Chapter

ALTRUISTIC NETWORKS: WHERE EVERY NODE MATTERS

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ABSTRACT

Traditionally, wireless ad hoc networks have been used for emergency situations due to the feasibility of fast deployment and connectivity. However, multimedia services are much demanded nowadays and bandwidth and delay requirements of this kind of services are very restrictive. Offering real-time video services in wireless ad hoc networks is not an easy task because of the difficulty of guaranteeing certain quality in a shared medium. In this kind of network, nodes should be ready to route and forward data packets coming from other nodes. The cooperation of every node is essential for the proper operation of the network because there are many factors that may cause video quality degradation, from radio interferences to node mobility, which causes link breakages until a new route is calculated, producing annoying video interruptions to the receiver. The variability in network capacity and link quality, together with the dynamic network topology, has clearly influenced emerging wireless mesh networks, which tend to maintain a static backbone in order to provide sufficient Quality of Service. Moreover, since wireless propagation nature allows any node to overhear any neighbor transmission, the way opportunistic and cooperative routing protocols take advantage of the broadcast nature of wireless medium can be adopted for new routing proposals. In this sense, this chapter proposes and describes a new cross-layer mechanism for recovering lost packets by means of caching overheard packets in neighbor nodes and retransmit them to destination. Additionally, a video-aware cache is implemented in order to recover full frames and prioritize more significant frames. On the other hand, energy consumption is critical in mobile nodes because they may rely on battery power, and the whole network connectivity may be affected if some of the routing nodes run out of battery eventually. Thus, energy consumption is also taken into account in the recovering algorithm

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design to ensure longer network connectivity life. Finally, results show the improvement in reception, increasing the throughput as well as video quality, and reduce large video interruptions considerably. Moreover, by being aware of nodes energy consumption, the proposed algorithm is able to maintain network lifetime longer.

Keywords: routing protocols, OLSR, Quality of Service, video streaming, Quality of Experience, wireless ad hoc networks, ARQ.

INTRODUCTION

Mobile wireless ad hoc networks (MANETs) are characterized by versatility, feasibility and ease of deployment without infrastructure. This kind of network consists of a series of nodes that cooperate in order to create and maintain packet routes. In large networks, communications might have to cross some intermediate nodes in order to reach destination. These intermediate nodes act as routers so that packets can travel from one node to another through multi-hop routes. Consequently, every node should be able to forward packets addressed to other nodes. In fact, every node forming part of the network which can be a potential source or destination of data transmissions, has also to be able to route and forward packets from other communications. As far as fairness is concerned, this may be seen as initial condition to be part of an ad hoc network. This way, every node cooperates towards the proper operation of the network, with the aim of providing connectivity among nodes. However, besides the basic connectivity service offered, the number of real-time video services and multimedia applications is growing nowadays, and delay and bandwidth requirements of these kinds of services are very restrictive.

This sort of network represents a hostile environment for this kind of real-time data transmission to the extent that obtaining a good quality of viewer experience is challenging and still under study. Besides the research point of view, providing high-quality multimedia services is decisive for the practical usability and feasibility of wireless ad hoc networks so that service providers can broaden the range of services offered. So far, mobile wireless ad hoc networks have been used to provide network connection among users who could not have connectivity otherwise. However, quality expectations and requirements have been increased notably, fostered by the advent of real-time multimedia applications over mobile devices. Due to the considerable processing and bandwidth constraints underlying these types of devices, coupled with their ability to move freely, it becomes a difficult task to achieve an acceptable Quality of Service (QoS) throughout the entire video transmission.

In MANETs, routing protocols are in charge of establishing routes towards destination. Because of the multi-hop nature of this kind of network, 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 intra-flow contention are increased in every additional link [1]. Moreover, mobility of nodes makes it difficult to create and maintain these routes. In case a node moves out of coverage of its neighbors, part of the communication path has to be calculated again. During this rerouting time, following packets cannot be delivered and most of them are dropped, causing packet losses and non-negligible delays.

It is well known that MANETs can be set up at very low cost compared with networks based on access points that need wired infrastructure support. However, due to the difficulty of maintaining minimal QoS conditions, actual ad hoc networks tend to be designed with a static wireless backbone, which provide them with the minimal structure to assure connectivity and stability to a certain extent, like in emerging wireless mesh networks (WMNs) [2]. This could become a trade-off between cost effort and the transmission quality offered [3]. The hierarchical structure of WMNs can help in stabilizing routes despite the mobility of some terminals. A typical wireless mesh scenario is depicted in Figure 1.

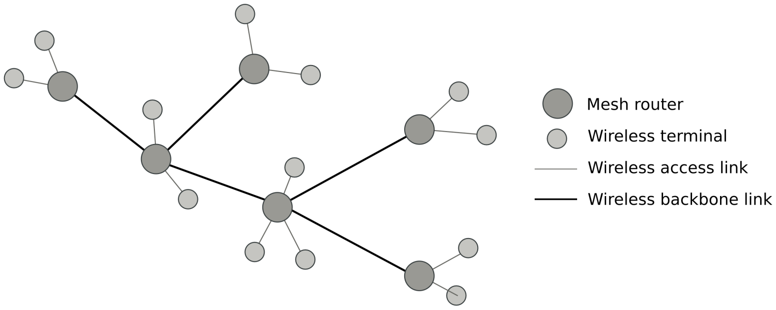


Figure 1. Typical ad hoc mesh network with a wireless backbone

In case the 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 case these packets arrive correctly at the node preceding the destination, it should be worth an effort to make those packets finally arrive at destination without having to be discarded or sent again through a new route, consuming time and resources. Since any neighbor of the destination node may have overheard those undelivered packets, it could send them again, although it does not take part of the original packet path. This can be achieved due to a particularity inherent to the wireless channel nature. Despite the fact of being one of the main reasons of interferences and contention, which affect the transmission quality negatively, the shared medium can be exploited to reinforce routes and build more robust packet paths, such in opportunistic [4] and cooperative routing protocols [5].

Even in mesh networks, where a backbone provides more topological stability, it is not assured high Quality of Experience (QoE). In such scenario, mobility of terminal nodes still causes link breakages until a new route is calculated. In the meanwhile, lost packets cause annoying video interruptions to the receiver. 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 chapter proposes a cross-layer technique that uses information drawn from link, 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 link layer are performed and only slight changes in the routing protocol are needed.

Additionally, and aiming at improving video transmissions particularly, this cross-layer proposal allows using video aware cache, which would provide altruistic nodes with the ability to recover full frames and prioritize more significant frames. Furthermore, energy consumption is a key factor for the proper operation of an ad hoc network, since the majority of nodes are mobile and battery-dependent devices. Therefore, despite the significant progress in battery capacity and duration, power resources in mobile devices are limited and, consequently, it is worth taking energy consumption into account. In this regard, nodes using the proposed mechanism may chose the better neighbor to retransmit lost packets according to their residual energy so that the overall lifetime of the network is increased.

With this proposal, both throughput and video quality are improved and, in addition, large video interruptions are considerably reduced, as results show. Energy consumption is also taken into consideration in order to increase the network lifetime.

This chapter is organized as follows. Next section exposes some related work. Then, the main challenges for video streaming in mobile ad hoc networks are briefly described. The proposal is explained in the next section and the performance and results are shown in the assesment section. Finally, conclusions are discussed.

RELATED WORK

Usually, MANETs present a mesh topology where every node may have one or more neighbors and any of them may act as a router. This network arrangement allows multipath routing protocols to choose among several possible routes if the current one results broken [6] [7]. Furthermore, Automatic Repeat Request (ARQ) mechanisms 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 [8]. In multi-hop networks, transmission paths are usually established taking into account the number of hops, but there are also other alternatives and measures such as path loss, available bandwidth, packet delay or link quality [9] [10]. In some cases, these routing protocols can even control video quality parameters in a cross-layer manner in order to adapt the transmission rate to the current network conditions and path bandwidth [11].

One of the drawbacks of the ARQ mechanism is that it negatively affects real-time video streaming when packets are retransmitted frequently, because additional traffic overload is generated throughout the network and, moreover, higher end-to-end delay is introduced for each retransmitted packet, which can become deprecated and discarded, leading to video playback interruptions. Some related works propose the utilization of special intermediate nodes along the path that act as video assistants [12]. These video assistants are in charge of buffering video packets and retransmit them when destination node sends an ARQ. By using an intermediate node instead the source node, the requested packet is sent back to the destination in 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. This mechanism reduces the delay of those packets that have to be retransmitted in comparison with end-to-end ARQ methods, at the cost of introducing some complexity when routes are created.

As aforementioned, the shared nature of the wireless medium allows nodes to hear packets sent by neighbors to other nodes. Taking advantage of this feature, retransmitter nodes in the ARQ scheme should not be limited to nodes belonging to the transmission path. Reference [13] proposes a method that uses neighboring terminals of the nodes along the route, not only the nodes that are currently part of the route, to forward packets cooperatively.

Therefore, lost packets acquire more chances to be retransmitted, improving the effectiveness of retransmission, although more complexity is introduced in order to coordinate possible retransmitters. Also, reference [14] proposes a cooperative relaying algorithm for interference reduction, where idle nodes can be used as potential video relays. Video rate and transmission power are controlled distributedly in order to maximize the overall video quality. Generally, however, cooperative routing may cause additional energy consumption since more nodes than in deterministic routing are participating in the transmission path. Taking this into account, reference [15] proposes a cooperative routing mechanism that uses variable transmission power in order to balance achievable throughput and battery life.

In general, many proposals involving energy-aware mechanisms are based on a cross-layer scheme, which combine information collected from different protocol layers and operate on a particular function within the protocol stack. Particularly, interaction between data link layer and network layer may contribute to provide routing protocols with some sort of energy awareness in order to deal with battery life limitations inherent to mobile devices. Some of these approaches make use of additional metrics in order to select better routes. In this sense, reference [16] proposes an algorithm that reduces network congestion by means of establishing routes using the nodes with maximum residual energy. Another approach proposes to build different routing entries according to the node power levels on demand, and select the minimum power level route for data delivery [17]. In [18] and [19], both the balance of the route and power conservation are considered, leading to cross-layer routing protocols that perform load balancing across multiple paths and extend network lifetime. Energy consumption is therefore an important point to consider because energy-aware algorithms could improve the overall network performance in the sense that some route breakages and packet losses might be prevented.

Commonly, actual implementations of wireless mesh networks [20] rely on an ad hoc backbone with stable topology, and cosequently, link losses are usually low within theses backbone nodes. This can be the case of real practical scenarios, such as in smart cities or campus universities. This fact causes that most of packet losses likely occur on the last hop due to possible movements of the destination node or some of its contiguous neighbors. Therefore, limiting retransmission mechanisms to the last hop surroundings is certainly reasonable, because interference caused to other nodes is minimized and the overall energy consumption and packet delay is consequently reduced, which is desirable in real-time video transmissions. In a similar wireless scenario, reference [21] 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.

CHALLENGES FOR VIDEO STREAMING SERVICES OVER MANETS

Shared Channel Limitations

The shared nature of the wireless channel in ad hoc networks may cause packet collisions within the carrier-sensing distance of the transmission node. Such situations can be avoided with proper mechanisms to access the wireless medium. The medium access control algorithm used in IEEE 802.11 (i.e. CSMA/CA) presents several basic mechanisms in order to avoid packet collisions, such as random back-off time or the RTS/CTS handshake mechanism. This kind of collision avoidance medium access entails some limitations in wireless ad hoc networks and, particularly, one of these limitations is the achievable transmission capacity. Specifically, the 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. All in all, the maximum bandwidth is reduced due to the fact that nodes cannot simultaneously access the shared medium. That is, when a node is transmitting a packet, neighbor nodes within its interference range must not transmit. As a result, an overall degradation in data rate is produced.

These results are not unexpected at all, but they have to be taken into account when analyzing wireless networks and specially when assessing services that consume an important amount of bandwidth, such video streaming services. Medium contention and transmission interferences do worsen the average network throughput when several data sources are competing for the medium access, but this contention exists even when only a single transmission is carried out through the network (or it is locally isolated in the network).

In multi-hop ad hoc networks, when a transmission is established, the nodes must cooperate to forward the packets through the network, which means that the available throughput on each host is limited not only by the access channel, but also by the forwarding load. As hop count increases, the maximum throughput of one flow decreases substantially and falls down because of the overhead of MAC layer and the mutual interference between packets of the same flow. This effect is called intra-flow contention [22] and represents the contention between packets of the same flow being forwarded at different hops along a multi-hop path, causing the actual bandwidth consumption.

Although node interference and intra-flow contention are constraining factors that affect the maximum throughput achieved in transmissions, there are still other issues that may cause additional packet losses and may also difficult good quality transmissions in such distributed networks, such as, for instance, mobility of nodes.

Ad hoc networks have the ability of self-organization and self-configuration but the topology of these networks is usually highly dynamic. Due to mobility and the multi-hop nature of ad hoc networks, any node can move out of the coverage area for a short time, losing the packet route to destination and even causing route breakages to other communications. Therefore, the node ability to move freely can become a problem because of these induced link breakages and the necessity to discover new routes towards destination for data transmission. These facts cause packet losses and delay while new routes are being configured, with the consequent loss of quality at the receiver.

Video Streaming over MANETS

Video streaming services, which are increasingly demanded nowadays, are bandwidth consuming and have high restrictive delay and loss constraints. Deploying such real-time services turns out difficult on wireless ad hoc networks due to the aforementioned issues. While video streaming requires a steady flow of information and delivery of packets by a deadline, wireless radio networks have difficulties to provide such a service reliably. Hence, the problem is challenging due to contention from other network nodes, as well as intermittent interference from external radio sources. Besides this, it is likely that any node might move away and therefore, the network topology may be altered causing link breakages and packet loss. Because of their nature, video streaming services are very sensitive to packet loss and delay. Figure 2 illustrates this video quality loss (PSNR degradation) when throughput is degraded because of node mobility, radio interferences or intra-flow contention.

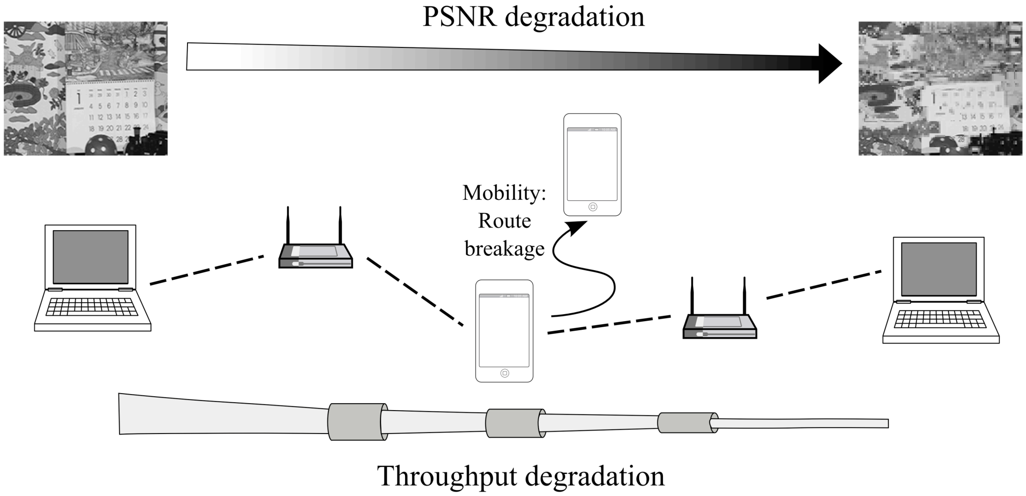


Figure 2. Video quality degradation in multi-hop wireless networks

Nowadays, most of video encoders are capable of reaching a quite low data rate and ensuring a rather good video quality. This is due to the use of a hierarchical coding, which causes many frames to be time dependent on others within the same video flow (e.g. MPEG-4, H.264, VP8). However, just because of this type of video encoding, the loss of a few packets can provoke the loss of one or several dependent video frames. Even a slight delay on some packets could result in deprecated frames, and therefore it would be better to skip it rather than play it back late. It is true that this time dependency is reduced to slice domain or even block domain within a frame in cutting-edge encoders, but the inter-frame dependency will be eventually unavoidable if a high compression rate is aimed to be achieved. This is why many video decoders have been developed with error concealment mechanisms in case of transmission failures.

Network simulators are useful tools that allow building huge network topologies and testing new protocols and algorithms that could not be assessed otherwise. However, it would also be interesting to check some results whenever possible over real networks and devices. In order to illustrate more clearly what happens when a node moves out of the coverage of the routing neighbor and how it affects the video quality, a real video transmission has been assessed, which not only is useful for a better understanding of the actual performance of wireless transmissions but also to measure the video quality received in a hostile environment. For scalability reasons, however, only a small-scale scenario has been assessed. Thus, real devices have been configured and arranged forming an ad hoc network.

The testbed has been built with laptops and smartphones. Source and destination nodes are laptops with Linux and 802.11b/g wireless cards. For multi-hop transmission, Android smartphones are used as intermediate nodes, which are in charge of routing video packets. These devices have been intentionally arranged so that the source node must always use any of the intermediate nodes to forward packets to the destination node. Therefore, transmission route is always forced to have two hops. During the experiment, the destination node moves at approximately 1 m/s, following the itinerary depicted in Figure 3.

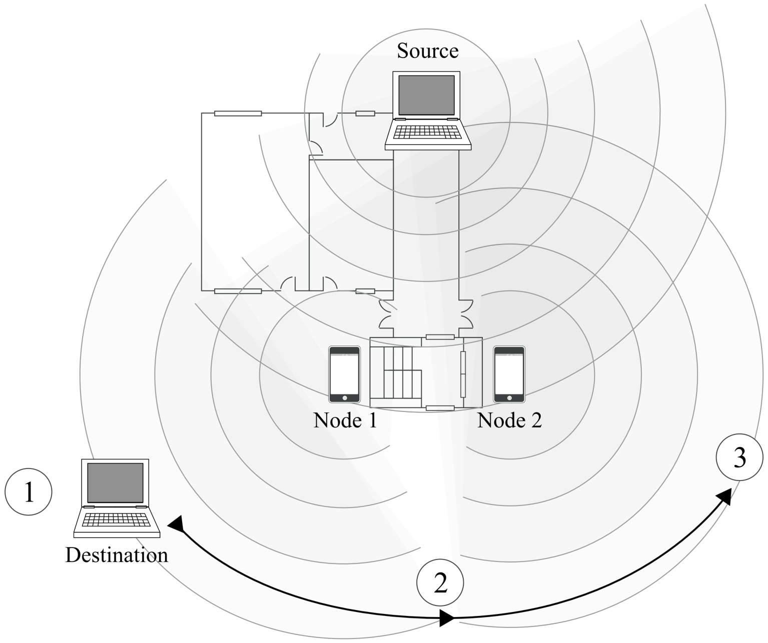


Figure 3. Network setup for testbed

Note that node 1 and node 2 do not see one another due to the thick walls. Hence, the experiment is carried out as follows. First, the destination is receiving the video transmission from source through node 1, which acts as a router (1). Then, destination moves away from the coverage of node 1, causing a route breakage and the consequent packet losses (2). Right away, destination node enters within the coverage of node 2. Video packets are then transmitted from source to destination through node 2. This route change does not occur immediately, because the routing protocol must first realize that the link has fallen and then recalculate the best route (3). The routing protocol used is an implementation of OLSR [23], which uses HELLO and Topology Control (TC) messages to perform routing operations. The main parameters used to configure the testbed regarding wireless card and routing protocol are described in Table 1.

Table 1. Testbed wireless configuration parameters

Parameter	Value
Wireless Standard	802.11g
Data Rate	54 Mbps
Transmission Power	0 dBm
RTS/CTS, Fragmentation	Off
Power Management	Off
Routing Protocol	OLSR
OLSR HELLO Interval	2 seconds
OLSR TC Interval	5 seconds

Once the network is set up, real video traffic is sent through the network. Source node transmits a video of 70 s of duration, the size of which is 352x288 pixels, with a frame rate of 30 fps (the video is a loop of *mobile.yuv* [24], available on the Internet and commonly used for video assessment) encoded at 500 kbps on average using H.264 with a GoP size of 30 frames, without B-frames (bidirectional). Then, it has been packetized to add RTP headers into packets of an MTU of 1400 bytes. So far, video is suitable to be streamed through the network.

During the experiment, the Received Signal Strength Indicator (RSSI) has been measured at destination node to depict the signal quality received from node 1 and node 2. Figure 4 shows the RSSI variation caused by destination movement along the scenario layout, highlighting the three stages.

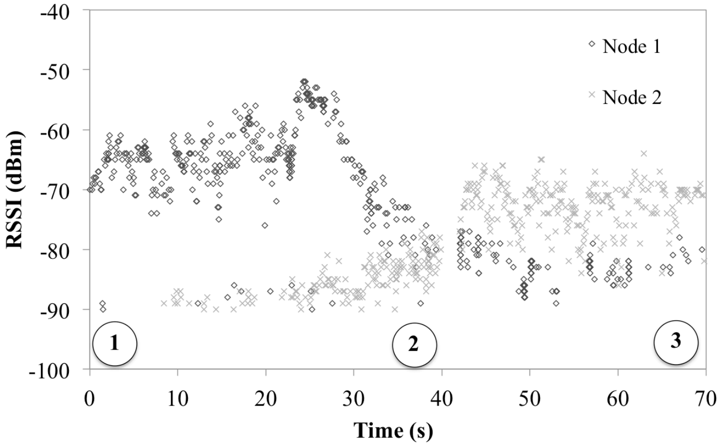
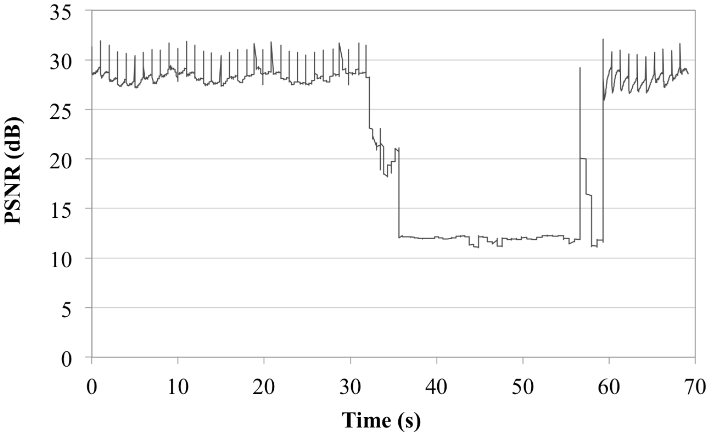
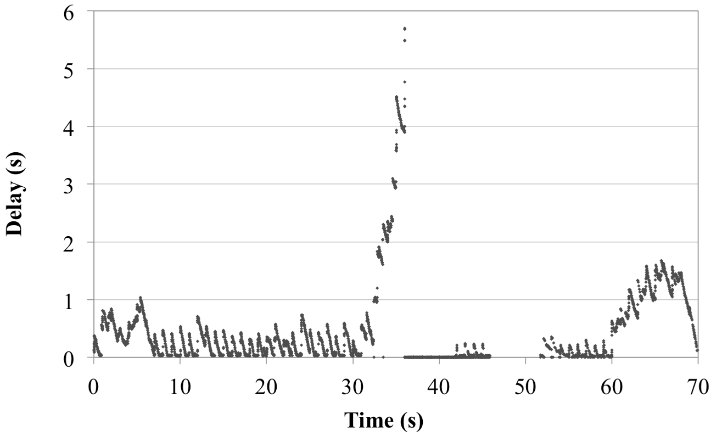


Figure 4. RSSI from node 1 and node 2 measured at destination

As long as destination remains within the coverage of node 1, RSSI values are high enough to guarantee the proper reception of video transmission. As destination moves out of range, depicted as stage 2, the signal received from node 1 decreases but signal strength from node 2 is progressively increasing. When destination node arrives at stage 3, RSSI values from node 2 indicate that destination falls within the coverage of node 2, and a new route can be established now. Finally, results regarding instant PSNR and packet delay are depicted in Figure 5.



a)



b)

Figure 5. Average PSNR (a) and packet delay (b) in the real testbed layout

Average PSNR of the encoded video used as a reference is 28.31 dB. However, average PSNR of the received video drops to 22.39 dB. This is due to the video playback interruption generated when OLSR is trying to discover the new route. Even in a rather simple scenario like this, the rerouting time is remarkable. OLSR takes about 20 seconds to realize that a link has fallen and recalculate the new route. It is true that this interval could be slightly shorter if OLSR is configured to keep routing tables faster updated (e.g. by reducing OLSR HELLO and TC intervals), but at the expense of increasing control traffic overhead. Regarding instant packet delay, it can be seen a noticeable increase when destination is arriving at stage 2. This fact coincides with the decrease in the signal strength received from node 1. A thorough analysis of packet delay and RSSI could be performed in order to anticipate link failures, as can be seen in other studies in the literature [25].

RECOVERING ALGORITHM IN ALTRUISTIC NETWORKS

In general, in ad hoc networks nodes must cooperate and work for the common good. Every node should be able to become a router and to forward packets from flows originated from or destined to other nodes. Particularly, in wireless mesh networks, packet routes rely on backbone nodes because they hardly suffer modifications and provide long-term stability to the wireless links. Logically, nodes that are likely to move around are devices that make use of the wireless backbone to communicate. This mobile nodes are usually the transmission source, the destination or any of their nearest neighbors. This mobility could affect the current packet route partially so recovering mechanisms should be implemented at network edges, where the mobility is more plausible, especially at the destination surroundings. Hence, the proposed mechanism tries to recover los packets by means of caching overheard packets in the surrounding of the destination node and retransmit them to destination.

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 6 depicts this situation in a reduced scenario with 5 nodes to assess the effect of node mobility. 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 of 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 6 left).

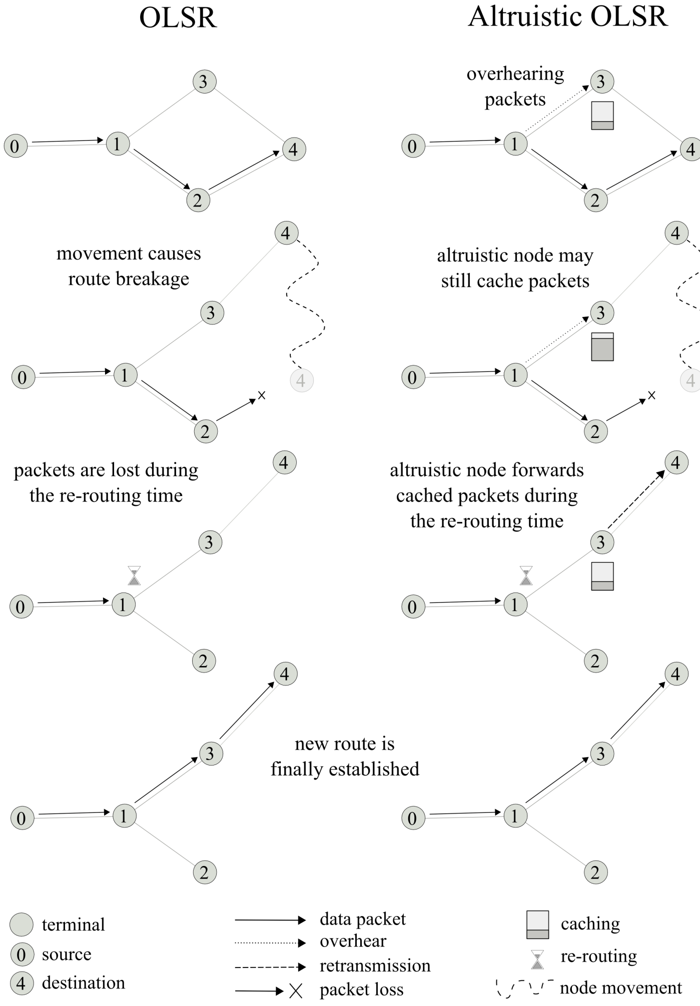


Figure 6. Behavior before a route breakage in OLSR (left) and Altruistic OLSR (right)

As a feature common to wireless ad hoc networks, all nodes within the radio range of a sender terminal can take advantage of the shared medium and overhear packets even if they are not the genuine receivers. In common data-link layer protocols, the overheard packets are discarded if the destination address is not the terminal's address. In the approach proposed, 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 6 right). 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 might be discarded.

In this approach, not every node forming the path has to buffer packets for retransmission, in contrast to other cooperative caching techniques, which use every possible node near the transmission route as a retransmitter candidate [26]. 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 7 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 this rerouting time. Note that destination can benefit from cached packets of altruistic neighbor nodes if they are still in range.

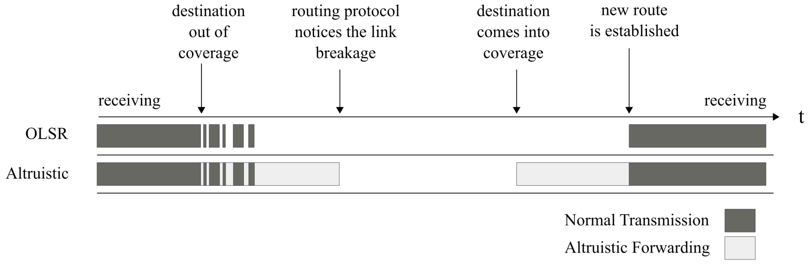


Figure 7. Timeline comparing the rerouting behavior between OLSR and Altruistic OLSR

Candidate selection

When relaying on extra nodes to retransmit lost packets, candidate selection becomes an important process to ensure the best performance. Reference [12] chooses the candidate before the route has been established, assuring a good position for the retransmitter throughout the path. Instead, opportunistic routing protocols [27] track all possible routes for each packet (or batch of packets [28]) 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 make those nodes be more effective retransmitters. Therefore, the way the retransmitter node is selected has to be considered carefully. In the scheme presented in this proposal, the candidate selection process 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. 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 packet format, not increasing message size and overhead. Otherwise, it is indicated using the reserved field of the HELLO message header. Figure 8 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.

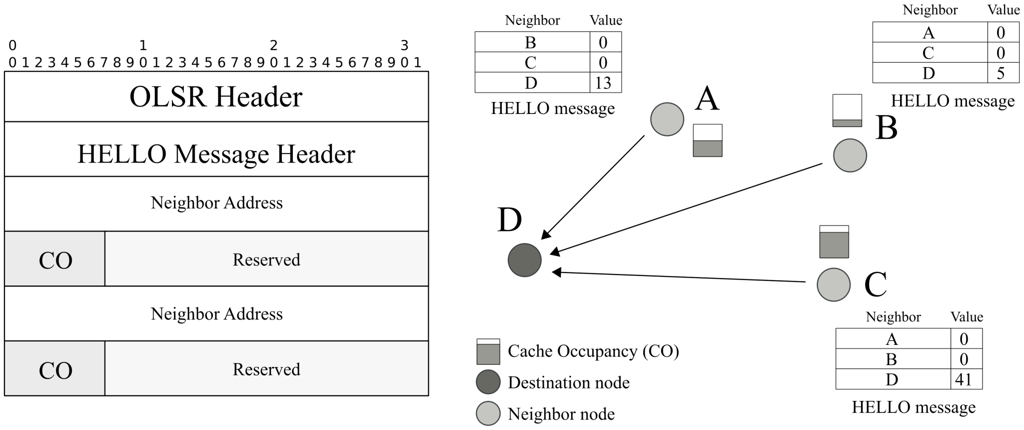


Figure 8. Modification to HELLO packets for the candidate selection mechanism

The aforementioned measurement value can be calculated in several ways, including but not limited 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; 3) Cache Occupancy (CO), that is, attending to the total amount of packets cached for a specific destination; or 4) residual energy, where nodes that have higher remaining battery would be selected. 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. Diverse local positioning methods could be used for this purpose [29]. Initially, in order to evaluate the proposed algorithm, 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 further used to send additional information about each neighbor node (ETX, geoposition, remaining battery, etc.), which could be employed jointly to select the best retransmitter.

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) message. This AR packet contains the identifier (sequence number) of the last correctly received packet (Last Packet ID) 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) [30]. 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 (Altruistic Neighbor Address). All these parameters are encapsulated in a new AR message according to Figure 9. 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.

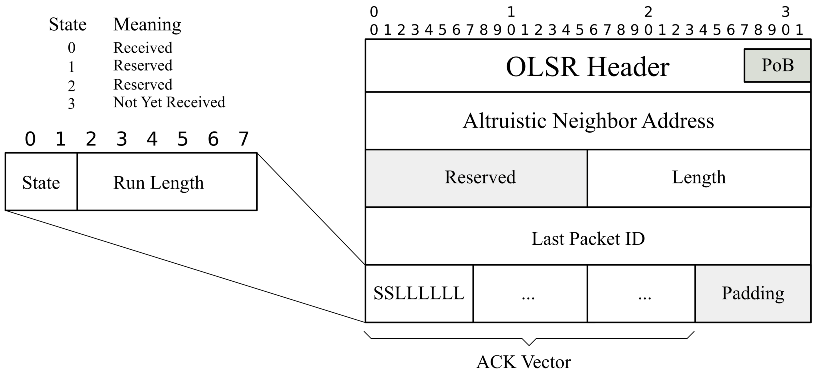


Figure 9. AR message format

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.

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, by means of AR messages, destination node can inform other nodes about which is the maximum PoB time allowed for the current video transmission. 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.

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 forward 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 10). This way, the algorithm tries to not split I-frames especially, because they are usually formed by a considerable number of packets.

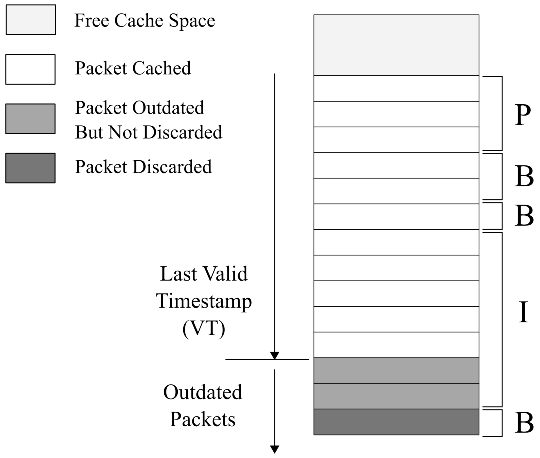


Figure 10. Discarding policy for cached video packets

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) [31]. By using this coding scheme, video packets from base layer can be prioritized over other improvement layers in order to reduce interruptions considerably.

Energy awareness

Proper energy management could be essential for maintaining routes as steady as possible and foresee any upcoming link breakage in order to forestall packet losses. Due to the retransmission mechanism proposed, altruistic neighbors might have extra battery consumption while sending not-acknowledged packets. Hence, exchanging information about the battery levels of neighbors can help in the selection of the proper altruistic neighbor, taking into account that a longer network lifetime is also desired. In this sense, HELLO messages are modified again in order to include a new metric so that the remaining bettery level of a node can be known by its neighbors. This energy parameter will help at destination in the decision of selecting which neighbor fits better as an altruistic forwarder. Hence, Figure 11 illustrates how HELLO message can be modified using the reserved field in the header to house the new Residual Battery parameter.

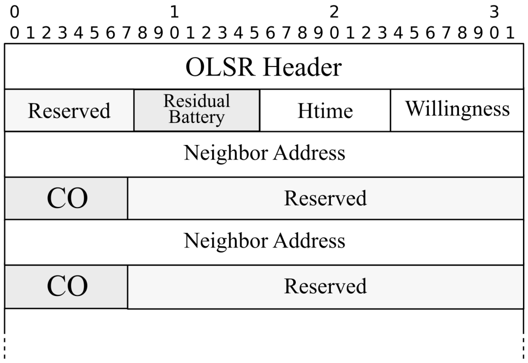


Figure 11. New HELLO message containing information about node residual battery

PROPOSAL EVALUATION

In order to offer a general overview of some of the related work and solutions mentioned in previous sections, Table 2 compares them with the mechanism proposed in this chapter 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 the wireless shared medium 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 energy-aware, which both help improve QoE by reducing video interruptions when node mobility causes route breakages.

Table 2. Qualitative comparison among recovery solutions

Mechanisms	ARQ	Video Awareness	Exploits shared medium	Caching	Adaptive	Multipath
Reference [8]	Yes	No	No	No	No	Yes
Reference [11]	Yes	Yes	No	No	Yes	No
Reference [12]	Yes	Yes	No	Yes	Yes	No
Reference [13]	No	No	Yes	No	No	Yes
Altruistic OLSR	Yes	Yes	Yes	Yes	No	No

Sample network

Firstly, the scenario depicted in Figure 6 is assessed regarding throughput, 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 regarding wireless channel and transmission conditions, as well as video properties, are shown in Table 3. 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.

Table 3. Scenario and simulation parameters

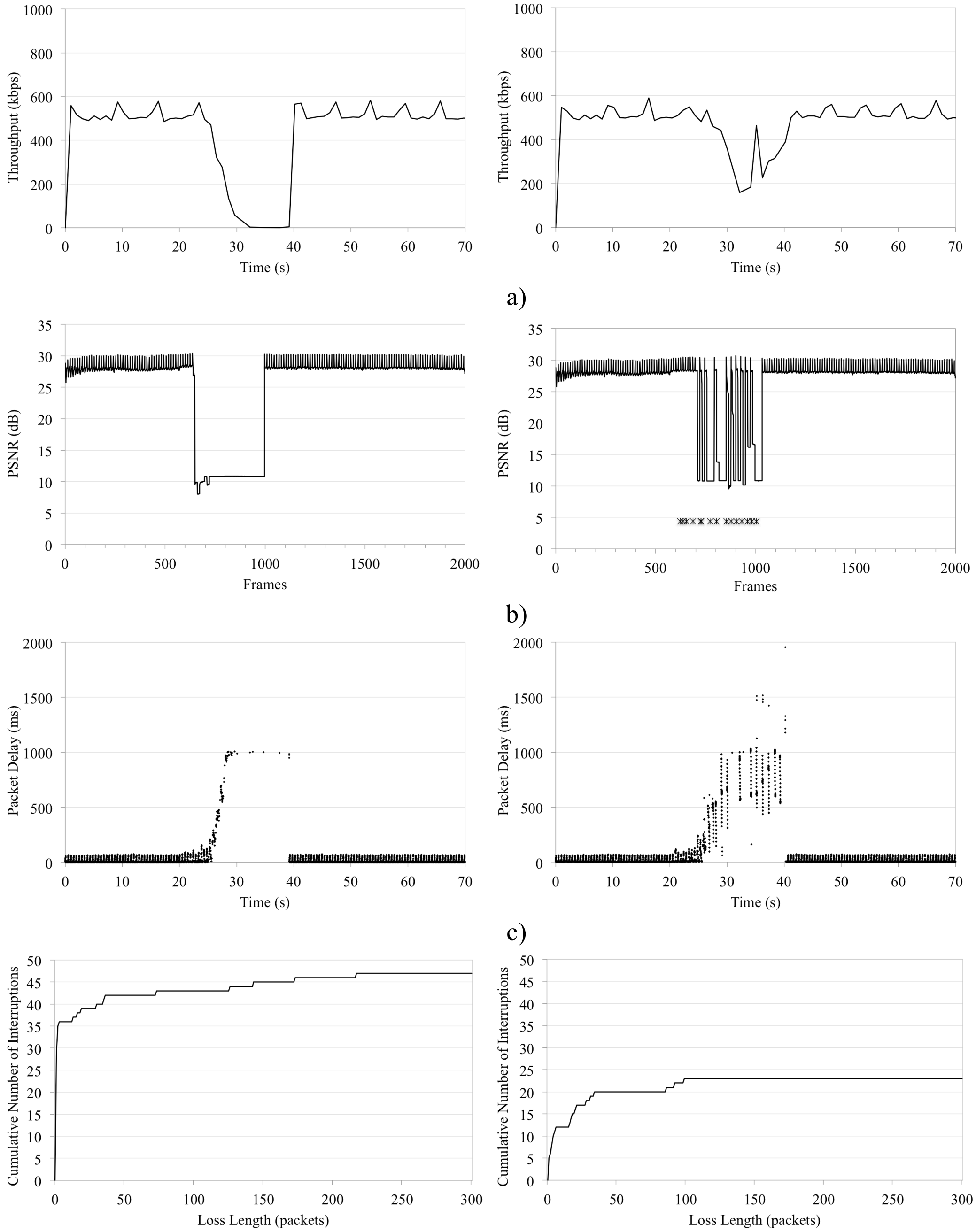
Parameter	Value
Wireless Standard	802.11g
Data Rate	54Mbps
Transmission range	30m
RTS/CTS	Off
Video resolution	352x288
Video duration	70 seconds
Average video rate	500 kbps
Max. queue delay	1s
Cache validity time	2s
HELLO interval	1s

Figure 12 shows the results comparing the scheme proposed with the standard OLSR. Figure 12a 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 12b, 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 process, 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 12c 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 12d 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.



a)

b)

c)

d)

Figure 12. 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 25.12 dB in OLSR to 26.38 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 15.99 dB in OLSR to 21.01 dB in the altruistic scheme). PSNR reference value is 28.31 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.

Energy consumption

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 [32] 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.

Regarding this 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. Therefore, energy consumption is analyzed in the situation that nodes become altruistic nodes and compared with the introduced improvement about energy-awareness.

Usually, wireless radio interfaces consume different amount of energy depending on the state they are working in, which can be transmission (TX), reception (RX), idle and busy. A node in TX or RX state is likely to consume more power than in busy or idle state. Nodes that are not taking part of the actual path are also receiving packets and dismissing them, which mean non-negligible consumption. Power consumption parameters used in the simulations are described in Table 4.

Table 4. Power consumption parameters for wireless network cards configuration

Parameter	Value
Transmission	2.6 W (transmitting at 17 dBm)
Reception	60 mW
Idle mode current	1.3 mW
Busy mode current	1.3 mW
Operating voltage	3 V

Figure 13 shows a similar scenario but there are now two additional nodes that can potentially become altruistic neighbors. In this scenario, both node 4 and node 5 have the same initial battery level. With the aim of assessing the algorithm, node 6 moves following the diagram during the simulation at 2 m/s, causing routes to be recalculated. Specifically, the packet path keeps changing among nodes 2, 4 and 3.

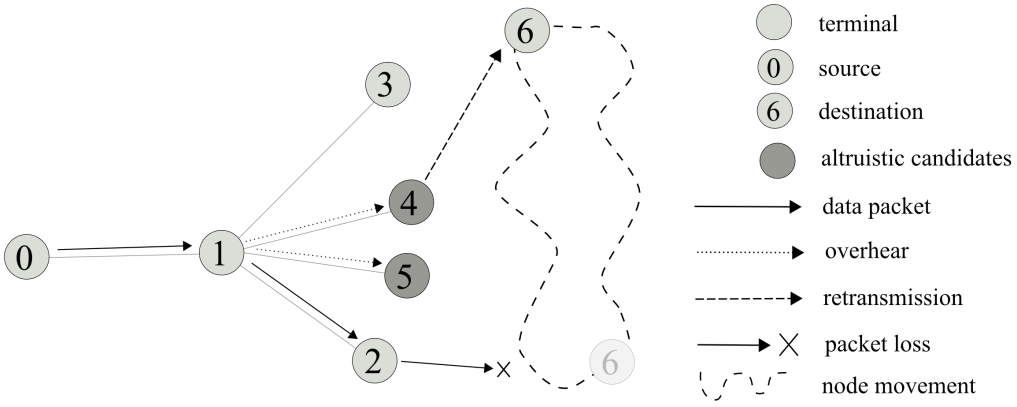
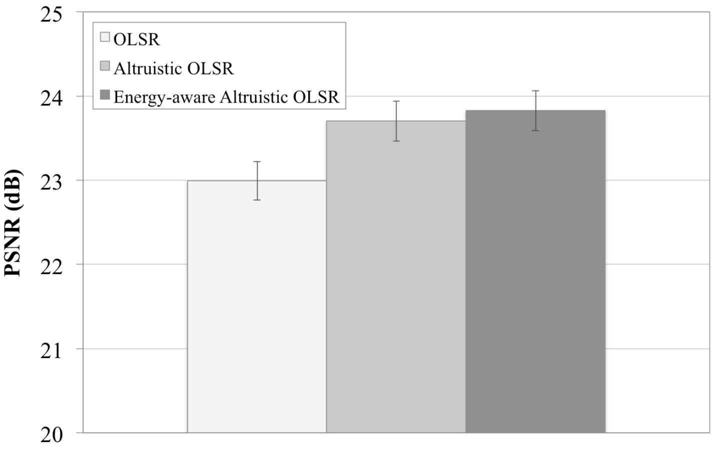
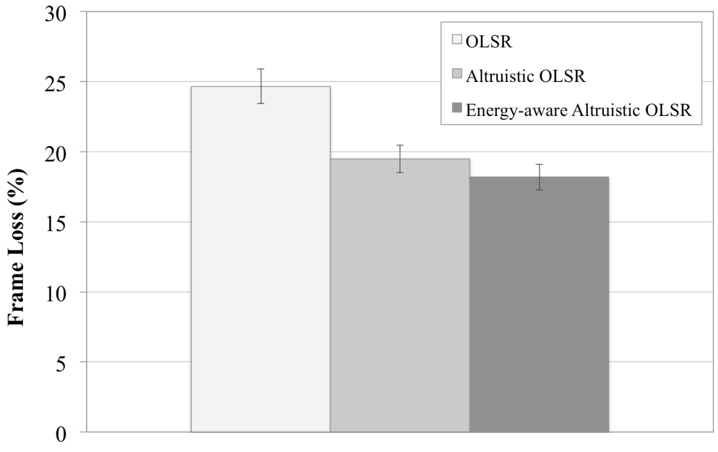


Figura 13. Scenario for energy assessment

When destination node (node 6) is moving, packet route is lost during the transition from the coverage of one neighbor to another. When the transmission path is broken, both node 4 and node 5 are candidates to become altruistic neighbors and retransmit possible lost packets. However, as route suffers several changes along the simulation, this will cause video degradation and reduction in PSNR during the rerouting time. The video flow (with the same encoding parameters as in previous evaluation) is sent after 25 seconds from the begining of the simulation and during 200 seconds. Figure 14 depicts the average PSNR and frame loss depending on the protocol used.



a)



b)

Figure 14. Average PSNR (a) and average frame loss (b) for OLSR, Altruistic OLSR and energy-aware Altruistic OLSR

Average PSNR is increased from 22.99 dB in OLSR to 23.7 dB in Altruistic OLSR and 23.82 dB using the energy-aware enhancement. As long as PSNR is measured for the whole video sequence, these are average values, so the improvement is not as remarkable as though it was measured just during the rerouting time, as mentioned in previous results. Frame loss is reduced from 24.66% in OLSR to 19.48% and 18.18% in Altruistic OLSR without and with energy improvement, respectively.

Besides the improvement in video quality, additional enhancing mechanisms may cause an increase in power consumption, which can be critical in some situations since ad hoc networks usually consist of battery-dependent devices. In this sense, Figure 15 shows the energy consumption for the altruistic nodes in the scenario under analysis.

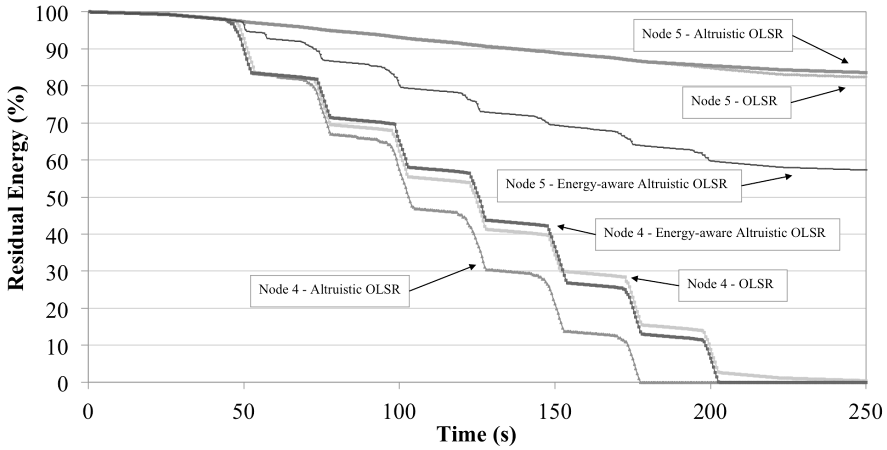


Figure 15. Power consumption of altruistic candidates (node 4 and node 5)

Particularly, it can be seen that when node 4 is performing routing operations, the energy consumption is higher, as can be seen in the steep slope at certain points. In OLSR, only node

4 is participating in the packet route and node 5 only has minimal consumption. In Altruistic OLSR, node 4 sometimes becomes an altruistic neighbor and retransmits cached packets to destination. The residual energy is affected and is depleted faster. However, node 5 has never been chosen as altruistic neighbor, probably because it would have cached the same amount of packets as node 4. It is worth noting that in the case that node 4 run out of battery, packet route would be broken. In this example, this happens after 177 seconds using Altruistic OLSR whereas in OLSR, node 4 is still running after 202 seconds. Nevertheless, using the energy-aware improvement for Altruistic OLSR, energy consumption is balanced among the altruistic candidates. Therefore, node 5 is sometimes selected to be the altruistic neighbor, as far as it has cached packets to retransmit. Hence, node 4 can save energy to perform routing operations, although it can become altruistic neighbor when no other altruistic candidates are present. Node 4's lifetime has been increased about 14%, practically like in OLSR, but with the advantage that PSNR and video quality is increased as well.

Finally, it is worth mentioning that other 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). Then, by using this altruistic scheme, only the surrounding area of destination node is affected by retransmissions. Moreover, the proposed energy-aware improvement can achieve higher network energy balance, which definitely enhances route stability.

CONCLUSION

Wireless ad hoc networks are altruistic networks by nature, that is, every node should be ready to serve as a router and forward packets from other communications in order to ensure connectivity and the proper network operation. However, node mobility hinders the creation and maintenance of steady routes in this kind of network. Hence, providing real-time services, such as video streaming, which is very sensitive to packet loss and delay, is still a topic under research because of the difficulty of guaranteeing a certain QoE. When any node moves out of range, routes have to be recalculated and, in the meanwhile, packets could be lost, with the consequent video interruptions and quality degradation.

In order to deal with video interruptions, a cross-layer technique is proposed, which uses information gathered from data-link, routing and application layers in order to increase the overall packet delivery ratio and reduce frame losses in video transmissions. This mechanism proposes that neighbors of the destination node can help in recovering lost packets by using cache and retransmission when a route breakage occurs.

Results show that the altruistic recovering solution reduces video playback interruptions considerably (about 50% on average) and frame losses (21%), and therefore improves PSNR the average PSNR from 1% to 5%, even achieving about 31% of improvement when considering only the rerouting period. Because of retransmitted packets, average packet delay is considerably increased (37%). However, due to the proximity of the retransmitter to the destination, packets are delivered faster than in source ARQ solutions.

Furthermore, by taking into account energy metrics, the algorithm has been enhanced in order to take into account the residual battery of the nodes. Hence, it can be possible to decide which retransmitters are optimal to guarantee a longer network lifetime, and consequently, preventing excessive usage and fast depletion of the altruistic nodes' battery. With this improvement, altruistic nodes can increase battery life about 14%. However, energy issues are rather complex because of the wide amount of variables that come into play regarding power consumption in mobile devices, so a thorough analysis would need further research.

Finally, it is worth noting that this kind of altruistic network is based on the concept that every node could perform caching and retransmitting functions when required and, moreover, there should not be other limitations, such as processing constraints or user restrictions.

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