video-streaming applications over Mobile Ad hoc Networks (MANETs) poses a specially challenging problem. In this paper we propose a Cross-Layer (XL) network architecture design to optimize the overall performance of video-streaming services over MANETs, called ViStA-XL. The idea relies on applying several optimization strategies to different network layers in a holistic way. In our proposal, a real-time XL Optimizer (XLO) collects information about the node and network states from different layers of the network’s protocol stack. Then, in order to minimize the error between received and transmitted video, the XLO module takes the necessary decisions to act dynamically over different layers’ parameters. In addition, our proposal exploits path diversity as a mean to reinforce QoS provision to layered-coded video-streaming applications, by protecting the most important video information packets. To show the advantages of our approach, we have developed an algorithm based on ViStA-XL. Simulation results show that our proposed network design can improve the performance of video-streaming transmissions over MANETs in spite of frequent changes in network topology and node’s conditions.

1. INTRODUCTION

Video-streaming allows the transmission of video files through a network in the form of time continuous flows of data packets (video streams). End-user application at the receiver doesn't need to download the video file before start playing. Instead, it uses a limited-size buffer to temporally store the arriving data to be played almost instantaneously, so it is possible to visualize a video file at near real-time.

On the other hand, a Mobile Ad hoc NETwork (MANETs) is formed by a set of wireless mobile nodes that are able to communicate with each other in a peer-to-peer basis, without the need of any fixed infrastructure or centralized administrative support. Because the transmission range of wireless network interfaces is limited, several intermediate nodes may be needed for one host to transfer data to another one in the network. MANETs are mainly useful in military and other tactical applications such as emergency rescue or exploration missions. In addition, commercial applications (i.e. conferences, course training, lectures, museum visits, city tours, peer-to-peer applications, e-gaming, etc.) are likely where there is a need for ubiquitous communication services.

Mobile nodes of a MANET can move freely, producing changes in network topology. Besides, the radio channel vagaries (e.g. interference, channel multipath effects, fading) and node’s energy power limitations may also produce frequent changes in topology and connectivity. Consequently, MANETs should adapt dynamically to continue operating in spite of changes in network conditions [1].

Furthermore, the dynamic nature of MANETs makes difficult to provide the QoS required for applications where a best-effort service is not enough (e.g. video-streaming). Actually, traditional QoS management techniques developed for infrastructure-based networks have shown to be inadequate, even if some IntServ and DiffServ techniques can still be used to manage and control flows through queuing, marking and dropping packets [2]. Therefore, QoS provision in MANETs poses a very interesting challenge and remains an open issue.

By the way, QoS does not depend on any single network layer, but on the coordinated efforts of all layers. Thus, we argue that, for dynamic networks as MANETs, it is necessary to develop dynamic solutions to QoS provision based on a cross-layer approach that take into account the network specific characteristics [3], [4]. Moreover, a proper QoS-aware architecture for ad hoc networks should make sure the cooperation among all the components related to QoS provision, e.g. signaling, routing and Medium Access Control (MAC) mechanisms to support QoS.

The rest of the paper is organized as follows. In Section 2 we present the main ideas of cross-layer design. In Section 3 we introduce ViStA-XL, our cross-layer design. Some simulation results are shown in Section 4 for a QoS-provision algorithm based on ViStA-XL networking design. Finally, Section 5 summarizes the paper, presents some conclusions and foresees the future work.

2. CROSS-LAYER DESIGN

Modern communications systems are based on layered network architectures because they have several characteristics that make them very attractive. Some advantages of a layered approach are the reduced design complexity due to well-defined functional entities, the improved maintainability due to the modular nature, and the
high degree of flexibility, since layers function independently of each other. Strictly layered network architecture forbids direct communication between nonadjacent layers, and communication between adjacent layers is limited to procedure calls and responses.

Cross-layer design, at the contrary, refers to protocol design done by exploiting the dependence between protocol layers to obtain a better system performance. In a cross-layer design approach, information can be shared among layers in both senses, upper to lower layers and lower to upper layers. This information exchange can be used to optimize the overall performance of the system in a holistic way, by adapting the protocols functionalities in the presence of changing networking conditions; for decision processes such as route selection, or as input to algorithms.

Cross-layer design approach is more suitable for wireless networks, where time-varying conditions of wireless links present new problems, as well as the possibility of opportunistic communications, that cannot be handled well by a strictly layered architecture. Additionally, the wireless medium offers new modalities of communication that the layered architectures do not accommodate. Moreover, to deal with more challenging networking environments such as MANETs, where nodes’ mobility and energy power limitations can produce frequent topology and connectivity changes, cross-layer design has emerged as an alternative to allow the network to adapt dynamically in order to maintain on-going communications in spite of these changes.

Also, because the dynamic nature of MANETs and since QoS provision depends on the coordinated efforts from all layers, cross-layer network design must be applied to MANETs to provide the necessary adaptive QoS support to resource demanding applications, such as multimedia applications, which are sensitive to changing networking conditions.

In [5], authors classify the cross-layer design proposals in literature in four main categories, depending on the way the layers of the network architecture are coupled: (a) creation of new interfaces, (b) merging of adjacent layers, (c) design coupling without new interfaces and (d) vertical calibration across layers. The first approach consists on creating a new interface not available in the layered architecture to permit the information sharing between layers. This approach requires adding extra code to the original participating protocols and defining new headers or methods to access to cross-layer information. In the second approach, the idea is to design two or more adjacent layers together such that the service provided by the new superlayer is the union of the services provided by the constituent layers. This does not require any new interfaces to be created in the stack, because the superlayer can use the interfaces that already exist in the original architecture. The third category involves coupling two or more layers at design time without creating any interfaces for information sharing at runtime, but by designing the involved protocols with reference of each other. The problem of this approach is that it may not be possible to replace one layer without making corresponding changes to another layer. The fourth approach refers to adjusting parameters that span across layers. This cross-layer design approach is motivated by the idea that the performance seen at the level of the application is a function of the parameters at all the layers below it. Thus, join tuning of parameters can help to achieve better performance than individual setting of parameters can achieve. Even if vertical calibration can be done in a static manner at design time to optimize some specific metric, it could be more advantageous if it is done dynamically at runtime, emulating a flexible protocol stack that responds to variations in the channel, traffic, and overall network conditions. This requires, however, mechanisms to retrieve and update the values of the parameters being optimized by the different layers. Nevertheless, this is the approach that we have followed in our cross-layer design (Figure 1).

<table>
<thead>
<tr>
<th>Protocol Stack</th>
<th>Cross-Layer Optimizer</th>
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<tbody>
<tr>
<td>Application Layer 5</td>
<td>Up-to-date Local and Network Information Cache</td>
</tr>
<tr>
<td>Transport Layer 4</td>
<td>Inter-layer Communication Interface</td>
</tr>
<tr>
<td>Network Layer 3</td>
<td>QoS Control</td>
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<tr>
<td>MAC Layer 2</td>
<td></td>
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<td>Physical Layer 1</td>
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**Figure 1 - Vertical calibration approach to cross-layer networking design**

3. VISTA-XL

ViStA-XL (Cross-Layer design for Video Streaming over Ad hoc networks) has been designed to provide soft-QoS (i.e. with no strict QoS guarantees) in MANETs.

In ViStA-XL, all network architecture layers (Physical, MAC, Network, Transport and Application) cooperate with each other to fulfill the task of QoS provision to video-streaming applications by service differentiation (Figure 2).

Even if our system has been designed to transmit hierarchical layered-coded video mainly, it can actually manage any kind of layered-coded video, e.g. hierarchical, Multiple Description Coding (MDC), Fine Granularity Scalability (FGS).

In this work we have considered MPEG-2 hierarchical temporal scalable layered-coded video. MPEG-2 coded video is formed by GoPs (Groups of Pictures). A GoP is composed by a fixed number of coded frames and has a defined structure. There are basically three types of frames: I frames, P frames and B frames. I frames are the main type of frames
in the structure. They carry the most important information of the pictures and encode spatial redundancy. There is only one I frame in a GoP. P frames mainly encode temporal redundancy and carry differential information from the preceding I or P frame. In general, their size is about 10% the size of I frames. Finally, B frames also encode temporal redundancy and carry only differential information from the preceding and following I or P frames. Their size is only about 2% the size of I frames.

It is important to say that I frames are absolutely necessary to decode the video sequence, and an entire GoP would be lost if we don’t have the corresponding I frame at decoding time; even if we have all the P and B frames of that GoP. In the same way, B frames are useless if preceding and following I or P frames are not present at decoding time. On the other hand, GoPs can be decoded even if just I frames are present. Thus I frames contain the most important video information, while information carried by B frames is the least important one for the decoding process at the receiving side when recovering the video sequence.

The main element of our ViStA-XL design is the Cross-Layer Optimizer (XLO). By exploiting periodically obtained interference) and in nodes (mobility, available resources).

As it can be seen in Figure 2, all network architecture layers send information to XLO module. Thus, in our design, Physical Layer informs about received signal power from each one of the neighbors of a node (RxPrx), as well as the signal to interference-plus-noise ratio (SINR x). MAC Layer sends information related to the radio channel usage, such as quality of links to its neighbors, interference level in channel, number of sent and received MAC frames, channel utilization, hidden nodes, etc. Network Layer informs to XLO module about of the D available paths between source and destination nodes, which it maintains in cache memory. Network Layer also informs periodically about the quality of each one of those D paths by issuing probe messages which return with the following information relative to each path: reliability (RM, Reliability Metric), mobility index of nodes (MM, Mobility Metric), end-to-end available bandwidth (BW_e), percentage of packets’ losses, mean packet delay and mean delay jitter. With that information, XLO module decides dynamically which K paths will be used to route the data packets from source to destination until next arrival of information about the quality of the D available paths. By means of RTCP (Real-Time Control Protocol) generated reports, Transport Layer informs about the quality metrics for each end-to-end communication: percentage of packets’ losses, mean packet delay and mean delay jitter. This information helps XLO module to ask application to adjust its QoS requirements to network and node’s conditions, if possible. The Application Layer passes information to the XLO module about the QoS requirements from the specific application (layered-coded video-streaming): required bandwidth (BWREQ), minimum user acceptable bandwidth (BWMIN), and maxima packets’ losses, delay and delay jitter (LMAX, DMAX y JMAX, respectively) that can be accepted by the application. With this information and the end-to-end available bandwidth estimation carried out by XLO module, this latter performs the Admission Control (CAC) of new communication requests.

One of the main characteristics of ViStA-XL is that it has been conceived for flexible applications that can adapt to dynamic conditions of MANETs and heterogeneity of network nodes. Transmission of layered-coded video allows to light mobile nodes with scarce resources and low profile features (e.g. PDA), as well as to more powerful and with more resources mobile nodes (e.g. laptop computers), to be able to access to video-streaming services (e.g. video-on-demand, VOD). Moreover, flexibility of layered-coded video makes possible to applications to keep alive on-going video communications even in low performance network conditions. This could be done by lowering the quality of the transmitted video, instead of just cutting the service off.

At Network Layer we use an algorithm that allows us to find and manage multiple paths between a source and a destination. Our multipath algorithm is based on DSR (Dynamic Source Routing) protocol. By using several paths for video packets transmission, it is possible to obtain the necessary bandwidth to let a video-streaming communication to be admitted by the CAC mechanism with certain end-to-end QoS. Also, path diversity allows to unequally protect video information packets (depending on their importance) and to perform load balancing. It is important to note that it is not this algorithm which performs the routes selection for

Ad hoc Network Protocol Stack

<table>
<thead>
<tr>
<th>Layer</th>
<th>Parameters</th>
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<tbody>
<tr>
<td>Application Layer</td>
<td>Video-streaming</td>
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<tr>
<td>Multi-Layer coded</td>
<td>Video-streaming</td>
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<tr>
<td>Video-streaming</td>
<td>Video-streaming</td>
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<tr>
<td>Transport Layer</td>
<td>UDP, RTP/RTCP</td>
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<tr>
<td>IP, multipath DSR</td>
<td>Pkt Classifier and Queue Mgmt</td>
</tr>
<tr>
<td>Network Layer</td>
<td>IP, RSSM, BW, K, d, j</td>
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<tr>
<td>MAC Layer IEEE802.11x</td>
<td>MAC Layer Parameters</td>
</tr>
<tr>
<td>Physical Layer</td>
<td>SINR x, RxPrx</td>
</tr>
</tbody>
</table>

Cross-Layer Optimizer (XLO)

- Admission Control
- Maximum Allowable BW
- Delivered QoS Monitoring and Control
- Congestion Control
- End-to-end Available BW Estimation
- Selection of the K best paths
- Node’s Available BW Estimation
- Node’s Relative Mobility Metric and Links’ Reliability Computation and Grading

Figure 2 - ViStA-XL architecture overview
packets’ routing but the XLO module, based on the knowledge of node and network states (e.g. end-to-end available bandwidth, percentage of packets’ losses, end-to-end mean packet delay, index of mobility of nodes in a path, path reliability, etc.).

One of the main functions of the XLO module consists on making possible interactions between different layers of the network architecture (interfacing). Thus, for example, packet classification, queuing and scheduling performed at Network and MAC Layers are based on packet marking done at Application Layer. Furthermore, these interactions depend on assigned bandwidth to each communication and the number of selected paths.

The design of ViStA-XL is based on the well known and widely used IP (Internet Protocol) at the Network Layer, and UDP (User Datagram Protocol) and RTP/RTCP (Real-Time Protocol/Real-Time Transmission Control Protocol) at the Transport Layer, as well as on IEEE 802.11x protocols at the MAC and Physical Layers. We have also based our design on some radio channel measurements ideas taken from the IEEE 802.11 TGk work [6].

4. SIMULATION RESULTS

In this section we present some simulation results obtained with a cross-layer QoS-aware algorithm, presented in [7], which is based on ViStA-XL design. Simulations have been carried out using the NS-2 simulator [8], over which we have developed the multipath DSR-based routing protocol. Table 1 summarizes simulation settings.

<table>
<thead>
<tr>
<th>Table 1 – Simulations settings</th>
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<tbody>
<tr>
<td>Simulation area</td>
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<tr>
<td>Number of nodes</td>
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<tr>
<td>Nodes’ speed</td>
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<td>Mobility model</td>
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<td>Tx range</td>
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<tr>
<td>MAC Tx rate</td>
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<td>Video sequence</td>
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<tr>
<td>Video format</td>
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<tr>
<td>Simulation time</td>
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<tr>
<td>Simulation runs per scheme</td>
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</table>

Five scenarios have been simulated, each one of them using a different multipath scheme (Figure 3). We have set high priority to I frames, medium priority to P frames and low priority to B frames substreams.

Figure 4 shows the mean percentage of packet losses for each one of the simulated scenarios, obtained from the fraction lost packets field reported by the RTCP packets sent each second from the destination node. We also show the 99% confidence interval for these values.

From Figure 4, it can be seen that packet losses increases as the number of paths increases. This is due to the combination of several factors. First of all, less quality paths are used to transmit the packets from all P and B frames (which counts for 93.3% of all transmitted video frames), and those paths have higher probabilities of becoming broken routes by the end of the algorithm iteration. So there is a high probability to lose the low priority packets we sent through these routes (as we can see in Figure 5). Besides, P frames are bigger than B frames, and so they must be fragmented in more packets and they have more probability of being lost. It is worth noting that once a packet of a fragmented frame is lost, the entire frame becomes lost.

![Figure 3. Simulated scenarios for N=1, 2, 3, 4 and 5 paths](image3)

![Figure 4. Losses percentage for N=1, 2, 3, 4 and 5 paths.](image4)

![Figure 5. Frames losses for N=1, 2, 3, 4, and 5 paths](image5)
Nevertheless, our framework exploits the benefits of load-balancing (i.e. achieving higher equivalent rates, using the available resources more efficiently and decreasing the end-to-end delays) in order to do not saturate the best path with packets from P and B frames. Therefore, other video-streaming users could use the better paths to send their high priority packets, which is certainly important in MANETs due to the dynamic and limited available bandwidth. Setting higher priority to I frames has proved to be a good option, as they are the most important for the decoding process. Thus, the user will notice a higher video-quality as I frames are closely related to the subjective quality.

In Figure 6 we show the mean delay jitter obtained for the five simulated schemes. As we can see, the delay jitter decreases when using 2 and 3 paths schemes with respect to the 1 path scheme, while it increases considerably when using 4 and 5 paths schemes. We also show the 99% confidence interval.

![Figure 6. Delay jitter for N=1, 2, 3, 4 and 5 paths.](image)

All things considered, in order to achieve scalability in an ad hoc network used by different users, we can affirm that the most proper multipath scheme is the one with N=3 (see Figure 3) and it is also not worth managing more than three paths.

### 5. CONCLUSION AND FUTURE WORK

In this paper, we present ViStA-XL, a cross-layer network architecture design for QoS-provisioning to video-streaming applications over MANETs. Based on ViStA-XL principles, we have developed and tested a cross-layer QoS-provision algorithm to support a multipath routing scheme for video-streaming applications over ad hoc networks. This way, our design is also able to provide load-balancing and unequally protection to different types of video substreams. This allows using the available network resources more efficiently, which is certainly important in this type of networks. Besides, several nodes can share the best paths to send their most important video packets, improving the final user-level QoS.

We are also considering the option of working with relative thresholds values regarding the scenario, instead of absolute values. This way, the different parameters involved in the algorithm would vary dynamically depending on the network evolution, taking into account the mobility of the scenario, and the number of paths between source and destination.

As we mentioned before, we base our ViStA-XL design on some IEEE 802.11x standards and drafts. However, until now, we have been working with the IEEE 802.11b standard only. In a near future we will expect to have some work based on IEEE 802.11e and IEEE 802.11k the draft proposal. Also, we are implementing a Proportional Differentiation (PD) approach to guarantee proportional QoS between different classes of services.

Finally, we devise to analyze the performance of our design using directional antennae arrays and Orthogonal Frequency Division Multiplexing (OFDM) to diminish the co-channel interference. In addition, we will evaluate the benefits of introducing redundancy to protect some video packets by sending them through several paths, looking for increasing the probability of data delivery and final objective and subjective video quality.

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