

Mechanisms for Improving Video Streaming in Mobile Ad Hoc Networks

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Abstract

Offering a real time video transmission service, using mobile ad hoc networks and granting a specific Quality of Service (QoS) is a hard challenge. In fact, the network topology is extremely unstable and its variability causes the loss of transmitted information. To avoid the system breakdown, it is necessary to incorporate a powerful mechanism against channel failures in different levels of the communication process. In this paper, we show two research fields for improving the video streaming service in mobile ad-hoc networks: Hierarchical Routing Protocols and Multiple Description Coding (MDC). A variety of workload and scenarios, as characterized by mobility, load and size of the ad hoc network have been simulated using NS-2. A performance evaluation of video streaming using both flat (OLSR, Optimized Link State Routing) and hierarchical (HOLSR, Hierarchical OLSR) routing protocols is shown in this paper. On the other hand, we have evaluated the effect of MDC techniques, which generate multiple video streams, called descriptions. These can be independently decoded, increasing the quality of the played video. The simulation lets us compare the QoS of the video streaming paying attention to objective parameters such as Peak Signal to Noise Ratio (PSNR), packet delivery ratio and interruptions.

Keywords. AdHoc Networks, Video Streaming, Routing Protocols, Multiple Description Coding, Performance

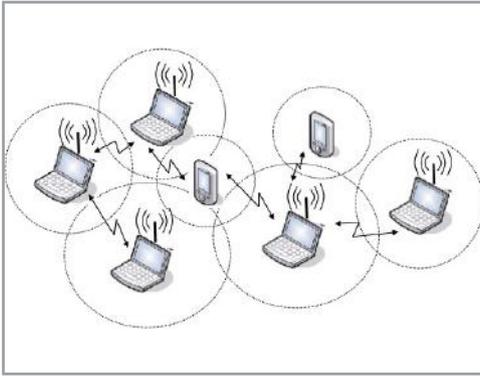
1. Introduction

In recent years, wireless technology has experienced an important growth. The main improvements can be found both in network infrastructures and in application and mobile devices development. We can now find a wide variety of these, such as mobile phones, laptops or PDAs (Personal Digital Assistant), which are capable

of sending and receiving real-time information like video. Nowadays, a great interest is focused on Mobile Ad hoc Networks (MANETs) (Figure 1). MANETs are formed by mobile nodes, which are connected via wireless links without using an existing network infrastructure. Thus, MANETs don't require any fixed infrastructure such as a base station to operate. Moreover, routes between nodes may include multiple hops –that is why these networks are called multihop wireless ad hoc networks– because in order to communicate with nodes that are out of its transmission range, these nodes need to use intermediate nodes as routers [1].

The defining characteristics of ad hoc networks include resource-poor devices, limited bandwidth, high error rates, and a continually changing topology. Because of the dynamic topology of MANETs, routing protocols are more complex than traditional routing protocols used on the Internet. Anyway, the main objective of these routing protocols is achieving efficient routes between the nodes so that the information will be available in destination nodes reliably and within boundary time. A good performance of these protocols should have low overhead and bandwidth consumption, and a fast route convergence, even when there are changes in traffic load or the number of nodes (scalability).

A lot of works has been done on the routing protocols in ad hoc networks, taking into account different scenarios and traffic conditions [2, 3, 4]. Most of the routing protocols proposed consider ad hoc networks as a homogeneous one; that is that all nodes have the same capabilities. This kind of protocols is known as flat protocols [5, 6, 7, 8, 9]. However, many ad hoc networks may be considered heterogeneous because there are mobile nodes with different capacities (bandwidth, transmission range, etc.). To maintain scalability in these heterogeneous ad hoc networks (capacity of a network to maintain its performance when the number of nodes increases) hierar-



■ **Figure 1.** Example of a MANET

chical routing protocols should be considered as a good option [10, 11, 12].

On the other hand, if the objective of the MANET is offering real-time services –such as video streaming- it will be interesting to evaluate the performance offered by the routing protocols and use mechanisms that improve quality of service in video transmissions. These mechanisms can be used at different layers of the transmission architecture such as encoding layer, transport layer, routing layer, or even physical layer. As an example, multidescription coding is emerging as a promising mechanism to improve video error resilience and quality [13].

Multiple description coding is a video encoding technique, which generates several bitstreams called descriptions from a media source, where every description can be decoded independently, providing a useful reproduction of the original stream. In order to decode the video stream, any description can be used. Moreover, the descriptions contain complementary information in order to improve the quality of the decoded video when the number of received descriptions increases.

As performance metric, it is important to pay attention to PSNR, packet delivery ratio and interruptions, which are parameters related to objective quality of reconstructed videos [14].

This paper focuses on describing two mechanisms for improving video streaming in mobile ad hoc networks. A hierarchical routing protocol (HOLSR) is introduced and later compared with the flat version (OLSR), and additionally, MDC is explained and also shown as an error resilience technique for video encoding, using the well-known Network Simulator NS-2.

The rest of this paper is organized as follows. Section 2 briefly compares the two routing protocols: OLSR and HOLSR. In Section 3 we describe an introduction to the MDC mechanism. Section 4 shows the simulation results of the routing and the multidescription performance evaluations. Finally, we present the conclusions and our future work in Section 5.

2. Ad Hoc Routing protocols

Depending on how routing protocols gather information about nodes reachability, they can be classified as proactive, reactive or hybrid. The main characteristic of proactive protocols is that each node in the network maintains a route to every other node in the network all the time. In proactive approaches each node steadily keeps and updates a route to every node in the ad hoc network. So, routes are always available when they are needed. As a consequence, there is a constant overhead due to routing traffic but there is no initial delay in data communications. This constant overhead could become a disadvantage in large ad hoc networks or in ad hoc networks with a high mobility in the nodes. Examples of proactive approaches are OLSR, DSDV (Destination-Sequenced Distance Vector), FSR (Fish State Routing) or TBRPF (Topology Broadcast based on Reverse-Path Forwarding).

Reactive protocols, however, try to determine routes on demand by flooding the network with route request packets. This mechanism produces high latency time in route finding but, on the other hand, routing traffic is generated only when a route is requested. Examples of reactive approaches are AODV (Ad hoc On Demand Distance Vector), TORA (Temporary Ordered Routing Algorithm) or DSR (Dynamic Source Routing).

Hybrid protocols combine the advantages of proactive and reactive routing. Routes are initially established with some proactively prospected routes and then routing information is updated by reactive flooding. Zone Routing Protocol (ZRP) is a hybrid protocol, which divides the topology in zones and uses proactive routing inside a zone and reactive routing among zones.

Both OLSR and HOLSR studied in this paper are proactive routing protocols.

2.1. Optimized Link State Protocol (OLSR)

The OLSR Protocol is described in RFC 3626 [5]. It is a variation of traditional link state routing, modified to improve operation in ad hoc networks. The optimization is based on a technique called MultiPoint Relaying (MPR). Particularly, OLSR defines these basic types of control messages:

- HELLO – They are transmitted to all neighbours.
- TC (Topology Control) – They spread topology information to their neighbours. This mechanism of diffusion is optimized using MPRs.
- HNA (Host and Network Association) – They are used by a host to announce itself as a gateway to specific networks.

A node sends a HELLO message to identify itself and it also contains a list of neighbouring mobile nodes. From a HELLO message, the mobile node receives information about its immediate neigh-

A good performance of ad hoc routing protocols should have low overhead and bandwidth consumption, and a fast route convergence

HOLSR is introduced to increase scalability of OLSR in large ad hoc networks

hours and two-hop neighbours. In these messages nodes also announce their own availability to act as MPR. There are 8 levels of willingness, from the lowest (indicates that this node must never be chosen as an MPR), to the highest (indicates that this node should always be chosen as an MPR). The willingness must be considered when calculating MPRs. RFC 3626 proposes a simple method to optimize MPR calculation. A TC message is generated by the MPR nodes, announcing which node has selected them as MPRs. Such messages are relayed by other MPRs throughout the whole network, enabling the remote nodes to discover the links between MPRs and their selectors. Based on such information, the routing table is calculated using the shortest-path algorithm.

The OLSR protocol supports nodes having multiple interfaces. However, OLSR employs a “flat” mechanism, whereby a node sends HELLO and TC messages through all its interfaces without regarding the link capabilities of the other nodes. Thus, the flat OLSR mechanism does not scale well for large heterogeneous ad hoc networks.

2.2. Hierarchical OLSR (HOLSR)

HOLSR is introduced to increase scalability of OLSR in large ad hoc networks. In [11] and [12] it is proposed a layered version of OLSR with a hierarchical structure, developed by the Communications Research Centre (CRC) of Canada, hereafter called CRC HOLSR.

This approach of HOLSR dynamically organizes nodes into cluster levels. At each level the cluster head declares its status and invites other nodes to join its cluster by means of Cluster ID Announcement (CIA) messages. Then, a Hierarchical TC (HTC) message is used to transmit the members-

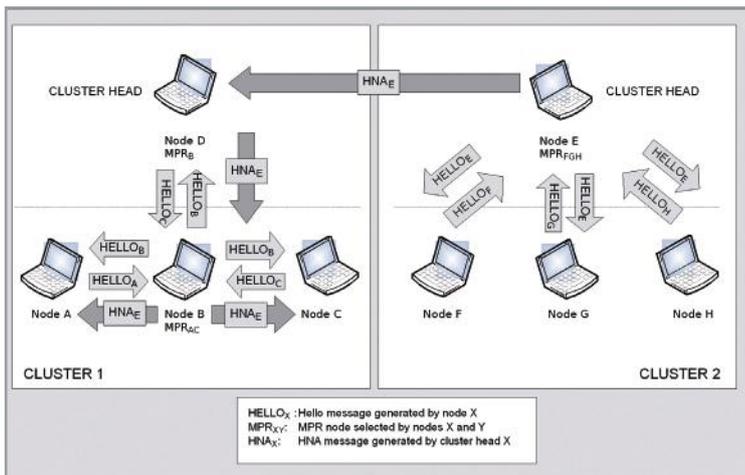
the amount of necessary topology control information, the efficient use of high capacity nodes, and a reduction in routing computational cost.

In this paper we introduce another version of HOLSR based on the AdHocSys approach [15], maintaining the main advantages explained before. The basic principle in our hierarchical OLSR approach is similar to the CRC HOLSR described above but there are several differences. In our proposal, we consider that there are only two levels in the hierarchy, where level-1 corresponds to connection among type-1 nodes (core network) and level-2 corresponds to connection among type-2 nodes (access network). An access subnetwork which is connected to other access subnetworks is hereafter referred to as a cluster. A type-1 node serves as the cluster head and advertises its reachability to other clusters. The cluster heads are predefined, so there is no need to develop an algorithm for cluster head selection. In addition to this, the cluster heads are aware and connected to each other, either directly or via multi-hop relays. Communications between cluster heads can also be conducted using unicast traffic, as an alternative to subnet-directed-broadcast. As in CRC HOLSR, the cluster nodes should have at least two wireless interfaces, for inter- and intra-cluster communications respectively. A directional antenna or more transmitting power is supposed to be used for inter-cluster connection. The data rate for inter-cluster connection should be higher than the ones for intra-cluster communication.

The main difference between our approach and CRC HOLSR is that we only use HNA messages for both inter-cluster and intra-cluster topology dissemination (Figure 2), while hierarchical TC messages are used for inter-cluster topology dissemination in CRC HOLSR. In other words, no modifications to HELLO and TC messages, or MPR selection, are foreseen in our approach.

According to the ideas described above, our HOLSR solution will be implemented based only on the modifications of HNA messages. Besides, it is the cluster head’s responsibility to advertise its reachability to both internal nodes and other clusters. Nodes with associated hosts and/or networks, as cluster heads, should periodically generate HNA messages. When HNA messages are received from other cluster heads, a cluster head should update its HNA Information Base and propagate new information to its cluster members via internal subnet-directed-broadcast HNA messages. Furthermore, in order to keep HELLO and TC messages bounded within one cluster, address aggregation and private address allocation are used as simple mechanisms for this purpose.

With the aim of comparing the routing behaviour of our HOLSR with the previous proposals, a flat OLSR network with the same number of nodes should also be established. The NS-2 implementation should be able to demonstrate how the



■ **Figure 2.** AdHocSys HOLSR Control Messages

hip information of a cluster to the higher hierarchical level nodes. Cluster formation and topology dissemination are carried out with these new message types. The main improvements realized by the CRC HOLSR protocol are a reduction in

proposed solution works in terms of connectivity, scalability and quality of real-time services.

The performance of the OLSR and AdHocSys HOLSR protocol has been evaluated with the NS-2 simulation tool with the Evalvid video evaluation tool-set [16]. Evalvid allows trace generation from real video sources and the later reconstruction of received flows, obtaining more realistic statistics and the possibility of viewing received video quality. Simulation environment consists of 50 wireless nodes (moderate-scale network size) forming an ad hoc network with the OLSR in an area of 1200 x 600 m. With the HOLSR protocol, two clusters define the network architecture. Each of these clusters is defined as an area of 600 x 600 m. A video streaming is established from an arbitrary source node to a random selected node. The radio model used for simulation is based on the Two-Ray Ground Propagation Model and the standard 802.11b. Node transmission and carrier-sensing ranges are approximately 170 and 423 m respectively.

The channel capacity was set to 11 Mbps. We have selected 200 seconds as simulation time. Each node in the simulation scenario (including the source and destination of video flows) moves according to the "random waypoint" model [17]. That is, the wireless node randomly selects a destination, moves in the direction of this location at a certain speed, and when it arrives to destination it pauses during the interval known as pause time. With the aim of evaluating the influence of node movement on the quality of video transmission, we have simulated different scenarios where each node moves using random waypoint model at a 0 m/s (all nodes are static), 5 m/s, 10 m/s, 15 m/s and 20 m/s. The video resolution used is 176x144 (QCIF) with the GoP (Group of Pictures) pattern IBBPBBPBBPBB. The traffic load used consists of 20 UDP sessions with constant bitrate (CBR), established between nodes that are randomly selected. Each source sends 2 packets of 512 bytes every second (we use a traffic pattern which is between the medium and the heavy ones) [12].

3. Multiple Description Coding (MDC)

Multiple description coding has emerged as a promising approach to enhance the error resilience of a video delivery system. MDC is a coding technique that generates several descriptions such that different levels of reconstruction qualities can be obtained from different subsets of these descriptions. In contrast to layered coding (LC), there is no hierarchy among the descriptions so that each description may be independently decoded.

The fact that each description is independent and equally important makes the use of MDC suitable on lossy systems where there is no pac-

ket delivery priority, as in ad hoc networks or the Internet. Moreover, an acceptable quality of video can be achieved in MDC without the need of retransmissions so it is appropriate for real time applications, like video streaming.

There are several procedures for generating descriptions. Most of them divide the source video stream in different groups or substreams, in order to be independently encoded later and generate each description. Fragmentation of video sequence can be carried out in temporal, spatial or frequency domain.

Despite the aforementioned advantages of MDC, single description codecs (SDC) are still predominant. The reasons are probably the high complexity of codec development, the loss of some compression efficiency as well as the caused transmission overhead.

3.1. Encoding and decoding processes

The encoding and decoding process is described in detail below.

In this paper, we have specifically used multi-description in temporal domain. This is achieved by splitting the original video frames in subsets depending on their time position. Therefore, the raw video is separated into n descriptions with a frame rate n times lower than the original frame rate. Later, every subflow is independently encoded resulting in the video descriptions.

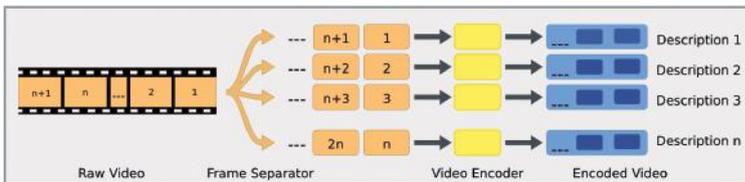
The encoding process is shown in Figure 3.

The required bandwidth for multidescription transmissions is greater than the one required for single-flow video. This is due to the fact that the substreams are generated from non-consecutive frames causing lower compression efficiency. The more dynamic the video sequence, the bigger the mean frame size.

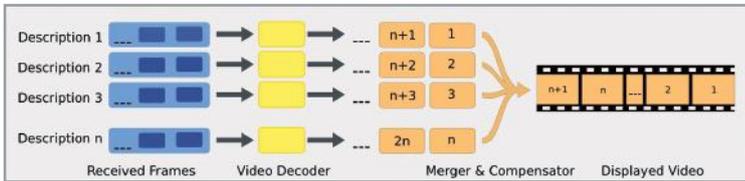
The decoding process is shown in Figure 4. On the receiver, each description is independently decoded and the reconstructed video flows are merged in order to generate the video with the same temporal resolution as the original sequence. At this point, the error compensation scheme replaces the lost or undecodable frames by the last successfully decoded frame, regardless the description it belongs to. Therefore, lost frames from a specific description are replaced with frames from the others descriptions so the perceived distortion is diminished.

If losses occur in every description at the same time, no video reconstruction is obviously possible. Thus, the descriptions must be sent through disjoint paths. Several techniques are developed for this purpose even involving routing protocols [18, 19, 20]. In this paper, we have used multiple sources to send the descriptions to the same destination node, which is called multipoint-to-point (M2P) transmission.

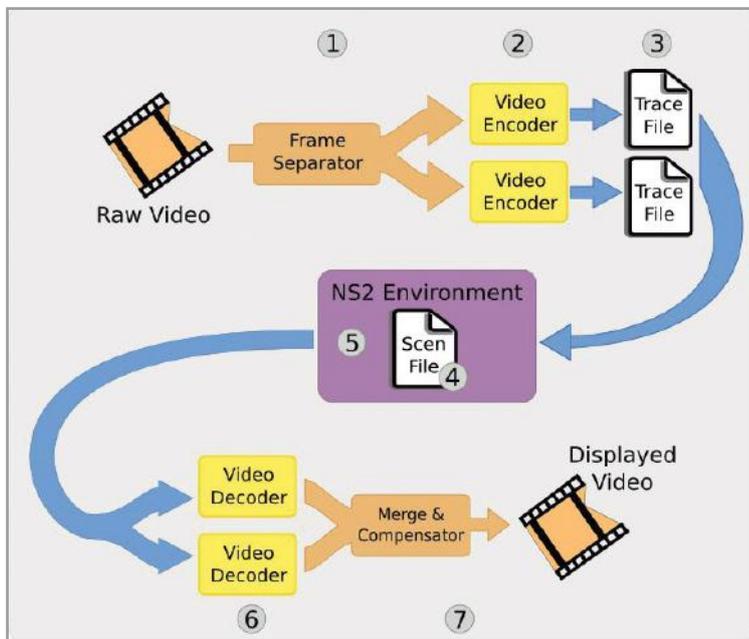
There is no hierarchy among the descriptions so that each description can be independently decoded



■ **Figure 3.** Temporal Domain MDC Encoder



■ **Figure 4.** Temporal Domain MDC Decoder



■ **Figure 5.** Simulation Process

The process carried out in each simulation is shown as follows (Figure 5)

1. Frame separation of the raw video

The first step in order to generate the descriptions is to cleverly divide the raw video in subsequences, as many flows as descriptions are desired, reading frame by frame and saving them on a different file according to their position.

2. Encoding

Every description is encoded independently. At this point, any standard video codec could be used or even a multidescription specific one. In this paper, we have used MPEG-4 to encode the descriptions.

3. Video traces generation

Every description is sent and received in an emu-

lated video server and client. Video packets are captured and the information obtained is used to generate trace files. These trace files serve as traffic pattern for the video source in NS-2.

4. Scenario generation

The simulation scenario contains information about the network elements employed such as the routing protocol (OLSR in this case), wireless nodes and channel characteristics as well as the mobility pattern for nodes.

5. Simulation of video streaming

During the simulation, the source and destination nodes involved in the video transmission save information regarding the packets sent and received and the time stamps into trace files.

6. Reception and decoding

When the simulation ends, the received descriptions can be reconstructed from the generated video traces. The resulting videos could be distorted due to possible losses.

7. Description merging

Finally, the decoded descriptions are merged and a new video sequence is generated with the same temporal resolution and frame number as the original.

The simulations were carried out under NS-2 with the Evalvid tool. The simulation environment consists of 50 wireless nodes random scattered in an area of 1200 x 600 m and OLSR is used as routing protocol. Two descriptions are transmitted from different nodes towards the same receptor performing a multipoint-to-point transmission. The radio model used for simulation is based on the Two-Ray Ground Propagation Model and the standard 802.11b at 11 Mbps. Node transmission range is approximately 250 m. Nodes move according to the "random waypoint" model with maximum speeds of 0 m/s (static), 2.5 m/s, 5 m/s, 7.5 m/s, 10 m/s, 12.5 m/s and 15 m/s.

The video resolution used is 352x288 (CIF) and two descriptions are generated based on it. The original video and the descriptions are encoded in MPEG-4, with the GoP pattern IPPPPPPPPPP. Original video source is used as SDC. Background traffic consists of 5 UDP connections with constant bitrate (1 KB/s) between arbitrary nodes.

4. Evaluation

4.1. Evaluation parameters

In order to perform a thorough analysis of the effects and improvements on video quality, we have used the following parameters.

We have chosen the Peak Signal to Noise Ratio to measure the quality of the video transmission sequence. PSNR is one of the most common objective parameter used to evaluate video quality. The following equation shows the definition of the PSNR:

$$PSNR = 10 \log_{10} \left(\frac{255^2}{MSE} \right)$$

$$MSE = \frac{1}{MN} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} [I_{org}(m,n) - I_{dec}(m,n)]^2$$

Where I_{org} is the original image and I_{dec} is the decoded image; M, N is the size of the image; and MSE is the Mean Square Error.

On the other hand, the performance of the video transmission has been evaluated in terms of packet delivery ratio (throughput). This metric is defined as the percentage of video packets successfully delivered to the destination against total packets sent.

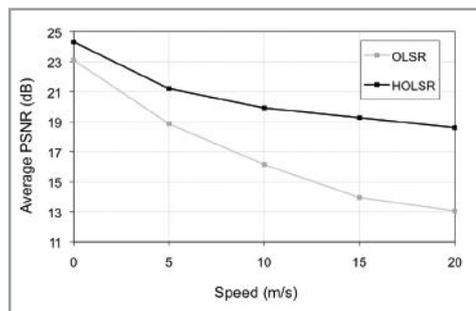
Furthermore, we use a new performance metric called interruption, introduced by [18] and redefined for the study carried out in this paper.

An interruption is observed when one or more consecutive frames cannot be decoded due to losses of some video packets. The nature of the human visual system makes it very difficult for a viewer to notice distortion if only a small amount of consecutive frames are lost. When the number of lost packets increases beyond a limit, the distortion can be noticed. The seriousness of an interruption depends on how long the interruption occurs. Interruptions can be classified according to their seriousness as minor and major interruptions. We assume an interruption can be considered minor if it causes a lesser distortion. A major interruption distorts the received video or even stops it momentarily. Considering the aforementioned GoP size used in video coding, we have established a threshold in 0.5 seconds. It is worth mentioning that the frequency the interruptions occur is another parameter to be considered as well. Interruptions are due to packet losses and they negatively affect the mean PSNR.

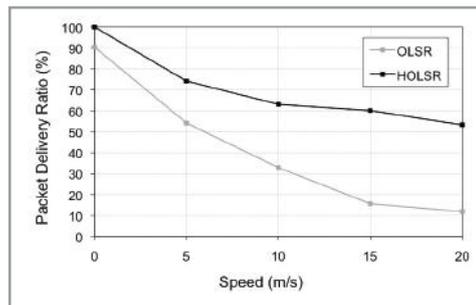
4.2. Routing Evaluation

The results obtained allow us to evaluate the improvement when the ad hoc network is configured by means of clusters and a head node is in charge of communicating the different clusters. In Figure 6, we present the results we have obtained regarding the Average PSNR metric. As shown, both protocols follow similar tendency to decrement the PSNR with the speed. However, OLSR seems to be very more sensitive to the effects of the wireless nodes' mobility and HOLSR improves the average PSNR up to almost 6 dB (for high node mobility).

PSNR results are close related to packet losses. Figure 7 highlights the effect of the speed in the packet delivery ratio parameter. OLSR suffers a very high percentage of video packets loss. From the results, it is clear that the HOLSR protocol delivers at least 10 percent more packets than the flat OLSR protocol and more than 40 percent more packets for 20 m/s.



■ Figure 6. Average PSNR vs. Speed



■ Figure 7. Packet Delivery Ratio vs. Speed

This essential improvement of HOLSR with regard to flat OLSR is due to the cluster formation. When a route is lost or a link falls in flat OLSR, the newfound route could be totally different and use different nodes so the MPR set has to be recalculated. In HOLSR, the hierarchical architecture forces to pass by the cluster heads and hence, there is a part of the route that remains static, allowing a faster recovery of the broken route.

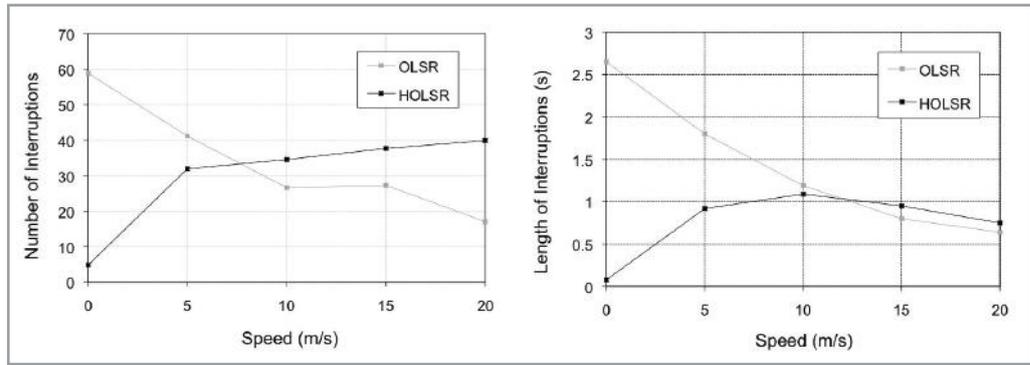
We examine the occurrence of interruptions in order to have a closer look on the video quality. We can see the effect of the speed of the wireless nodes. As we said before, a minor interruption just causes a slight distortion on the received video. In Figure 8 we can see that even if the number of this kind of interruptions is close to 60, it hardly means 2.5 seconds in all, against 200 seconds, which is the total time simulation. In the graphs we observe that HOLSR has a better performance than flat OLSR regarding the speed in the measured range. Although HOLSR works better with low average speeds, both protocols have a similar behaviour regarding interruption length with higher average speeds.

Analyzing major interruptions (which cause more noticeable distortions), Figure 9 shows how the number of interruptions and its total length increases when speed increases, as can be expected. Comparing both protocols we observe that there are less interruptions and a shorter duration in HOLSR, so that means there will be fewer gaps on the received video.

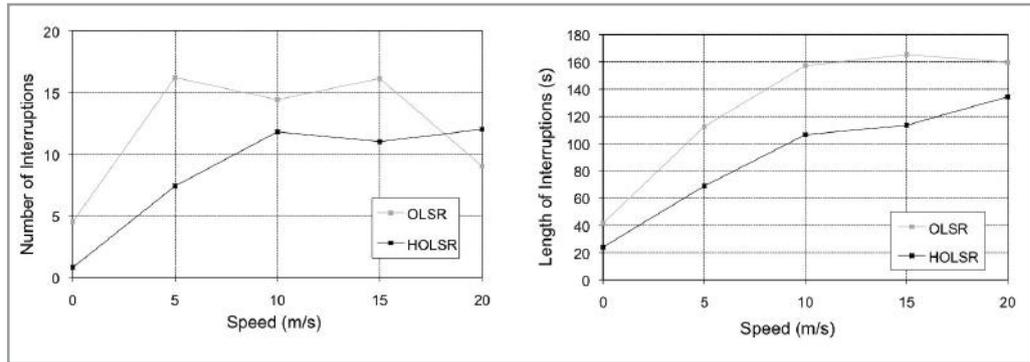
HOLSR has a better performance than flat OLSR due to its hierarchical structure. Although

The essential improvement of HOLSR with regard to flat OLSR is due to the cluster formation and its hierarchical structure

There are less interruptions and with shorter duration in HOLSR, which produces fewer gaps on the received video and increases the Quality of Experience of the user.



■ **Figure 8.** Number and Length of Minor Interruptions vs. Speed



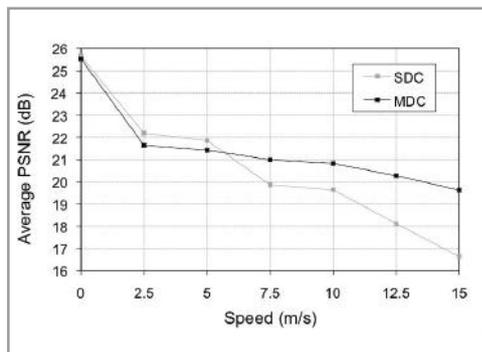
■ **Figure 9.** Number and Length of Major Interruptions vs. Speed

HOLSR has more interruptions for high speeds, their duration (as well as the distortion effect produced) is smaller. Even so, losses in both protocols could be unacceptable for high speeds due to the effect in the received video that they involve.

4.3. MDC Evaluation

Next, the results comparing the video evaluation using MDC and SDC (single flow coding) are shown.

Figure 10 shows how the average PSNR diminishes when node speed increases, as can be expected. For low speeds, SDC presents a better performance regarding to PSNR (approximately 0.5 dB). However, for higher speeds, MDC achieves better results (up to 3 dB).



■ **Figure 10.** Average PSNR vs. Speed

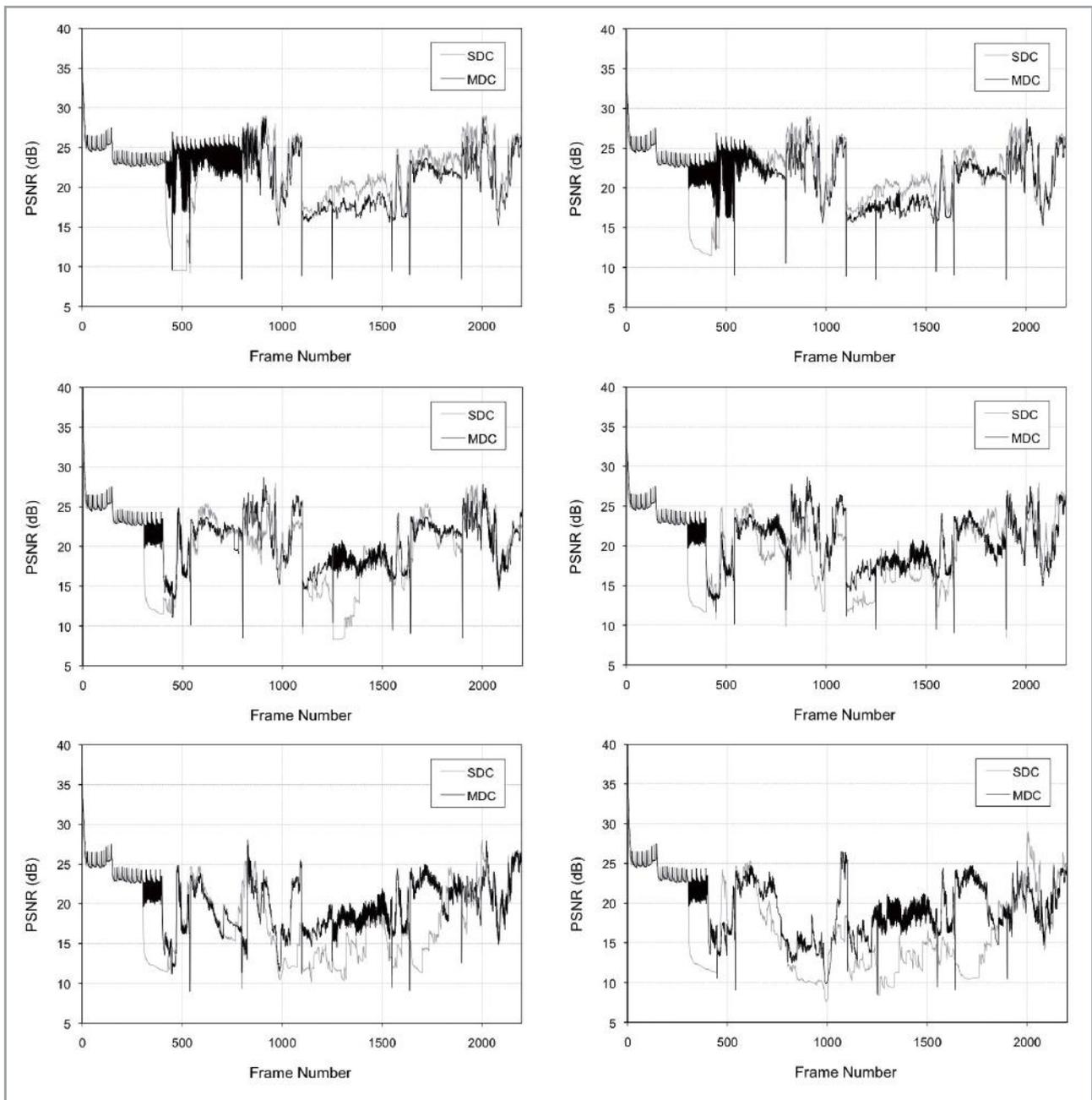
In [21] a subjective analysis of video transmission using scalable coding is mentioned. These results show that average PSNR does not always correspond with the quality experimented by the user. This is due to the fact that instant PSNR can present high peaks resulting in a high average value, whereas the user could experiment gaps or high degradation in the rest of video reproduction.

Therefore, in order to thoroughly analyze the results, PSNR values of every frame are shown below. In Figure 11 we can observe that MDC allows faster error recovery after packet losses, which is meant to maintain a more constant PSNR, so the perceived quality improves even if the absolute value of PSNR is higher in SDC. On the other hand, multidescription technique shows better results while speed grows starting at 5 m/s.

Figure 12 illustrates the packet delivery ratio (throughput) measured in the simulations.

Results show that the percentage of correctly received frames decreases with higher node speeds. For medium and high speed, SDC suffers a greater amount of packet losses than MDC, according to the previous PSNR results.

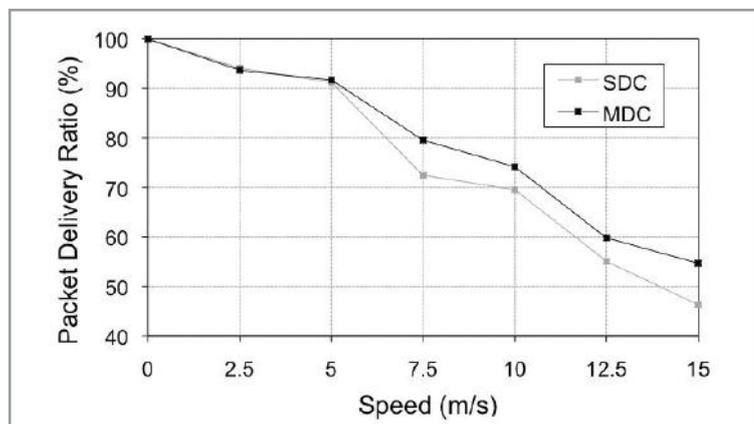
Figure 13 and Figure 14 show the number and the length of minor and major interruptions respectively. In Figure 13 we can see that, at worst,



■ **Figure 11.** PSNR vs. Frame Number for 2.5 m/s (up left), 5 m/s (up right), 7.5 m/s (middle left), 10 m/s (middle right), 12.5 m/s (down left), 15 m/s (down right)

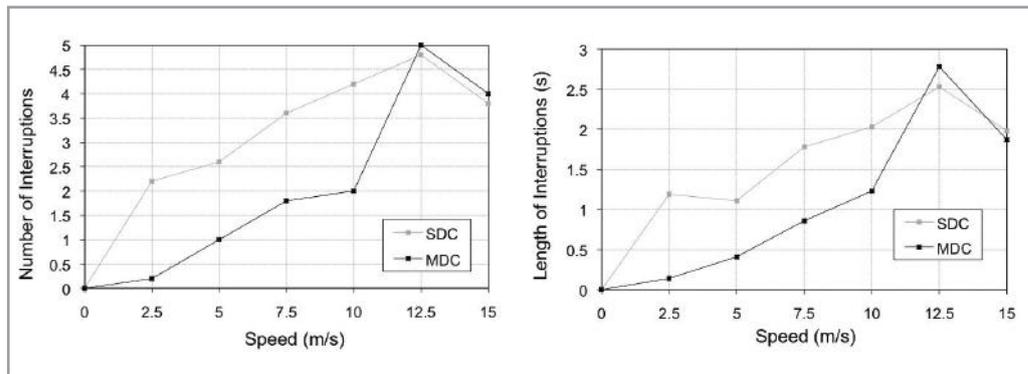
the total length of minor interruptions corresponds to 2.78 s distributed in 5 interruptions when node speed is 12.5 m/s. For 15 m/s minor interruptions decrease because of the increment of major interruptions. Thus, MDC shows a better performance except at high speeds, where both mechanisms present similar results.

Figure 14 clearly shows that using MDC noticeably reduces the number and the length of major interruptions. This is an important point because MDC is capable of providing video with an acceptable quality minimizing the pauses or video gaps caused by losses. This is due to the fact that the destination node probably receives information from at least one of the source descriptions.

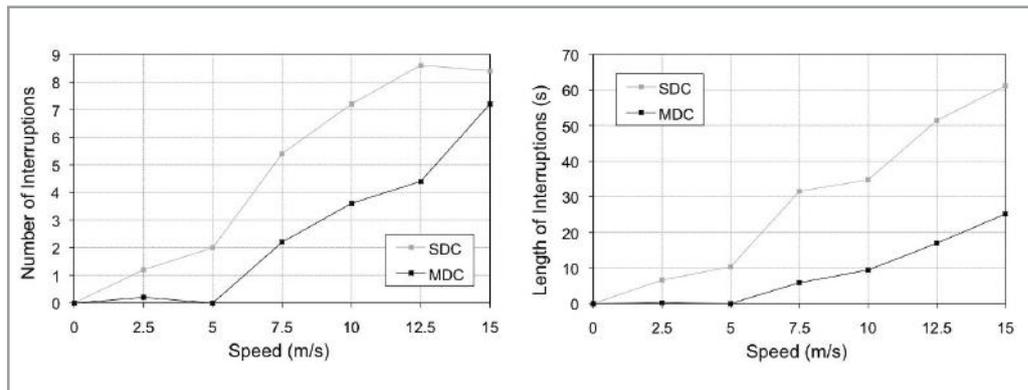


■ **Figure 12.** Packet Delivery Ratio vs. Speed

MDC noticeably reduces the number and length of the interruptions



■ Figure 13. Number and Length of Minor Interruptions vs. Speed



■ Figure 14. Number and Length of Major Interruptions vs. Speed

5. Conclusions

Providing real-time video transmission services over ad hoc networks while offering a certain Quality of Service is not an easy task. The use of MANET networks is continuously growing due to their versatility and feasibility, but on the other hand, the characteristics of this kind of networks, like node mobility, cause constant losses in data transmission.

In this paper, we have performed a study considering a well-known flat protocol (OLSR) and an algorithm based on a hierarchical protocol (HOLSR). The AdHocSys HOLSR has demonstrated to have better results on performance evaluation. This protocol gets better PSNR (from 1 dB to 6 dB in certain cases), reduces the packet delay by reducing hops and causes less control overhead than flat OLSR due to the clustered structure, so the packet delivery ratio becomes higher (from 10% to 50%). The main drawback of a hierarchical framework is the necessity of a minimum infrastructure for the cluster heads. Another issue is the overload that the link between cluster heads could bear. The main conclusion is that HOLSR is a good candidate for video transmission over ad hoc networks and, consequently, it is a good starting point to apply any other QoS technique. For this purpose, we have studied the Multiple Description Coding and compared it with traditional single-flow video coding mechanism. Results have shown that MDC noticeably increases PSNR for high speeds (up to 3 dB) and

reduces the number and length of interruptions, providing a video with acceptable quality along the entire transmission. This is achieved because of using disjoint paths in a multipoint-to-point transmission.

As future work, we plan to study how to incorporate QoS mechanisms in a cross-layer manner in order to take advantage at any layer of the TCP/IP stack. Therefore, we plan to use QoS routing and multipath routing at network layer, combined with error concealment mechanisms as FEC (Forward Error Correction) at transport layer. Furthermore, we plan to study and compare Multi-State Video Coding (MSVC) as an improvement of MDC, where a lost frame from a description can be repaired with reference frames from other descriptions. Finally, as human perception may be different from objective measurements, we plan to evaluate subjective quality of received videos making tests for this purpose.

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