Survey of Cross-layer Proposals for Video Streaming over Mobile Ad hoc Networks (MANETs)

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Abstract – **Efforts to realize video streaming over Mobile Ad hoc Networks (MANETs) meet many challenges, which are addressed by different techniques. In the highly dynamic and unpredictable environment of MANETs, cross-layer mechanisms seem to be the most suitable for optimising video streaming. This paper presents a survey of 44 studied papers on the area, comparing tools, parameters and metrics used for their evaluation. It also indicatively describes in more detail some of these proposals.**

Keywords- cross-layer mechanisms; mobile ad hoc networks; video streaming;

I. INTRODUCTION

Emerging services in the context of the Future Internet pose new requirements on the underlying network infrastructure [1] [2] that derive from the need to operate on top of dynamic, heterogeneous and complex environments. In order to cope with these requirements, such services will be expected to (i) be aware of the context and the environment in which they operate, (ii) self-configure and self-adapt according to the network conditions that they sense and (iii) require minimum feedback from the end-user avoiding any explicit human intervention.

These requirements become more challenging in case of video streaming services. Since several years, video streaming over the Internet has become a well-established service and has many successful applications including video conferencing, surveillance systems and news on demand. The recent developments in mobile computing and wireless networking provide the opportunity to extend these video streaming services to mobile use, not only within established cellular infrastructures, but also in mobile ad hoc networks (MANETs). The latter involve multi-hop routing where nodes may act as servers, clients and routers, in an attempt to cover large geographic areas without any pre-existing infrastructure.

Video streaming over MANET introduces significant challenges, not only with regard to constrained node resources (CPU, link bandwidth, storage and energy consumption) but also associated with the high dynamicity of the MANET topology, combined with the increased sensitivity of video streaming services against network conditions. The effects introduced by the challenging requirements of video streaming service, wireless links, mobility and limited node resources present a rich set of challenges that span all layers of the protocol stack [3].

After an extended survey of the existing techniques for optimising video streaming over MANETs, we concluded that the most used and efficient approach is the cross-layer logic; over 65% of the papers which have been examined propose cross-layer mechanisms. As a result, the pool of our survey comprises 44 papers proposing a cross-layer mechanism for optimizing video streaming over MANETs.

The rest of the paper is organized as follows: in Section II, the main idea of the cross-layer optimisation is briefly presented, followed by a comparison of the surveyed proposals and a brief description of some representative ones; strategies for performance evaluation of the aforementioned cross-layer proposals are presented in Section III; finally, Section IV summarizes the paper, presents some conclusions and discusses future work.

II. CROSS-LAYER OPTIMISATION PRINCIPLES

A. General Approach

A layered architecture, like the seven-layer OSI model [4], divides the overall operation of the network into layers and defines a hierarchy of services to be provided by the individual layers. A strictly layered network architecture forbids direct communication between nonadjacent layers, and communication between adjacent layers is limited to procedure calls and responses.

Alternatively, protocols can be designed by violating the reference architecture, for example, by allowing direct communication between protocols at nonadjacent layers or sharing variables between layers. Such violation of a layered architecture is the cross-layer optimization approach, which refers to protocol design by exploiting the dependence between protocol layers to obtain a better system performance. In cross-layer technique, instead of considering a layer as a completely independent functional entity, 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 decisions processes such as route selection, or as input to algorithms.

In general, cross-layer technique proposals can be classified in four main categories, depending on the way the layers of the network architecture are coupled [5]: (a) creation of new

interfaces, (b) merging of adjacent layers, (c) design coupling without new interfaces and (d) vertical calibration across layers.

B. Cross-Layer Optimisation in MANETs

Cross-layer optimisation is used very often in MANETs. MANETs exhibit specific challenges that do not exist in other networks, due to time-varying conditions of wireless links, mobility of nodes and energy power limitations that can produce frequent topology and connectivity changes. That is why these networks need a tailored networking design approach, which allows them to adapt dynamically to changing conditions in order to maintain on-going communications. In fact, adoption of cross-layer mechanisms in MANETs is almost mandatory. Indeed, the most used technique for realizing video streaming over MANETs is the cross-layer approach. In general, out of more than 70 studied papers presenting techniques for optimizing video streaming over MANETs, approximately 65% of them (44 papers) utilize some sort of cross-layer optimization.

C. Categorization

Cross-layer proposals for video streaming over MANETs can be further divided in categories (see Fig.1), with regard to the layers which are covered.
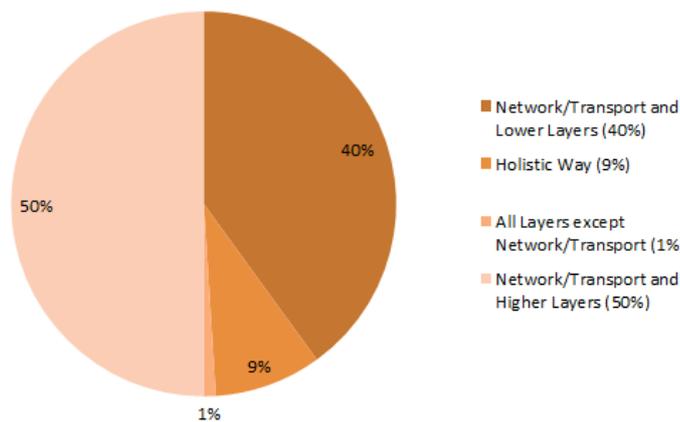

Figure 1 – Categorisation of surveyed cross-layer proposals.

One typical approach, constituting 50% of all the identified efforts, involves information exchange and optimization between the application layer operations (codec configuration etc.), the routing mechanisms at the network layer and the transport protocols in order to obtain optimal combinations of video bit rates and selected transport and routing policies. In these techniques, the routes are selected to fit stream requirements, and where encoding bit rates and redundancy are adapted to available routes, respectively.

Other efforts consider routing and transport combined with parameter exchanges with lower layers (i.e., PHY/MAC). These constitute 40% of the identified efforts. Lower layer

optimization, based on parameter exchange with some higher layers, exists.

Some approaches also can be considered as more holistic, since they span across all layers. They represent 8% of the total surveyed papers.

The following paragraphs provide a brief description of indicative research efforts within each of the aforementioned categories.

D. Network/Transport and Higher Layers

Such proposals, constituting 50% of the total, as aforementioned, use adaptation and optimization at the network/transport layers along with upper layers [6, 7, 8, 9]. Niraula et al. [6] adopts Multiple Description Coding (MDC) to create multiple video descriptions for a given video stream. A novel cross-layer and P2P based solution (CLAPS), which is proposed, distributes pieces to the closest peer which on its turn shares the pieces among the interested peers using a Multicast Overlay Spanning Tree protocol (MOST). Greco et al. [7] propose a content routing/delivery protocol inherently designed for MANETs, exploiting the intrinsic broadcast property of the medium. Since MANETs are usually built to support a specific application (application-driven networking), they assume that all nodes are interested to whatever stream is distributed and willing to cooperate to its distribution; hence, there is no need to flood any request: when a stream is distributed, the goal of the source is to reach any other node of the MANET as quickly and as reliably as possible. Thus, the proposed protocol is meant to provide an application-driven MAC-level selective flooding that can efficiently relay a real-time video stream represented in multiple description. Andreopoulos et al. [8] propose an integrated cross-layer optimization algorithm aiming at maximizing the decoded video quality of delay-constrained streaming. The key principle of their algorithm lies in the synergistic optimization of different control parameters at each node of the network across the protocol layers (application, network, etc.). Mastronarde et al. [9] focus on delay-sensitive multimedia transmission among multiple peers. They propose a distributed and efficient framework for resource exchanges that enables peers to collaboratively distribute available networking resources among themselves based on their quality of service requirements, the underlying channel conditions, and network topology. The knowledge of networking resources allows efficient adaptation of the media stream to the network conditions.

E. Network/Transport and Lower Layers

Such proposals, constituting 40% of the total, as aforementioned, use adaptation and optimization at the network/transport layers along with lower layers (MAC, PHY) [10, 11, 12]. Gomathi et al. [10] propose a novel method for enhancing the quality of multimedia applications in MANETs. The enhancement is achieved via the Connectionless Light Weight Protocol (UDPLite) that supports multimedia applications. In addition to implementing the transport layer protocol, parameters of MAC layer are also considered to

propose an approach that achieves a reduction in delay, jitter and increase in PSNR. Navaratnam et al. [11] study the impact of medium contention on transport layer performance and then propose a new transport protocol for improving quality of service performance in MANETs. Their proposed protocol, Link Adaptive Transport Protocol provides a systemic way of controlling transport layer offered load for multimedia streaming applications, based on the degree of medium contention information received from the network. Oh et al. [12] present a cross-layer design for a reliable video transmission based on multichannel MAC protocol with TDMA. After a study of the multichannel MAC protocol through Markov chain model, two novel cross-layer modules are adopted for the design of multichannel MAC protocol. First, they adopt maximum latency rate (MLR) as the channel quality metric. Unlike the traditional MAC design based on network allocation vector (NAV), MLR is implemented to provide differentiated traffic so that the channel with smaller MLR time is initiated for higher priority traffic. Second, they adopt two congestion-aware metrics, namely MAC utilization and queue length of MAC layer, to improve the congestion-aware routing protocols with AODV and DSR.

F. Holistic Approach

While all above proposals succeed their optimization by concentrating on lower or higher layers, there are also more holistic approaches, spanning across all layers. Delgado et al. [13] present an architecture for such holistic cross-layer optimisation. Their architecture relies on applying several optimization strategies to different network layers. A real-time cross-layer optimizer collects information about the node and network states from different layers of the network protocol stack. In order to minimize the error between received and transmitted video signals, the optimizer module takes then the necessary decisions to act on different layers' parameters dynamically. Their simulation results show that this proposed network design can improve the performance of video streaming transmissions over MANETs in spite of frequent changes in network topology and node conditions. Wu et al. [14] propose a cross-layer optimized framework which jointly considers the video coding and transmission in MANETs. In their framework, video coding parameters, network path selection, MAC layer frame size, and modulation and coding schemes at PHY layer are systematically optimized across the entire network protocol stack. To achieve the goal of real-time video communication with high-quality and/or stringent delay requirements, the proposed framework is formulated into a minimum distortion and/or minimum delay problem. The formulated problem is efficiently solved as a Lagrange dual problem.

G. Discussion

It seems widely accepted that solutions targeting video streaming over MANETs require a cross-layer approach in order to obtain an acceptable subjective user experience (QoE). It is realized that higher layers need to adapt to lower layers' conditions, and that lower layers need to adapt to higher layers' requirements.

All the studied papers show that the most popular cross-layer approach combines techniques belonging to the upper layers, i.e. the network, transport and application layers. The encoder at the application layer typically adjusts video bitrate to available bandwidth by varying coding parameters, adding redundancy to cope with transmission failures, and splitting the video stream into more than one descriptions (e.g., layered coding, SVC (Scalable Video Coding), MDC (Multiple Description Coding) for transmission across several paths.

At the network layer, multipath routing is preferred over single path routing to add path diversity. With multipath routing, the probability of packet loss bursts is reduced and higher aggregate bandwidth is achieved. Congestion is prevented by the spread of the load across several nodes and links. These routes' (often two or three) characteristics should furthermore optimally match the requirements of the video streams they are intended to carry. Since path selection, packet scheduling, added redundancy and bit rate are all inter-dependent, parameters are usually exchanged in both directions of the stack. This tuning of parameter values, involving the optimal selection of multiple routes, according to a mathematical model of the streaming environment, is often formulated as a hard optimization problem. Thus, it is typically solved by heuristic methods. To obtain efficiency, distribution of such algorithms would be beneficial. However, because of the communication challenges already mentioned, this distribution becomes especially challenging.

III. STRATEGIES FOR PERFORMANCE EVALUATION

This section presents and discusses the strategies followed for the evaluation of the performance of the proposed approaches. The summary starts with the evaluation tools, which are used. Then, an overview of the chosen evaluation parameter values and metrics is presented.

A. Evaluation Tools

An overview of the surveyed papers shows that the most evaluation experiments (95%) are performed through simulation. Network Simulator 2 (NS-2) is the most popular of the well-known simulation tools utilized in 62.5% of the simulation reports. The rest of the proposals use different simulators like OPNET or NEMAN [15]. Very few papers follow a purely analytical approach (see Fig. 2). There is also one more survey, which is very interesting, for MANET simulation studies reported in papers published at MobiHoc from 2000 to 2005 [16].
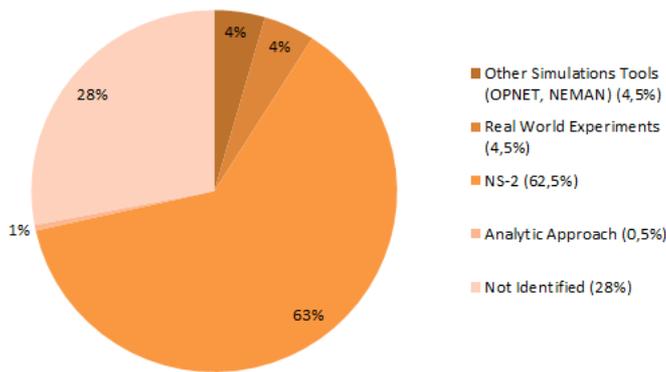
Figure 2 – Distribution of simulation tools

Utilization of a well-known and popular simulator can be beneficial for both comparability and repeatability, since large parts of the utilized models are identical. It is also easier when it is specified which version of the evaluation tool and operating system (OS) was used, along with the relevant parameter values of the experiment. But, this is not always the case. Although many of the reported results (about 72%) identify all the tools that they used for their utilization, which is important since results from such evaluations can hardly be repeated and compared. So, it is notable the need of increasing the report of which simulator etc. they used to obtain the presented results.

In network environments such as MANETs, the real-world experiments are usually designed to investigate performance during well-defined events that are expected to occur regularly in the target scenario. This kind of experiments can be argued as producing the most realistic results for the scenarios similar to that in which they are conducted, but they are not always feasible in MANETs. If the solutions to be evaluated target scenarios with many nodes, it becomes very hard to conduct real-world experiments in realistic scenarios. In addition to implementation issues, this is particularly difficult due to nodes mobility. The number of nodes included in the surveyed real-world experiments is maximum 4, which is very low compared to simulated experiments. The difficulty of handling large test beds and their complex implementation are the reasons why so few papers conduct real-world experiments.

B. Evaluation Parameters and Metrics

In this section, an overview of the parameter values utilized by the surveyed techniques will be presented. Note that parameters vary considerably among the contributions, due to the difference in the targeted scenarios. This is a considerable issue, since a certain common ground is clearly desirable for the purpose of fair comparability of similar techniques. The three basic experiment parameters are: (i) number of nodes, (ii) node transmission radius and (iii) area size of the scenario size. In few experiments, the above parameters are treated as factors where the values change between the various scenarios. It is seen that most simulations involve from 20 nodes up to 300 nodes in some cases and that their transmission range spans from 250m down to below 30m. Of course, for products conforming to the IEEE 802.11 standards, a communication range of 250m is only realistic in open space without obstacles.

So, it is questionable whether setting a high transmission range will yield realistic results.

The area of the scenarios (typically two-dimensional) is found to be highly variable between evaluation reports. It could be said that although most scenarios involve areas smaller than 800 m^2, there is considerable variability in this parameter. Only few scenarios use bigger areas than this, ranging up to 2,000 m^2. For comparison of these scenarios the number of nodes, their transmission range and node density should be considered. The fact that so many reports fail to specify one or more of these parameter values is significant, as this makes comparability and repeatability more difficult or even impossible. The majority of scenarios have a density (referring to the number of neighbors per node) of less than 10, and a peak between 5 and 7 could be seen. Although many of the reported results are based on comparable values of the node density, many are unfeasible for comparison due to highly varying.

The node mobility models can have significant impact on the results of the performance evaluation [17]. In the analyzed papers, the most commonly used mobility model is the random waypoint mobility model [18], which is employed in 90% of MANET scenarios. In the remaining scenarios, other mobility models are used like the Manhattan mobility model, which are more realistic patterns of mobility and thereby provide more reliable results. Random waypoint models are on the other hand often selected for comparability and to avoid excluding any particular real-world pattern. These can compromise realism, since such mobility rarely or never corresponds directly to any real-world scenario. However, the most important factor for the proper comparison between results is the speed of the randomly moving nodes. In most cases, this is a random value rather than a constant parameter. The ranges of the node speed vary considerably among the scenarios; the minimum speed tends typically to vary between 1 up to 20m/s in some cases.

These values indicate that there is no clearly defined pattern on the speed for e.g., human movement. Most of these values usually exceed the average speed of a human walking, which is typically up to 2m/s. It should be noted that speed could be seen in relation to node density, and although high speeds are usually associated with the challenges of increased dynamicity, and it should be noticed that many caching, replication and store-carry-forward solutions could benefit from the high mobility. Also, it should be considered that for some metrics, increasing the node speed is equivalent to increasing the duration of the simulation.

The workload, which is utilized in experiments, consists of video clips of a few minutes' duration. The streamed video clips are usually of modest resolution: either CIF (352x288) or QCIF (176x144). About 75% of reports state the video resolution, which they used. For encoding, codecs compliant with H.264 and MPEG appear to be the most common, utilized for the majority of reports which identify the codec. Regarding encoding rate, it is usually below 600 kbps, although a few evaluations involve clips encoded over 1 Mbps. Considering that mobile nodes participating in MANETs are typically resource constrained with small displays, these are in general

realistic parameters for video streams. The motion characteristics of the content have an impact on the results. So, one should conduct experiments with both highly dynamic video content (like action clips) and more static content (like interviews). The majority of the video traces, which are used for evaluation in the surveyed papers, are available from [19]. From the reports, which are studied, identifying video content, the clip entitled "Foreman" is the most utilized, used in several experiments. Since this is an interview clip, this can be regarded as a common ground for video workload with low motion. About 60% of reports utilize more than one clip for comparison of results with varying amounts of motion. Some popular high-motion videos are those entitled "Highway" and "Aviator".

Finally, regarding the metrics utilized for performance assessment, the most common is peak signal-to-noise ratio (PSNR), calculated using both the transmitted and the received video stream. PSNR was used to measure the received video quality in the most surveyed evaluation reports. Other measured metrics involve packet loss, delay and jitter.

C. Discussion

All the above findings suggest that there is no clearly defined common ground for comparison between experimental results through a commonly used set of experiment parameters. Although researchers provide accurate comparisons between the proposed solution and a small set of similar solutions, comparison between results from unrelated papers often appears unfeasible due to the variability of basic experimental parameters. The main cause for variability lies in the highly heterogeneous types of scenarios targeted by the solutions, and hence such comparisons are often meaningless. In many situations, comparability is compromised in favor of realism. It appears that researchers have different opinions on what constitutes the typical MANET scenario. An open and difficult question is associated with the degree of realism obtained in these evaluations. Only 4.5% (see Fig. 2) of the results is obtained from real-world experiments, and the ones conducted cannot be said to properly correspond to circumstances in which the evaluated solutions are to be deployed. For simulations, realism is reduced because almost no efforts consider node resources in their models. Also, it is clear that most of the evaluation reports fail to include sufficient information for the experiments to be repeatable.

IV. CONCLUSION

This article presented a comparative survey of cross-layer proposals addressing the challenges of video streaming over MANETs. In addition to overall statistics, an overview of some indicative proposals was given. Also, a summary of the strategies for performance evaluation and their analysis with regard to realism, repeatability and comparability were provided.

Although the survey indicated several interesting and quite effective proposals, there are still certain issues, which need to be addressed properly, affecting the real-world applicability of the proposed mechanisms. First, since MANETs are assumed to involve quite resource-constrained devices, techniques for

efficient resource management should also be included. As very few proposed solutions have been implemented and tested on real equipment, the employment of hardware testbeds in addition to network emulators would be desired. There is also an additional issue with regard to sparse MANETs; end-to-end video streaming requires a physical end-to-end path between the source and the destination. In sparse MANETs, however, the probability of the existence of such a path may be low at any given point in time. Therefore, research should also be extended to study streaming mechanisms especially tailored to sparse MANETs.

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