An Altruistic Cross-Layer Recovering Mechanism for Ad Hoc Wireless Networks

P. Arce, J. C. Guerri

Institute of Telecommunication and Multimedia Applications (iTEAM)

Universitat Politècnica de València, 46022 Valencia, Spain

paarvi@iteam.upv.es, jcguerri@dcom.upv.es

Tel: 0034-963879588

Abstract. Video streaming services have restrictive delay and bandwidth constraints. Ad hoc networks represent a hostile environment for this kind of real-time data transmission. Emerging mesh networks, where a backbone provides more topological stability, do not even assure a high Quality of Experience. In such scenario, mobility of terminal nodes causes link breakages until a new route is calculated. In the meanwhile, lost packets cause annoying video interruptions to the receiver. This paper proposes a new mechanism of recovering lost packets by means of caching overheard packets in neighbor nodes and retransmit them to destination. Moreover, an optimization is shown, which involves a video aware cache in order to recover full frames and prioritize more significant frames. Results show the improvement in reception, increasing the throughput as well as video quality, whereas larger video interruptions are considerably reduced.

Keywords. Mobile Ad Hoc Networks, Video Streaming, Quality of Experience, Opportunistic Routing, OLSR, Cooperative Caching, Mesh Networks, ARQ

1. INTRODUCTION

Mobile ad hoc networks (MANETs) are infrastructureless wireless networks where nodes act as relays in order to forward packets from source to destination when they are not directly within the same wireless transmission range. Consequently, every node should be able to forward packets addressed to other nodes. In this kind of network, routing protocols are in charge of establishing routes towards destination. When the number of hops increases in a route, the throughput is negatively affected. This is due to the fact that the packet loss probability and the interferences caused by the intraflow contention are increased in every additional link [1]. Moreover, mobility of nodes makes it difficult to create and maintain these routes. When any node moves out of range of its neighbor, the entire route (or partially) has to be recalculated. Within this rerouting time, packets cannot be delivered, causing packet losses and non-negligible delays.

New wireless technologies and enhancements (e.g. 802.11n, 802.11ac, etc.) are being developed with the aim of increasing transmission rate and capacity, but in contrast, new services appear, which have higher bandwidth requirements. On the other hand, current technologies are wide spread and have more and more users. For this reason, it is worth taking advantage of these existing technologies and proposing new improvements that allow current infrastructures and standards to be used, always without losing sight of the upcoming technologies. This will be helpful in order to provide these new services with Quality of Service (QoS) attending to the new requirements that they entail.

MANETs can be set up at very low cost compared with those networks based on access points that need wired infrastructure support. However, due to the difficulty of maintaining minimum QoS conditions, ad hoc networks tend to be designed with a static wireless backbone, which provide them with the minimum structure to assure connectivity and stability to a certain extent. This is the case of the upcoming wireless mesh networks (WMNs) [2], which could become a trade-off between cost effort and the transmission quality offered [3].

A typical wireless mesh scenario is depicted in Figure 1, where a hierarchical structure can help in stabilizing routes despite the mobility of some terminals. In case a destination node is moving around in such environment, packet losses are likely to be concentrated on the last hop, when such node moves out of the forwarding neighbor range. When this occurs, next packets cannot be sent and could be discarded as long as the new route is not established. In the event that these packets have arrived correctly at the node preceding the destination, it makes sense to make an effort to finally reach those packets to their destination without having to be discarded or resent again through a new route consuming time and resources. Since any neighbor of the destination node may have overheard those packets, it can become an altruistic node and forward those packets, although it does not take part of the original packet path.

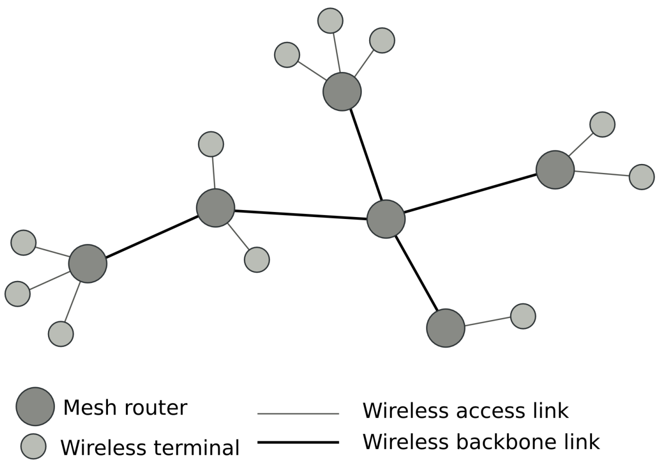

Fig. 1. Typical mesh network topology

Video streaming services, which are increasingly demanded nowadays, are bandwidth-consuming services and may suffer from playback interruptions when packet losses occur. These interruptions can be annoying and may cause a significant decrease on the Quality of Experience (QoE) of the viewers. Routing protocols that do not consider these constraint conditions regarding packet delay and losses will not be suitable for video streaming and it could therefore result in diminishing video quality and cause interruptions. Hence, it is worth considering cross-layer routing solutions, which can extract useful information from other protocol layers. Furthermore, wireless networks have a particularity inherent to the wireless channel nature that is exploited by opportunistic [4] and cooperative routing protocols [5]. Neighbor nodes can overhear the packets that are being sent within their coverage area, even though these packets are not addressed to them, which is called Wireless Broadcast Advantage (WBA) [6]. This feature from the link layer can also aid the routing protocol in order to improve network performance and connectivity.

Following this idea, this paper proposes a cross-layer packet recovering mechanism that benefits from the inherent broadcast nature of wireless medium in such a way that neighboring nodes of the destination node may help in recovering lost or undelivered packets within the last hop. This proposal increases the throughput and the mean quality experienced by the user in video transmissions, as it considerably reduces interruptions caused by link breakages and node mobility. In this sense, this proposal seeks to improve network connectivity and QoE of video streaming services. By definition, nodes belonging to an ad hoc network could become routers and forward traffic even if they are not part of these conversations. Following this philosophy, nodes can become cooperative nodes just because of the fact that they belong to the network. However, it is true that either being an ad hoc router or a cooperative node will consume battery and device resources. In situations when users do not want to waste device resources in helping foreign communications to be carried out, it would be necessary some additional incentive, such as higher priority, or a penalty otherwise. Governmental or emergency networks are the typical examples where nodes cooperate for a common goal, but it is not limited to them as long as a proper motivation is offered. The proposed technique has been implemented as an improvement of the Optimized Link State Routing (OLSR) protocol [7], which is one of the proactive protocols most used in MANETs and mesh networks.

The rest of the paper is organized as follows. Section 2 briefly introduces some related work. The proposed scheme is described in Section 3. Section 4 shows a thorough evaluation of this proposal and results are presented. Finally, conclusions are discussed in Section 5.

2. RELATED WORK

Ad hoc networks usually present a mesh topology, where every node may have one or more neighbors and any of them may act as a router. In order to benefit from this feature, multipath routing protocols store several routes for the same destination in order to be able to choose among the possible routes if the current one results broken [8, 9]. Moreover, an Automatic Repeat Request (ARQ) mechanism can be implemented to retransmit lost packets from the source through one of the alternative routes, increasing the overall throughput and even providing the possibility of changing to a new route seamlessly without video interruption [10]. Usually, routes are established taking into account the number of hops, but there are also other routing protocols that take into account information from other protocol layers so that the best route can be selected depending on various factors: path loss, delay, available bandwidth or link quality [11, 12]. Some of them can even control video quality parameters to adapt the transmission rate to the current network conditions and path bandwidth [13].

The ARQ method negatively affects real-time video streaming when packets are retransmitted frequently, because a higher end-to-end delay is introduced for each retransmitted packet, which can become deprecated and discarded, leading to video playback interruptions. In this sense, [14] proposes a cross-layer framework for video streaming, which incorporates special intermediate nodes through the path. These nodes act as video assistants, which are in charge of buffering video packets and retransmit them when destination node sends an ARQ. The requested frame is then sent back to the destination in a shorter time than the source could do. For this purpose, routes are built dynamically and the shortest path is selected in which a suitable video assistant is located. Compared to the end-to-end ARQ method, this mechanism reduces the delay of packets that have to be retransmitted at the cost of introducing some complexity when routes are created.

As stated before, WBA allows nodes not taking part in the communication to hear packets sent by a neighbor. Therefore, retransmitter nodes in the ARQ scheme should not be limited to nodes belonging to the transmission path. Reference [15] proposes a method that cooperatively uses neighboring terminals of the nodes along the route to forward packets, not only the nodes that are currently part of the route. Therefore, lost packets have more chances to be retransmitted, improving effectiveness of retransmission. Cooperative routing may cause additional energy consumption since more nodes than in deterministic routing are participating in the transmission path. Hence, reference [16] takes into account this power consumption and proposes a cooperative routing mechanism that uses variable transmission power in order to balance achievable throughput and battery life.

Actual implementations of wireless mesh networks [17] rely on an ad hoc backbone with a stable topology, and consequently, link losses are usually low. This can be the case of real practical scenarios, such as smart cities or campus universities. For this reason, most of packet losses will occur on the last hop due to possible movements of the destination node or some of its neighbors. Therefore, it is certainly reasonable to limit retransmission mechanisms to last hop neighboring in such scenarios, causing less interference to other nodes and reducing the overall packet delay and energy consumption, which is desirable in real-time video transmissions. In a similar wireless scenario, reference [18] proposes a buffering scheme during handoff between access points in order to avoid packet losses. In this case, signal strength is measured in these access points to foresee when client nodes are moving.

3. ALTRUISTIC RECOVERY

In wireless mesh networks, due to the long-term stability of the backbone, packet routes rely on these static nodes, which hardly suffer modifications. Logically, nodes that are likely to move around are devices that make use of these ad hoc networks to communicate, which usually are the transmission source, the destination or any of their nearest neighbors, which could affect the current packet route. Thus, it makes sense to apply recovery mechanisms at network edges, more precisely at the destination surroundings.

With this in mind, the main objective of this proposal is to provide throughput gains in wireless communications and improve the QoS of video transmissions, providing the user with a higher QoE. To this end, this paper proposes a cross-layer technique that uses information drawn from MAC, routing and application layers in order to increase the overall packet delivery ratio and, in case of video transmissions, reduce packet delay so as to avoid playback interruptions. Furthermore, in order to maintain compatibility with existent wireless devices and network standards, no modifications to MAC layer are performed and only slight changes in the routing protocol are needed.

On traditional routing, e.g. OLSR, when a route is broken due to the movement of nodes, packets are likely to be discarded on the queue of any intermediate node during the rerouting time, causing a negative effect on the throughput. Figure 2 depicts this situation in a reduced scenario with 5 nodes. Node 4 is the destination and has two neighbors (node 2 and node 3). The packet route calculated by the routing protocol (OLSR in this case) is 0->1->2->4. Suppose now that node 4 moves and gets out the transmission range of node 2. The transmission route results broken and then, by means of the routing protocol signaling, a new route towards node 4 is established through the node 3. Therefore, the new route will be 0->1->3->4 (Figure 2a).

As a feature common to wireless ad hoc networks, all nodes within the radio range of a sender terminal can take advantage of WBA and overhear packets even if they are not the genuine receivers. In general data-link layer protocols, the overheard packets are discarded if the destination address is not the terminal's address. For the improvement proposed in this paper, the neighbors of the destination node (i.e. node 3) may cache packets that they overhear in promiscuous mode and are addressed to their neighbors (Figure 2b). In this example, node 3 can keep sending previously overheard packets that retains in the cache, until the new route is completely established. The ideal case is given when every packet that was not received at destination, has been overheard by a neighbor node and in addition, this neighbor node is able to retransmit it to destination. In practice, when the routing algorithm detects a link failure, source node queues outgoing packets (i.e. stops transmitting) and waits until a new route has been found. Packets that remain in the outgoing queue during a long time should be discarded.

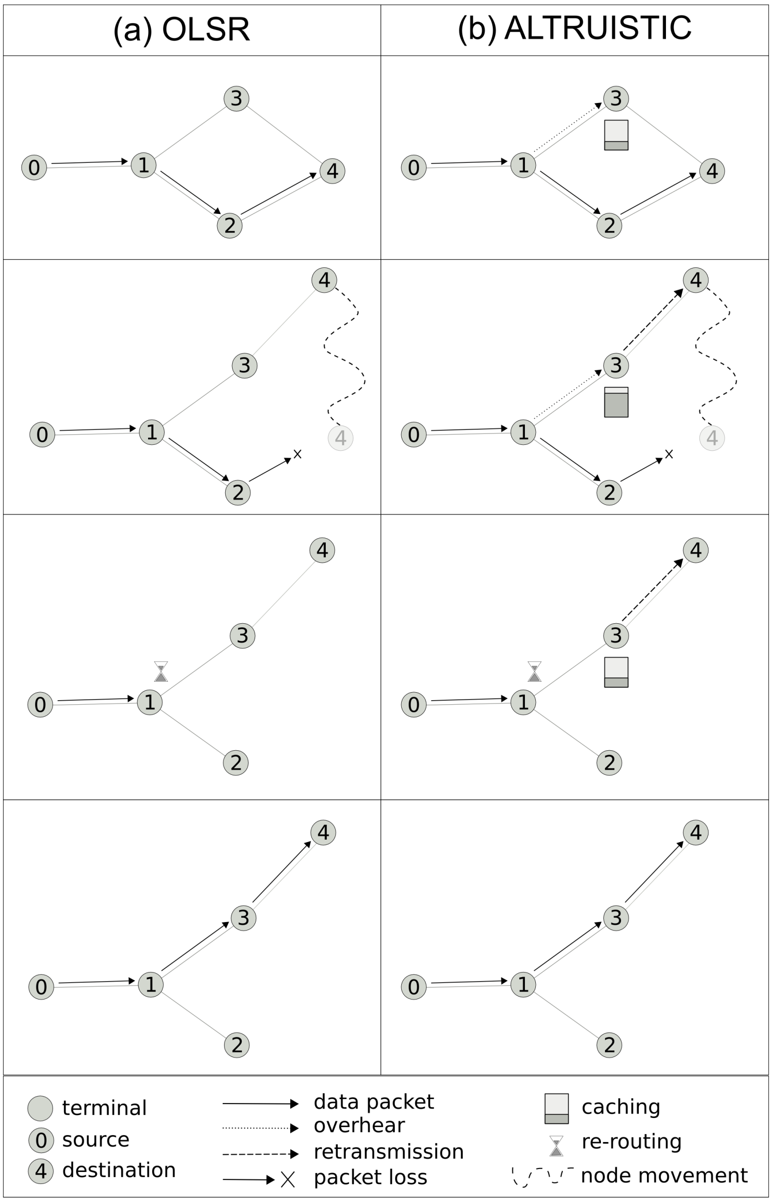

Fig. 2. Comparison between OLSR (a) and Altruistic OLSR (b)

In this approach, not every node forming the path has to buffer packets for retransmission, in contrast to other cooperative caching techniques, which make use of every possible node near the transmission route as a retransmitter candidate [19]. Usually, most of ad hoc mobile nodes are resource-limited devices so it would be worth limiting the amount of nodes that should perform packet caching and retransmission. In this scheme, a node caches most recently received packets only if they are addressed to a neighbor. If destination is no longer in the neighborhood (one-hop nodes), the cache is emptied for this node and no more packets addressed to it are cached. In order to avoid an excessive memory usage, this cache has a maximum size for each neighbor and packets are cached only for a short time. In addition, every cache entry stores both the packet and the arrival time so that packets that are older than a certain validity time (VT) are discarded, avoiding deprecated packets to be retransmitted.

For a better understanding, Figure 3 draws the main events that are taking place in this scenario. During the initial steady state, video transmission is being received correctly. When the destination node starts to move, there comes a time when packets cannot reach the destination and finally, the routing protocol notices that there has been a route breakage. Then, when the destination node comes into coverage again, transmission can be resumed after the new route discovering time. Note that destination can benefit from cached packets of altruistic neighbor nodes if they are still in range.

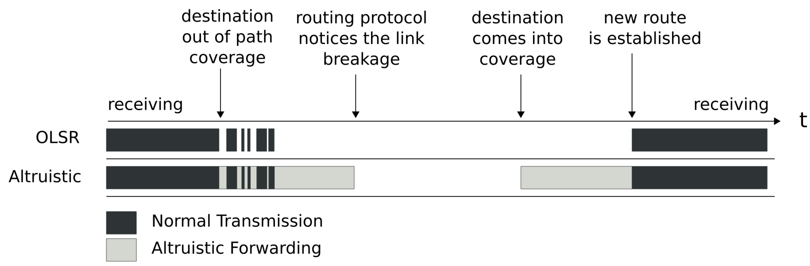

Fig. 3. Timeline comparing the rerouting behavior between OLSR and Altruistic OLSR

3.1. Candidate selection

When relaying on extra nodes to retransmit lost packets, candidate selection becomes an important process to ensure the best performance. Reference [14] chooses the candidate before the route has been established, assuring a good position for the retransmitter throughout the path. Instead, opportunistic routing protocols [20] track all possible routes for each packet (or batch of packets [21]) and mark the priority of each route.

Actually, among the nodes that have cached packets for retransmission, there will be some of them holding more packets and fresher ones, which turn those nodes into more effective retransmitters. Therefore, the way the retransmitter node is selected has to be considered. In the scheme presented in this paper, candidate selection is carried out by the destination node so that no coordination function is needed among all possible retransmitters, reducing complexity and overhead. In order to select the best retransmitter candidate, destination node chooses one of its neighbors attending to a measurement value, which will be described in detail later. This value, which can be estimated according to several methods, will help the destination node choose the most suitable neighbor to retransmit lost packets. Each node periodically informs its neighbors about this measurement value by means of a new field in OLSR HELLO message. As occurs in other proactive routing protocols, OLSR periodically broadcasts HELLO messages in order to discover and update neighboring information, which is very convenient for the aim of this proposal. When HELLO messages are generated to inform about neighbors' connectivity, each neighbor entry will also contain a value representing the goodness of the cache content for this neighbor. It is worth noting that the frequency of this update is closely related to the frequency configured for HELLO messages. As the interval of HELLO messages are configured shorter, cache information is updated more frequently, but the overhead is also higher. When destination node receives HELLO messages from its neighbors, it is able to compare and finally decide which one has the most valuable set of packets to be retransmitted. This decision is made from the values that neighbors have sent inside the modified HELLO messages and it will be explained in detail later. When cache is empty for all of its neighbors, no additional fields are inserted into the traditional HELLO, reducing message size and overhead. Otherwise, it is indicated using the reserved field of the HELLO message header. Figure 4 depicts an example, where node D is the destination, and nodes A, B and C inform periodically about their suitability to be retransmitters. In this example, node C will be chosen because it has a higher value.

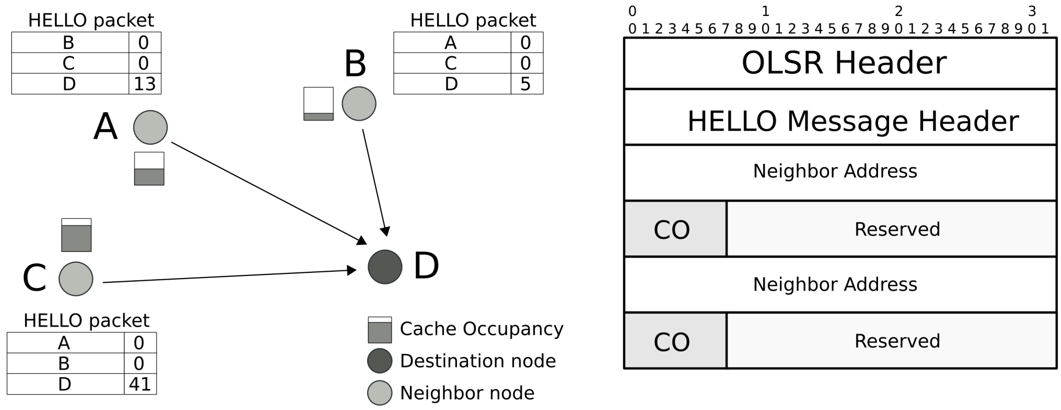

Fig. 4. Modification to HELLO Packets for the Candidate Selection Mechanism

The aforementioned measurement value can be calculated in several ways, attending to: 1) geoposition, where nearest neighbors would achieve greater values; 2) Expected Transmission Count (ETX), i.e. nodes with greater delivery probability would be more suitable; or 3) Cache Occupancy (CO), that is, attending to the total amount of packets cached for a specific destination. Other methods could also be used as long as they provide a measurement value to be set in HELLO messages, or even a combination of them. For instance, by knowing the position of the neighboring nodes and the cache occupancy in each of them, destination node could choose a candidate more accurately taking into account also the direction in case it is moving. In this evaluation, CO has been used as the measurement value so that caches that contain more packets are given higher values. Packets older than a certain validity time are discarded and therefore are not taken into account. Hence, as long as destination chooses a retransmitter neighbor that maximizes CO value, the amount of useful video packets for destination will also be maximized. Reserved bytes could be used to send further information about each neighbor node (ETX, geoposition, etc.), which could be employed jointly to select the best retransmitter. A full evaluation comparing which mechanisms for calculating this measurement value will give best results depending on the scenario falls outside the scope of this paper.

Then, the proposed scheme acts as follows. When the destination node detects any packet loss (examining sequence numbers in video packet headers or more generally, in Real-time Transport Protocol (RTP) headers), it generates and sends a report by means of a new kind of OLSR message: the Application Report (AR) packet. This AR packet contains the identifier (sequence number) of the last correctly received packet and an ACK Vector, which gives a run-length encoded history of previous data packets received at destination, as carried out in other standards such as Datagram Congestion Control Protocol (DCCP) [22]. Moreover, original OLSR packets contain a header field indicating how long after a reception of this packet, the information is still valid (Vtime). In AR packets this field is used to inform neighbors about the maximum time a retransmitted packet will still be valid for video playback, i.e. the play-out buffer (PoB) size. As explained before, destination node holds information about which neighbor has been estimated the most suitable for retransmitting lost packets ($N_{altruist}$). All these parameters are encapsulated in a new AR message according to Figure 5. The ACK Vector itself consists of two fields: State, which informs about reception or loss; and Run Length, which specifies how many consecutive packets have the given State.

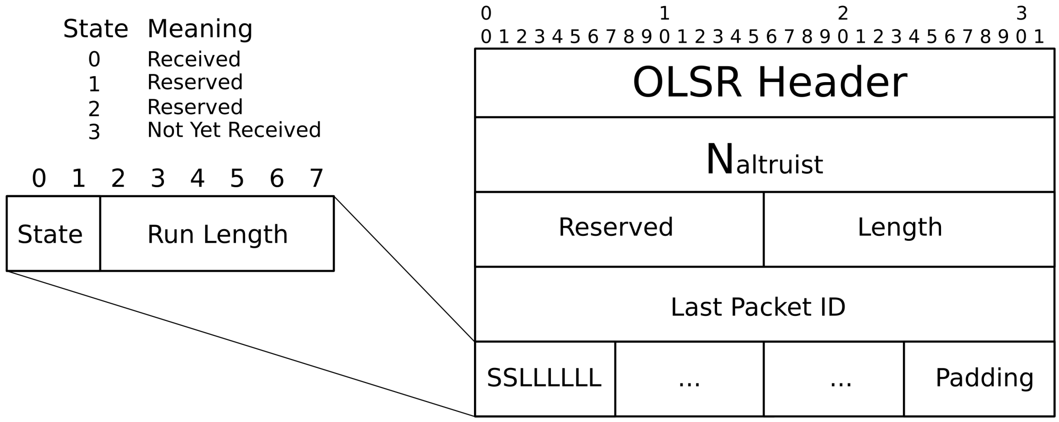

Fig. 5. AR Packet Format

Nevertheless, during a long link failure it may well be the case that no packets were received and therefore, packet loss cannot be detected from sequence numbers. For this reason, the destination node (and only this node) periodically informs about the last received packets through AR messages. This is also carried out in order to update neighbors' cache regularly, so that both deprecated as well as correctly received packets could be deleted. The network overload increase owing to AR packets is later assessed in Section 4.

3.2. Cache

Network nodes are configured with a certain maximum cache size and timeout in order to limit the total amount of packets stored and avoid retaining stale packets, respectively. When a node receives an AR message from one of its neighbors, it checks every packet in the cache addressed to this node and compare the packet arrival timestamp with the validity timestamp set in the AR message. Deprecated packets are immediately deleted. The rest of packets are checked against the ACK Vector, and those that are not set as received by destination are then retransmitted. Packets remaining in the cache are deleted after a preconfigured validity time. Optimal timeout period for caching packets closely depends on the size and state of the play-out buffer at destination node. If this buffer eventually underruns, QoE will be seriously degraded. Hence, destination node can inform other nodes about which is the maximum PoB time allowed for the current video transmission using the Vtime field in AR messages. Neighbors can now configure the cache validity time more accurately according to this. This way not only is the amount of packets the altruistic node caches optimized but also the amount of video packets that are retransmitted, with the concomitant bandwidth and energy saving.

3.3. Video awareness

As explained, this proposal could be appropriate for managing time-constraint transmissions because it takes into account temporal considerations and restrictions. Nevertheless, the relative importance of video frames (I, P or B) and the policy taken for which frames to cache and send ARQs are other considerable parameters, at the expense of adding some complexity to the algorithm. It is worth noting that this could be done below frame level with video codecs that support slicing. This sort of video awareness is carried out in altruistic neighbors that are able to discern and inspect video packets, and classify them according to the kind of frame they belong to (i.e. packets from I-frames are more critical than those from P- or B-frames). Moreover, intra-frame packets can be prioritized so that other packets will be discarded instead if node cache fills up. From a practical point of view, although deep packet inspection could consume extra time and computation, it could be feasible to check only the Differentiated Services Code Point (DSCP) field from IP headers or a Header Extension in RTP. In this case, video source must use this field to mark packets belonging to higher priority frames before sending them. In any case, this enhancement could be feasible for static power-supplied nodes with higher processing capabilities (e.g. backbone nodes).

Another interesting consideration can also be taken into account. Outdated packets that belong to a frame from which some packets are not deprecated yet, are not discarded until all packets from that frame are completely obsolete (Figure 6). This way, the algorithm tries to not split I-frames especially, because they are usually formed by a considerable number of packets.

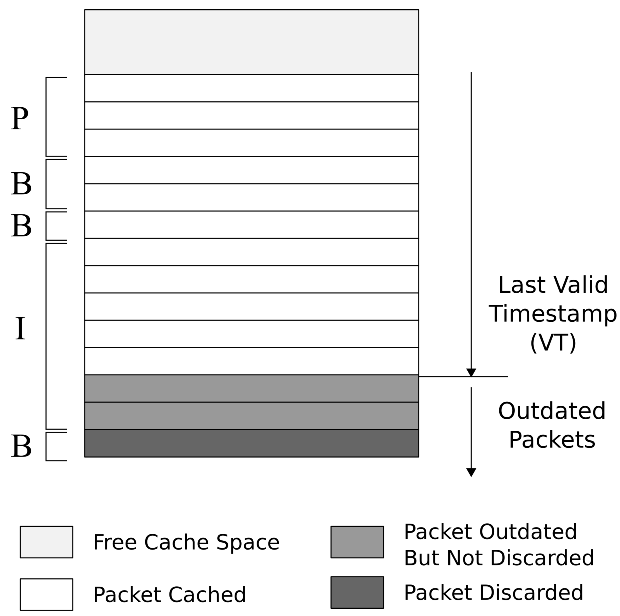

Fig. 6. Cached Video Packets and Discarding Policy

This scheme is not only valid for making decisions according to the type of frame, but also it is useful when using other sort of video coding that could be arranged into layers, such as Scalable Video Coding (SVC) [23]. By using this coding scheme, video packets from base layer can be prioritized over other improvement layers in order to reduce interruptions considerably, even though the video quality of received frames would not be so high.

In order to offer a general overview of some of the solutions mentioned in Section 2, Table 1 compares them with the mechanism proposed in this paper in order to show the main differences attending to some distinctive qualitative parameters. It is worth noting that, unlike other cooperative routing protocols, this proposal is not a routing algorithm itself but take advantage of OLSR information to implement an ARQ mechanism that also exploits WBA and performs caching in order to retransmit lost packets when needed. Moreover, the presented cross-layer solution is video-aware, which allows discerning video traffic and improving QoE by reducing video interruptions when node mobility causes route breakages.

4. EVALUATION

4.1. Sample network

Firstly, the scenario depicted in Figure 2 is assessed regarding throughput, Peak Signal to Noise Ratio (PSNR), packet delay and packet losses, using a video streaming source. All PSNR values cover both encoding distortion as well as channel induced distortion. This first scenario consists of 5 nodes, where destination node moves causing a route change.

This scenario has been simulated in NS-3 and the most relevant simulation parameters and video properties are shown in Table 2. Request-to-send/Clear-to-send (RTS/CTS) mechanism does avoid collisions that would decrease throughput due to retries, but on the other hand, this additional process adds a significant amount of protocol overhead that also results in a decrease in network throughput, so it is not used in the simulations. Additionally, wireless channel and transmission conditions are depicted in Figure 7, which shows the Packet Reception Rate (PRR) according to the distance between two nodes (i.e. the probability of receiving a packet correctly), with a 95% level of confidence.

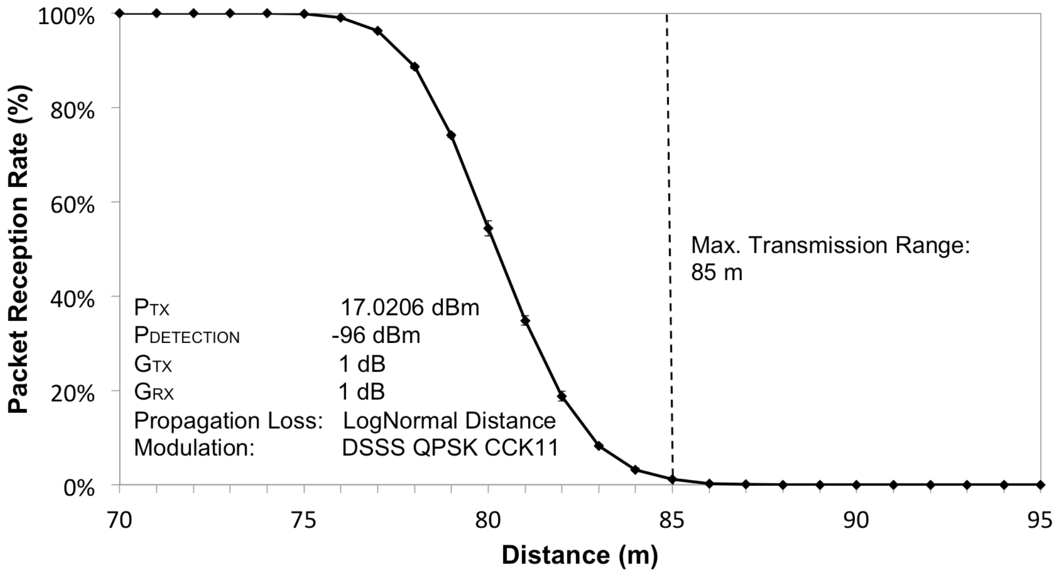

Fig. 7. Packet Reception Rate at 11Mbps according to distance

Figure 8 shows the results comparing the scheme proposed in this paper with the standard OLSR. Figure 8a illustrates the instantaneous throughput received in the destination node. It can be observed that packet reception is interrupted during a gap of time in traditional OLSR, due to the movement of the receiving node. A considerable decrease is stated in the altruistic scheme, but even though some glitches or slight interruptions may appear, it manages to recover a number of packets that allow video to keep playing almost seamlessly. This effect can be corroborated in Figure 8b, where PSNR is represented. There can be seen the effect of the interruption in the quality of the received video. Comparing with OLSR, the altruistic scheme manages to recover some additional video frames, thus improving the overall quality of video.

Besides PSNR, time instants of early AR packets are also depicted in the same figure, so it can be clearly shown the temporal relevance between the changes suffered in PSNR and the moment an AR packet is early transmitted. These are AR packets that are not sent periodically from destination, but only when a packet loss is detected. By sending these packets instantaneously, destination node may recover some useful packets in time, being able to recover video frames that would be lost otherwise. After the rerouting, altruistic neighbor become part of the actual route of packets and stops caching video packets (in case there would be more neighbors, they could become altruistic nodes).

Figure 8c illustrates end-to-end packet delay. As long as the maximum queue delay is set to 1 second, packets that stay longer than this delay in the queue are dropped. In this particular scenario, only one node is likely to suffer packet losses. Consequently, maximum packet delay reaches just over 1 second and below in OLSR. On the other hand, the altruistic recovering mechanism may present some packets with a higher delay due to retransmissions, even beyond 1 second, and there can also be distinguished some packet bursts retransmitted by the altruistic neighbor.

Figure 8d shows the cumulative number of interruptions or burst losses regarding their length in packets. It can be stated that there is a higher number of interruptions in traditional OLSR, especially burst losses that last few packets. In this case, altruistic retransmission recovers most of the small burst losses. Moreover, the maximum burst loss length is reduced considerably, as well as the number of bigger interruptions, compared with standard OLSR.

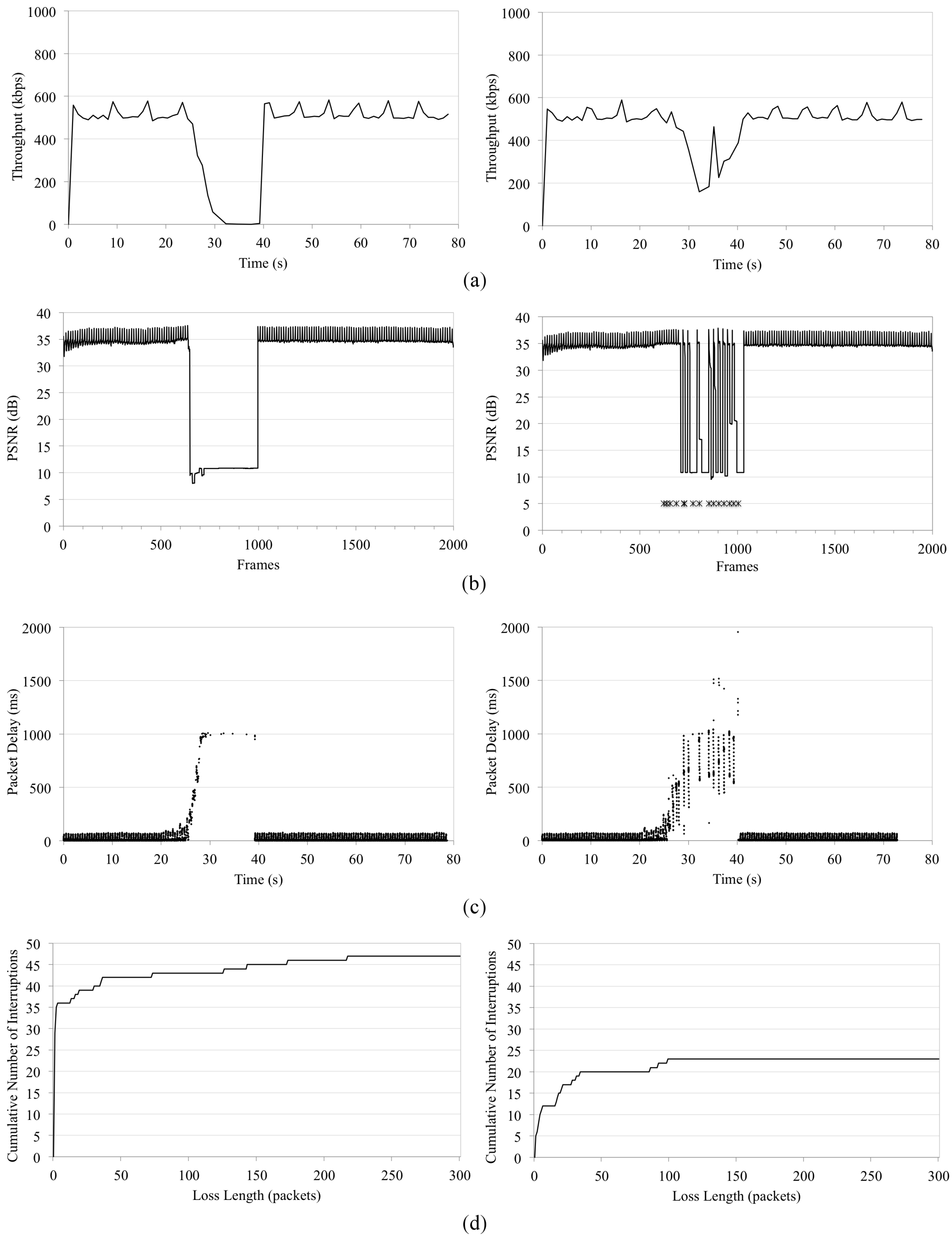

Fig. 8. Comparison between OLSR (left) and Altruistic OLSR (right) regarding Throughput (a), PSNR (b), End-to-end Packet Delay (c) and Cumulative Number of Interruptions (d)

Finally, it is worth mentioning that even though the average PSNR along the whole simulation increases from 30.59 dB in OLSR to 32.34 dB in the altruistic scheme, the improvement is even more noticeable if only the frames within the zone of interest (from second 20 to second 44, i.e. approximately the rerouting time) would be taken into account (from 17.99 dB in OLSR to 25.02 dB in the altruistic scheme). PSNR reference value is 34.89 dB, which is the average PSNR obtained from comparing the original video sequence with the encoded one, not taking into account any transmission loss. It is also worth mentioning that the goal is to show the relative improvement that this proposal offers over traditional OLSR routing and the exact absolute values are not to be necessarily concerned, since they strongly depend on the current video enconding parameters and network conditions. The fact of prioritizing I-frames has also slightly helped improve PSNR, since more interdependent frames could be decoded. However, such particularized analysis cannot be carried out in random scenarios where destination node moves freely, resulting in one or several (or none) rerouting occasions and link breakages. Nevertheless, average values can be measured, which shows the effectiveness of the proposed scheme, as described below.

4.2. Random scenario

Therefore, in order to carry out more thorough assessments of the proposed scheme, it has been evaluated in random scenarios with 20 nodes uniformly distributed along a simulation area of 300 m x 300 m. Only the destination node is moving during the simulation time, specifically at 1 m/s (walking speed) according to the Random Waypoint Model. In order to obtain more realistic scenarios, background traffic is sent during the simulations. It consists of 20 UDP sessions with constant bit rate (CBR) of 1 kbps each, established between nodes that are randomly selected. The rest of the simulation parameters are similar to the previous simulated scenario (Table 2 and Figure 7). These parameters entail certain Bit Error Rate (BER) depending on the packet Signal to Noise Ratio (SNR), which is calculated including propagation losses due to distance between nodes. Therefore, there can be some cases where destination or altruistic nodes fall out of coverage. In the particular case of the backbone, where nodes are static, nodes may still be subject to packet losses due to radio interferences and medium access collisions. Hence, packet losses could be caused because of either node mobility or congestion in the backbone nodes.

Since the proposed algorithm can be summarized as a video-aware ARQ mechanism based on packet caching, it is interesting to compare it with other ARQ mechanisms that perform caching of video packets, such as that described in [14]. It makes use of a special video assistant node in the route that is in charge of caching the video packets that it has forwarded previously. As the best results are achieved when the video assistant is located in the middle of the path, the simulated algorithm makes use of the node located as close as possible to the middle of the packet route to perform caching and retransmission. This node is selected dynamically so it will change if the route changes. Hereafter, this algorithm is referred as VAARQ. Figure 9 shows a comparison between traditional OLSR, VAARQ and the Altruistic scheme proposed in this paper regarding PSNR, frame loss, packet delay, overhead and cumulative number of interruptions, with a 95% level of confidence. Average results are presented.

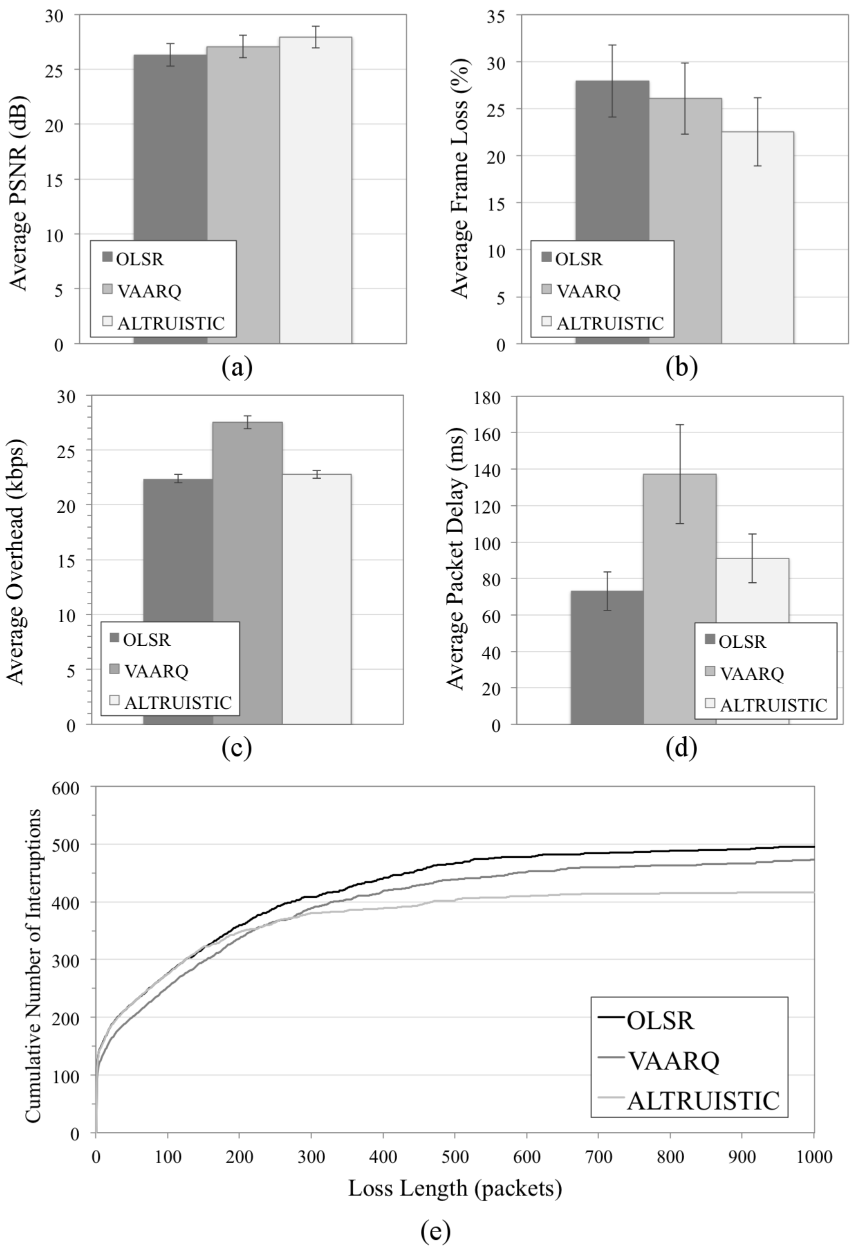

Fig. 9. Comparison between OLSR, VAARQ and Altruistic OLSR regarding Average PSNR (a), Average Frame Loss (b), Average Overhead (c), Average Packet Delay (d), and Cumulative Number of Interruptions (e)

Attending to Figure 9a and Figure 9b, both PSNR and video frame loss are improved by using the altruistic recovering mechanism (about 6% and 5% on average, respectively). VAARQ algorithm obtains better results than traditional OLSR but fails to recover some video packets due to the destination mobility, which causes that ARQ requests do not reach the video assistant. Figure 9c shows the total OLSR overhead introduced by all the 20 nodes in the simulation (including AR messages for ALTOLSR) and the overhead introduced by the ARQ packets in VAARQ (the difference is about 2% in the altruistic algorithm and almost 20% in VAARQ). The number of routing protocol packets in the altruistic scheme is increased due to the additional signaling (AR packets) between destination node and its neighbors and the extra information in HELLO messages. However, in this case VAARQ introduces a higher amount of overhead because ARQ packets are sent for every packet loss detected, even if there are several contiguous lost packets. Average packet end-to-end delay is also increased using the altruistic scheme (20%), according to Figure 9d. This is due to the fact that packet delay is measured only with correctly received packets. Packet retransmission obviously increases packet delay compared with no retransmission, but this delay would be greater if this retransmission was performed from the video source instead of retransmitting from a node close to destination. Even when retransmittion is carried out from an intermediate node (as in VAARQ), packet delay is dramatically increased (47%). As long as jitter is maintained rather steady and does not increase (as observed from the error bars in Figure 9d for the altruistic mechanism), it could be concealed at the receiver buffer, not affecting the video playback. Finally, Figure 9e shows the cumulative number of interruptions depending on their length in packets. Firstly, it can be stated that the background traffic coursed through the backbone causes losses along the path due to congestion and interferences. These packet losses could be recoverable using VAARQ if the retransmitter node has managed to cache the lost packets. On the contrary, ALTOLSR is only able to recover losses that are produced in the last hop, which are sometimes caused due to congestion but mainly produced due to the mobility of the destination node. Secondly, even though some kind of losses cannot be concealed using

ALTOLSR, this algorithm is able to obtain better PSNR. This is achieved because most of the packet losses are still caused near the last hop and there are some neighbors close to destination that are capable of becoming altruistic nodes. Since source node transmits approximately 75 packets per second on average (value obtained from the video trace files), it can be inferred that largest burst losses (greater than 150 packets, i.e. larger than 2 seconds) are reduced with the altruistic mechanism. Moreover, VAARQ manages to recover short interruptions (shorter than 5 packets), which are likely produced in the backbone, but eventually, it follows a similar trend as OLSR. Despite the fact that VAARQ also reduces video interruptions, the amount of recovered packets is higher in the altruistic approach, especially in scenarios with mobile destination nodes.

All in all, by reducing the amount of lost packets, more frames can be recovered and, therefore, PSNR is notably increased. Additionally, some of the video playback interruptions are also prevented, which all provide a significant improvement in video quality.

As aforementioned, ALTOLSR does not increase the amount of control packets notably, but as long as frame losses increase, more control overhead is generated in order to recover lost packets. Therefore, in order to analyze how frame losses affect the amount of overhead generated, ALTOLSR and VAARQ are compared regarding the number of retransmission requests (AR messages in ALTOLSR and ARQ packets in VAARQ) and the total control overhead generated. Hence, Figure 10 depicts the number of ARQ requests needed to obtain certain values of PSNR. It can be seen that in order to obtain similar PSNR, the amount of ARQ requests is definitely lower using ALTOLSR than using VAARQ (note the logarithmic scale in the x-axis).

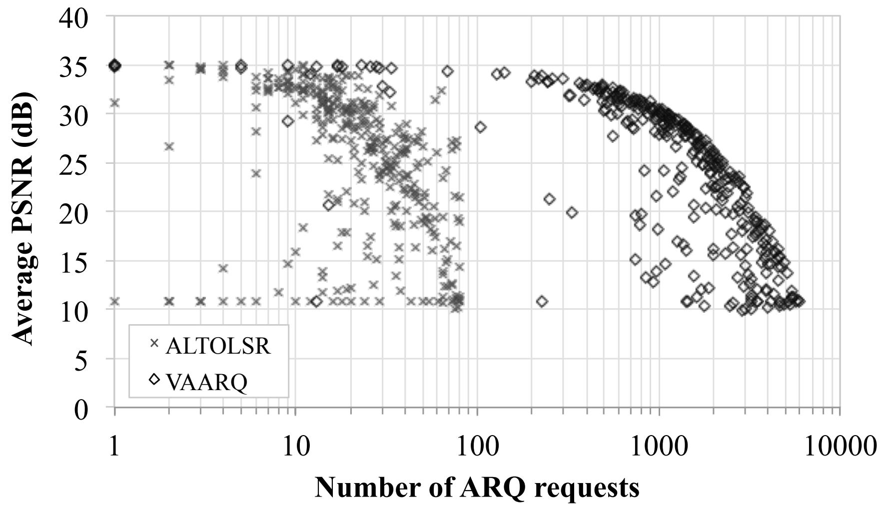

Fig. 10. Average PSNR vs. the number of ARQ requests

By using ACK Vectors in ALTOLSR, several video packets can be requested using only one AR message. Even if some AR messages or the recently retransmitted video packets are lost, next AR messages may contain the request for those video packets that are still missing, as long as they have not been deprecated yet. Additionally, Figure 11 depicts the overhead caused by both protocols according to the amount of lost frames compared to traditional OLSR.

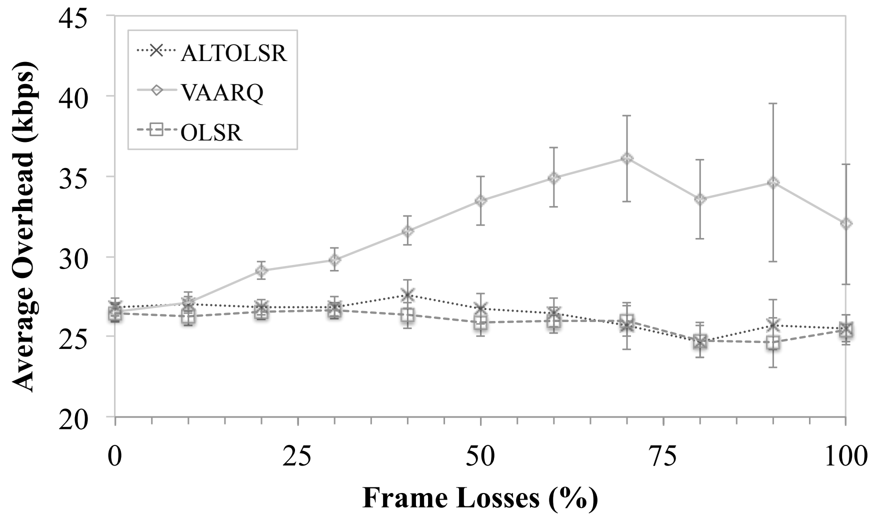

Fig. 11. Control overhead according to frame losses

Although high lossy environments may cause a rise in this kind of traffic for ALTOLSR, it is not really meaningful in comparison with all the routing traffic (under 5%). As depicted, other ARQ solutions such as VAARQ may introduce a higher amount of routing traffic when losses increase (28%). In ALTOLSR, it is worth noting that this traffic increase is only produced in the last hop and does not affect the rest of the network unlike in VAARQ. Unfortunately, although ALTOLSR can recover a great amount of lost packets, it would be useful only if losses are caused in the last hop or in the surrounding area of the destination node.

4.3. Resource consumption considerations

In general, wireless ad hoc networks are resource-demanding networks, especially because nodes that belong to a transmission route are consuming their own resources (e.g. processing time, memory and battery) although they are neither the source nor the destination of the communication. This tradeoff between connectivity and energy consumption has been analyzed in [24] and the feasibility and convenience of implementing ad hoc networks have been demonstrated, despite the fact that incentives to the users could be necessary to persuade them to share the capabilities of their devices with other users. In addition, if any of these router nodes has to become an altruistic node and it also has to cache packets to retransmit, this resource consumption increases inevitably.

In the mechanism proposed in this paper, altruistic nodes must allocate sufficient storage to perform caching properly. The amount of available storage in an altruistic node for caching packets from a specific destination node, as well as the interval of time packets are cached, may influence the quality of the received video. Also, play-out buffer (PoB) size is important to assess video quality because retransmitted packets could become deprecated depending on the kind of service. In these sense, new scenarios have been simulated varying the cache validity time. Furthermore, by using different valid PoB sizes, three typical situations have been defined in order to simulate scenarios close to real situations: a PoB of 150 ms, which represents an interactive videoconference; a PoB of 1 s, which represents a real-time videostreaming service; and finally a PoB of 5 s, which works as a video on demand (VoD) situation with a buffer slightly larger. Validity time of cached packets has been varied from 0 s (no packets are cached) to 5 s for each different situation in order to assess how PSNR is affected. Hence, Figure 12 depicts the average PSNR according to the cache validity time configured in the altruistic nodes.

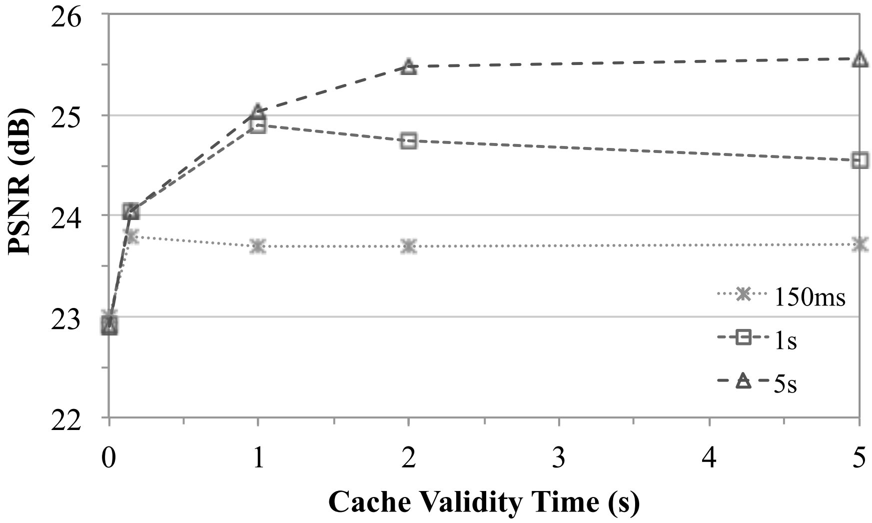

Fig. 12. Average PSNR according to the cache validity time for different PoB sizes

As shown, a cache validity time of 150 ms is enough to improve PSNR in about 1 dB. For a PoB of 150 ms, however, values greater than 150 ms do not improve video quality because most of recovered packets are already obsolete for the receiver. Similarly, cache validity time of 1 second is optimal for a PoB of 1 second in reception. In the case of using a PoB size of 5 seconds, either storing video packets during 2 seconds or 5 seconds in cache means no evident difference. This fact is tightly related to the AR interval, which was set to 1 second in the simulations. This means that, at least every second, the destination node is going to inform altruistic nodes about the packets that need to be retransmitted. In the case that cache validity time is 1 second, some of the cache packets might be dropped before retransmission request reaches the altruistic node. However, by caching packets during more than 1 second, e.g. a cache validity time of 2 seconds, the altruistic node is able to retransmit a slight higher number of packets as long as they are not deprecated yet. Therefore, higher cache validity times do not really improve PSNR provided that PoB size is big enough because lost packets are recovered continuously due to the periodical transmission of AR messages.

Additionally, Figure 13 shows the maximum cache occupancy according to the cache validity time. It represents the maximum amount of memory storage in kBytes that an altruistic node would need to cache video packets for each flow. Since a cache validity time of 5 s implies a greater amount of available storage but PSNR improvement is not remarkable compared with a validity time of 2 s, it can be concluded that a value of 2 s is more efficient in this analyzed scenario, although the optimal value will be determined by the actual destination PoB size and the AR interval. As aforementioned, destination node can inform altruistic nodes about the PoB size using AR messages, allowing altruistic nodes to adapt the cache validity time.

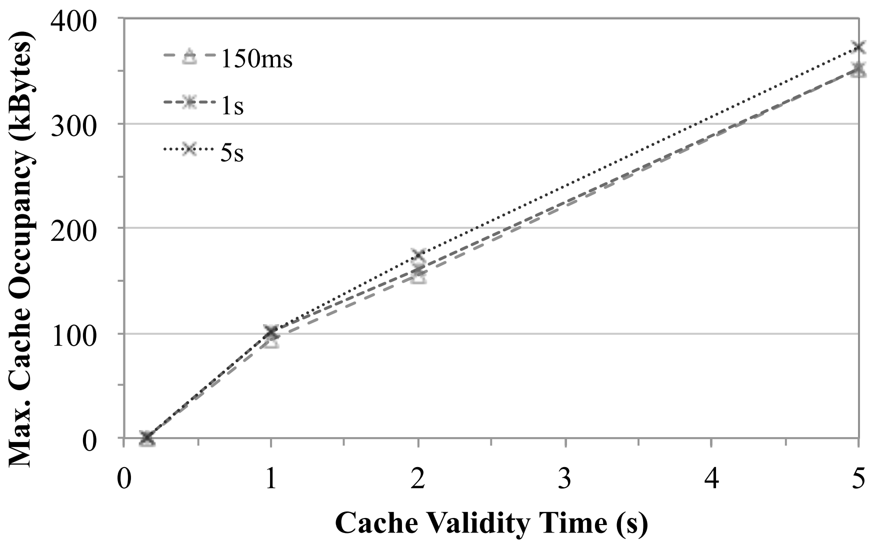

Fig. 13. Maximum cache occupancy regarding the cache validity time for different PoB sizes

Regarding energy consumption, the fact of adding further mechanisms that use packet retransmission necessarily entails an increase in battery consumption. Taking into account that in ad hoc networks most of the nodes are mobile nodes or battery-dependent devices, new proposed techniques should not be very energy demanding in general.

In order to understand how the mechanism proposed in this paper affects the battery life of participant nodes, additional simulations have been carried out and energy consumption has been measured. Figure 14 depicts the basic scenario under test, which consist of 7 nodes. The route is established between source node (node 0) and destination node (node 6), using node 1 and 2 as routers. Destination node is moving during the simulation, so that an alternative route has to be found through node 3. Node 4 and node 5 are only listeners, although node 4 becomes an altruistic node when simulating ALTOLSR, and node 1 is in charge of video retransmissions (VA) when simulating VAARQ. Simulation parameters regarding transmission power, propagation loss, etc. are similar to previous simulations.

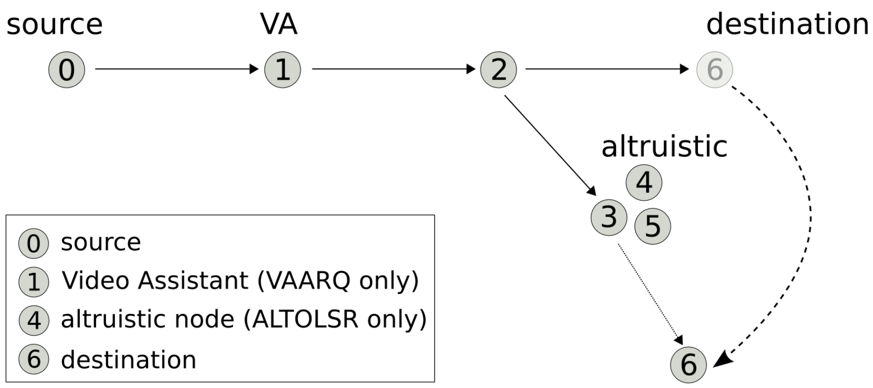

Fig. 14. Scenario for energy consumption measurement

Usually, wireless radio interfaces consume different amount of energy depending on the state they are working on, which can be transmission (TX), reception (RX), idle and sleep. A node in TX or RX state is likely to consume more power than in sleep or idle state. Nodes that are not taking part of the actual path, such as node 5 in this case, are also receiving packets and dismissing them, which mean non-negligible consumption. Power consumption parameters are described in Table 3. Finally, Figure 15 shows the maximum energy consumption for every node in the scenario under analysis.

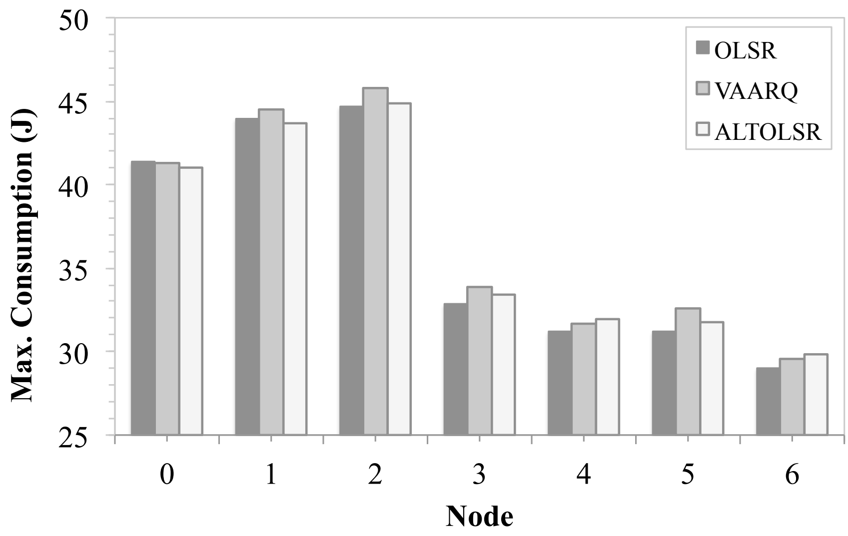

Fig. 15. Maximum energy consumption per node

Particularly, it can be seen that the altruistic scheme causes an increase in consumption only in the last hop (nodes 3-6), unlike VAARQ, which produces higher energy consumption from the retransmitter node until destination (nodes 1-6). Due to the intra-flow contention, which appears in multi-hop networks even for a single transmission, a forwarder node consumes energy because of both the reception of packets sent by the neighbors and the retransmission of packets. Using ARQ mechanisms that use caching nodes near the source will ensure that video packets have been cached, but at the same time, retransmitting packets through a high number of hops would entail higher energy consumption, not only in the nodes that take part in the path but also in neighboring nodes, which are actually receiving these packets as well (RX state). Moreover, altruistic node (node 4) has higher consumption due to retransmissions (2%) but this increase is not meaningful compared with a node that is carrying out packet forwarding (below 28%). Nevertheless, VAARQ mechanism increases the average consumption only in 1.6%, but this increase occurs in every node in the retransmission path and neighboring nodes, which eventually contributes to the faster network performance deterioration. Finally, it is worth mentioning that by using the altruistic scheme, PSNR is improved (e.g. from an average of 25.7 dB and 26.7 dB in OLSR and VAARQ, respectively, to 28.7 dB in ALTOLSR) and only the surrounding area of destination node is affected by retransmissions.

5. CONCLUSION

Mobility of nodes makes it difficult to create and maintain transmission routes in wireless ad hoc networks. Thus, providing loss and delay sensitive services such as video streaming in these kinds of networks and guaranteeing a certain QoE is still challenging. When any node moves out of range, routes have to be recalculated and in the meanwhile, packets could be lost.

The main objective of the proposal presented in this paper is to provide throughput gains in wireless communications and improve the QoS of video transmissions, providing the user with a higher QoE. To this end, this paper proposes a cross-layer technique that uses information drawn from MAC, routing and application layers in order to increase the overall packet delivery ratio and, in case of video transmissions, reduce frame losses so as to avoid playback interruptions. This scheme proposes that neighboring nodes of the destination node help in recovering lost packets when a route breakage occurs.

Simulation results show that the proposed algorithm reduces video frame loss considerably (5%) and thus improves average PSNR in approximately 2 dB (6%), even achieving about 7 dB (39%) of improvement when considering only the rerouting time window. Packet delay is affected by retransmissions, but due to the proximity of the retransmitter, the average packet delay is kept lower than in other mechanisms based on source ARQ. The number and length of burst losses is also reduced with the altruistic mechanisms, leading to a higher video quality and better user experience. Moreover, unlike other ARQ solutions, the proposed approach maintains lower overhead even though the amount of losses grows (5%), and energy consumption is only increased in nodes close to the destination node, which benefits the overall network performance.

Although an initial assumption has been taken about the stationarity of backbone nodes, this hypothesis is nowadays perfectly plausible considering how wireless mesh networks are evolving. Due to the nature of this proposal, it makes more sense in environments that concentrate packet losses in the last hop.

Finally, since received video streams are reconstructed during simulations, it is foreseen to perform subjective evaluations in order to assess how the improvement in PSNR and video interruptions is perceived by the viewers.

REFERENCES

[1] Li J, Blake C, De Couto DSJ, Lee HI, Morris R. Capacity of Ad Hoc Wireless Networks. *Proceedings of the 7th Annual International Conference on Mobile Computing and Networks (MobiCom)*, New York, 2001, pp. 61-69.

[2] Akyildiz IF, Wang X. A Survey on Wireless Mesh Networks. *IEEE Communications Magazine*, vol. 43, no. 9, pp. S23-S30, Sep. 2005.

[3] Suarez A, Macias E. *Multimedia Services and Streaming for Mobile Devices: Challenges and Innovations*. IGI Global, 2012, ch. 12, pp 244-261.

[4] Hsu C-J, Liu H-I, Seah WKG. Opportunistic Routing: a Review and the Challenges Ahead. *Computer Networks*, vol. 55, no. 15, 2011, pp. 3592-3603.

[5] Huang X, Zhai H, Fang Y. Robust Cooperative Routing Protocol in Mobile Wireless Sensor Networks. *IEEE Transactions on Wireless Communications*, vol. 7, no. 12, pp. 5278-5285, Dec. 2008.

[6] Wieselthier JE, Nguyen GD, Ephremides A. Algorithms for energy-efficient multicasting in ad hoc wireless networks. *ACM/Springer Mobile Networks and Applications*, vol. 6, no. 3, pp. 251-263, Jun. 2001.

[7] Clausen T, Jacquet P. *Optimized Link State Routing Protocol (OLSR)*, IETF RFC 3626, October 2003; http://www.rfc-editor.org/rfc/rfc3626.txt.

[8] Marina MK, Das SR. Ad hoc on-demand multipath distance vector routing. *Wireless Communications and Mobile Computing*, vol. 6, no. 7, pp. 969-988, Nov. 2006.

[9] Zhou X, Lu Y, Ma HG. Routing improvement using multiple disjoint paths for ad hoc networks. *International Conference on Wireless and Optical Communications Networks (IFIP)*, 2006.

[10] Fujisawa H, Minami H, Yamamoto M, Izumi Y, Fujita Y. Route Selection using Retransmission Packets for Video Streaming on Ad Hoc Networks. *IEEE Conference on Radio and Wireless Symposium (RWS)*, 2006, pp. 607-610.

[11] Badis H, Agha KA. QOLSR Multi-path Routing for Mobile Ad Hoc Networks Based on Multiple Metrics: Bandwidth and Delay. *IEEE 59th Vehicular Technology Conference (VTC)*, vol. 4, pp. 2181- 2184, May 2004.

[12] Wu Z, Wu J. Cross-Layer Routing Optimization for Video Transmission over Wireless Ad Hoc Networks. *6th International Conference on Wireless Communications Networks and Mobile Computing (WiCOM)*, 2010, pp. 1-6.

[13] Schier M, Welzl M. Optimizing Selective ARQ for H.264 Live Streaming: A Novel Method for Predicting Loss-Impact in Real Time. *IEEE Transactions on Multimedia*, vol.14, no.2, pp.415-430, Apr. 2012.

[14] Nikoupour M, Nikoupour A, Dehghan M. A Cross-Layer Framework for Video Streaming over Wireless Ad-Hoc Networks. *3rd International Conference on Digital Information Management (ICDIM)*, 2008, pp. 340-345.

[15] Yamamoto R, Miyoshi T. Distributed Retransmission Method Using Neighbor Terminals for Ad Hoc Networks. *Proceedings of the 14th Asia-Pacific Conference on Communications (APCC)*, 2008.

[16] Gravalos I, Kokkinos P, Varvarigos EA. Multi-criteria cooperative energy-aware routing in wireless ad-hoc networks. Proceedings of the 9th International Wireless Communications and Mobile Computing Conference (IWCMC), 2013, pp. 387-393.

[17] Abid RM, Benbrahim T, Biaz S. IEEE 802.11s Wireless Mesh Networks for Last-mile Internet Access: An Open-source Real-world Indoor Testbed Implementation. *Wireless Sensor Networks*, vol. 2, no. 10, pp. 725–738, 2010.

[18] Yen Y-S, Chang R-S, Wu C-Y. A seamless handoff scheme for IEEE 802.11 wireless networks. *Wireless Communications and Mobile Computing*, vol. 13, no. 2, pp. 157-169, Feb. 2013.

[19] Yin L, Cao G. Supporting cooperative caching in ad hoc networks. *IEEE Transactions on Mobile Computing*, vol. 5, no. 1, pp. 77-89, Jan. 2006.

[20] Biswas S, Morris R. ExOR: opportunistic multi-hop routing for wireless networks. *Proceedings of ACM SIGCOMM*, 2005, pp. 133-144.

[21] Chachulski S, Jennings M, Katti S, Katabi D. Trading Structure for Randomness in Wireless Opportunistic Routing. *Proceedings of ACM SIGCOMM*, 2007, pp. 169-180.

[22] Kohler E, Handley M, Floyd S, *Datagram Congestion Control Protocol (DCCP)*, IETF RFC 4340, March 2006; http://www.rfc-editor.org/rfc/rfc4340.txt.

[23] Schierl T, Ganger K, Hellge C, Wiegand T, Stockhammer T. SVC-based multisource streaming for robust video transmission in mobile ad hoc networks. *IEEE Wireless Communications*, vol. 13, no. 5, pp. 96-103, Oct. 2006.

[24] Iera A, Molinaro A, Paratore SY, Ruggeri G, Zurzolo A. Making a mesh router/gateway from a smartphone: Is that a practical solution? *Ad Hoc Networks*, vol. 9, no. 8, pp. 1414-1429, Nov. 2011.

Table 1. Qualitative Comparison Among Recovery Solutions

Mechanisms	ARQ	Video Awareness	WBA	Caching	Adaptive	Multipath
[10]	Yes	No	No	No	No	Yes
[13]	Yes	Yes	No	No	Yes	No
[14]	Yes	Yes	No	Yes	Yes	No
[15]	No	No	Yes	No	No	Yes
This proposal	Yes	Yes	Yes	Yes	No	No

Table 2. List of Relevant Simulation Parameters

Parameter	Value
Wireless Standard	802.11b
Data Rate	11Mbps
Transmission range	85m
RTS/CTS	Not Used
Video resolution	352x288 (CIF)
Video duration	80 seconds
Average video rate	500 kbps
Max. queue delay	1s
Cache validity time	1s
HELLO interval	1s

Table 3. Power consumption parameters of Intel PRO/Wireless 3945ABG (802.11a/b/g) Card

Parameter	Value
Transmission (max.)	1.8 W
Reception (max.)	1.4 W
Idle mode (nominal)	150 mW
Sleep mode (max.)	30 mW
Operating voltage	3.3 V