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Video transmission in mobile ad hoc networks using multiple interfaces and multiple channels

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SUMMARY

Mobile Ad hoc NETworks (MANETs) are an important part of wireless communications and the increasing use of mobile devices is confirming that. MANETs can be of great value in Emergency Response situations where communication between mobile deployed units is critical and wired or wireless infrastructures may not be present or functional. In emergency scenarios, multimedia communication is very important for decision making and situation assessment. This requires up-to-date (on-line) information feed on the situation, including voice and video from the affected zone. However, MANETs do not seem to efficiently support multimedia applications, and this is quite evident in video transmission. One way to remedy this is to use more (wireless) interfaces per mobile node and consequently more communication channels. In this work, we perform an analytical study on the use of multiple interfaces and multiple channels (MIMC) in video transmission with respect to the requirements of Emergency Response Ad hoc Networks. More specifically, we examine and present the impact of using MIMC on MANETs during video transmission applications, we evaluate the performance of three basic routing protocols in MANETs, and we propose a channel selection mechanism in MANET nodes with MIMC for enhanced video transmission. In addition, we evaluate video transmission streams with rate adaptation and present comparative results. The proposed mechanism is evaluated using the ns-2 network simulator and the simulations are performed for a variety of topologies. Simulation results show that the different routing protocols respond differently when MIMC is introduced. The Ad hoc On-Demand Multipath Distance Vector and (especially) the Ad hoc On-Demand Distance Vector routing protocols benefit significantly, while the Destination Sequenced Distance Vector shows fewer improvements. The proposed mechanism is shown to be beneficial for transmitting video streams and enhances the network's ability to accommodate more streams and reduce packet delay.

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KEY WORDS: MANETs; multi-interfaces and multi-channels; video transmission; emergency response

1. INTRODUCTION

The advantages of Mobile Ad hoc Networks (MANETs) over traditional telecommunication networks are significant. MANETs are decentralized, self-organized, and capable of restoring communications without depending on any infrastructure. Big catastrophes, over the past few years, have shown that wired telecommunications and common static wireless infrastructures are vulnerable and not efficient for usage when disasters take place. In MANETs, each device equipped with

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wireless modules can act as a node that can communicate with the other nodes, within its range, in the network area. The communication takes place using wireless channels, and connections do not have to be direct (over one hop) but can be established over multiple hops, using other nodes as intermediates (thus covering great distances). In addition, compared to traditional telecommunication networks, they are cheaper, because they do not require any infrastructure and more robust, because of their non-hierarchical structure and network management mechanisms. The most important advantages of MANETs are mobility and flexibility as they can be organized and dispersed in very short time.

Disaster management and direct response in emergency situations are currently one of the most important fields of MANET technology and has been under study for the last few years ([1–4]). This technology has increasingly drawn the attention of communications research communities over the past years and encouraged the attempts of applying it to challenging situations. The value and impact of MANETs are critical in emergency scenarios in disaster areas with infrastructures out of order.

However, MANETs are still facing a number of open issues that are under consideration by the research community. These include efficient routing, quality of service (QoS), energy consumption, and security. An important limitation is the routing complexity in dynamic emergency response topologies. Each protocol has its own routing strategy, but no such strategy can be effective for all topology conditions. Therefore, efficient deployment of MANETs might require hybrid approaches. Performance of each strategy depends on various network conditions (such as node density, moving speed, direction, etc), and varies accordingly. It follows that selecting the proper routing protocol for the each situation becomes critical.

Video transmission applications, in the majority of cases, make use of the UDP transport protocol. Although this may overcome latency problems, possibly caused by the overhead of TCP (e.g. the retransmissions), it is the reason for two rather major problems. The first one is injecting high volume video traffic in a possibly bandwidth-limited connection, with no provisions for flow control and congestion handling, causing significantly increased packet losses. The second one, which follows from the first, has to do with TCP-friendliness, that is the uncontrolled UDP traffic of the video transmission will most certainly lead to the other TCP-based streams, in the same network, significantly reducing their transmission rate, and possibly stopping altogether.

Last, but not least, there is a great interest in the use of Multi-Interfaces and Multi-Channels (MIMC) ([5]) in MANETs. It is noteworthy that the cost of multi-interface enabled devices is rapidly decreasing and more applications are based on them Several research efforts, like ([6]), over the last years have increased the interest of attaching the technology of MIMC on mobile nodes. In [5] the design of a channel abstraction module is included, as well as a hybrid multi-channel protocol that uses an (included) module for the required kernel support. The results show that only moderate overheads are required to perform the interface switching. In [7], the research focuses on the issue of routing, under MIMC usage. The work proposes a strategy for channel/interface assignment, which keeps one interface assignment fixed, and switches the channel assignments in the other interfaces to improve network capacity. The work also presents a routing protocol which selects (for the MIMC case) routes with high-throughput, and also accounts for the cost incurred by the switch of the interfaces. In addition, it ([7]) analyzes various factors affecting the routing and link-layer protocols for MIMC.

In this work, we study and evaluate Video Transmission in MANETs that use Multiple Interfaces and Multiple Channels (MIMC) in the same time. The target is twofold: (i) to evaluate the effect of the MIMC in video transmission and to compare how some well-known MANET routing protocols perform in the presence of MIMC, and (ii) to propose a simple (but efficient) mechanism for assigning channels to interfaces that enhances Video Transmission in MANETs with nodes supporting MIMC. The proposed solution makes use of the ability of the nodes to have more than one wireless interface and benefits from the simultaneous reception and transmission of video data. The proposed solution also makes use of multiple channels. This is also applicable in emergency response situations (e.g. a forest fire) as it is expected that in such areas there will not be any other active devices (because of the equipment collapse because of the emergency) making use of the available wireless channels.

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During the performance evaluation we follow the approach ([8, 9]):

- Initially, we evaluate the effect of using MIMC in the performance of the Ad hoc On-Demand Distance Vector (AODV) [10] routing protocol (see section 5: Performance Evaluation of MIMC in AODV).
- Then, we perform a comparative performance evaluation of MIMC approach in three routing protocols [9] (see section 6: Comparative Performance Evaluation of MIMC in Existing MANET Routing Protocols) in order to select the MANET routing protocol which supports better the MIMC. This comparative evaluation indicates AODV as the best (among the three routing protocols in evaluation) routing protocol to support MIMC approach.
- Finally, we perform an evaluation of the new proposed MIMC approach with the channel selection mechanism in the performance of the AODV routing protocol, which seems to better support the MIMC concept [11] (see section 7: Performance Evaluation of proposed MIMC approach).

The paper has the following organization: Section 2, presents related work; Section 3 lists specific End-User requirements for MANETs based on Hellenic Fire Brigade requirements; Section 4 presents the proposed channel selection mechanism; Section 5 presents the results of the simulation and evaluates the MIMC effect on AODV routing protocol; Section 6 presents the comparative results of the simulations and evaluates the effects of utilizing MIMC on various MANET routing protocols; Section 7 presents the results of the evaluation of the proposed channel assignment mechanism; and finally section 8 concludes the paper and presents plans for future work.

2. RELATED WORK

Several solutions have been presented in order to increase MANETs' applicability in crisis related scenarios. As far as routing is concerned, new adaptive protocols have been proposed that rely on the three standard routing protocols, namely Ad hoc On-Demand Distance Vector (AODV) [10], Dynamic Source Routing Protocol (DSR) [12], and Optimized Link State Routing Protocol (OLSR) [13]. In [1], Emergency MANETs (eMANETs) are presented as the networks consisted mostly from intelligent devices, using an adaptive routing protocol called ChaMeLeon (CML). The CML defines the size of the network Critical Area, and based on this information, it uses AODV for routing in small topologies and OLSR for larger topologies. Although this approach tries to exploit the characteristics of reactive routing both in small areas (AODV) and large areas (OLSR), in cases of nodes moving inside and out of the network, the CML is not effective. In [14], the Location Aided-Routing (LAR) improves the AODV's route discovery with the help of GPS coordinates for the estimation of the destination's possible location. In LAR, the source is aware of the destination node's position and speed and limits the search area, accordingly. In contrast, the GPS enhanced routing protocol GeoAODV [15], which also is a variation of AODV, dynamically stores and distributes the location information. Another version of LAR, namely Greedy Location-Aided Routing [16], aims in the reduction of the total number of routing packets. The Greedy Perimeter Stateless Routing [17] makes greedy forwarding decisions by keeping information only for the immediate neighbors of the intermediate nodes. In [17], Greedy Perimeter Stateless Routing outperformed DRS in successful data packet delivery in high numbers of nodes. In [4], a Hybrid Ad hoc Network is proposed which combines Static Ad hoc Network and MANET. This mesh network model can be easily built in situations where communications, power, and roads get disrupted. This model includes a different MAC protocol that is based on the directional smart antenna. Results indicated that is has better performance than the MAC used in IEEE 802.11-based MANETs. In [18], another solution type is a framework for disaster management. According to this solution, three phases of management are analyzed (Most Critical Phase, Optimal Power Phase, Average Reliable, and Power Phase). The simulations showed that Most Critical Phase is the most reliable model in data transmission with the fewer hops but with the most energy consumption.

Various researchers have evaluated video transmission over MANETs. In [19], the authors focus on the analysis of AODV and DSR and they compare their performance in H.264/SVC video transmission. In [20], the authors aim to investigate the combined impact of network sparsity and

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network node density on the Peak Signal Noise to Ratio (PSNR) and jitter performance of proactive and reactive routing protocols MANETs. Authors of [21] work in optimizing the network communication for video transmission by performing the static examination over the network nodes. In this context they evaluate AODV and DSR on the basis of performance parameters Packet Delivery Ratio, End-to-End, delay, Throughput, and Packet Drop Rate.

The implementation of MIMC support in the NS-2 simulator has seen some considerable efforts so far. The enhanced Network simulator [22, 23], and [24] seems to be the most complete implementation for MIMC in the ns-2 simulator. Another older project, MITF, at the University of Rio de Janeiro, with the goal to embed MIMC technology to the AODV routing protocol in ns-2.28 [24], was discontinued, and it is not accessible anymore. The project Hyacinth [25] was conducted at the University of New York for ns-2.29a and could be extended for use at ns-2.29. These three projects add many capabilities concerning the implementation of MIMC in NS-2, but do have several drawbacks. Static configuration, low routing flexibility, and inability to develop various tcl scripts are some of the drawbacks. However, the model of [24] about the MIMC implementation in NS-2, which is based on the combination of all the previous projects, is much more flexible and complete. In [24], a detailed set of changes that need to be applied on the simulation framework is presented, in order to use a flexible number of interfaces and channels per node.

In our solution, by following the model of [24], we design a cross-layer mechanism for effective channel assignment and routing based on specific metrics used in Cognitive Radio Networks [26] in order to improve the spectrum utilization. Routing metrics in Cognitive Radio Networks considerably affect the performance of channel assignment and routing algorithms, meaning that selecting the right combination of them is crucial. The Hop Count (i.e. a simple metric for the number of hops between the source and destination) has high stability which allows the efficient discovery of minimum weight paths, and for high mobility, it can outperform other metrics which are load dependent [27]. However, hop count, not taking into consideration metrics for each link such as link quality, capacity or interference, leads to reduced link and path reliability and is not suitable for the requirements of an emergency response scenario.

In contrast, the Expected Transmission Count (ETX) ([27, 28]) metric finds paths that require the fewest expected transmissions (including retransmissions). Its main goal is to discover high-throughput paths, after taking into consideration interference, link loss ratios, and acknowledgement in the reverse direction. Although ETX is considerably a more effective metric than the Hop Count, it still lacks effectiveness in multi radio–multi channel environments ([27, 29]) as it does not use information about co-channel interference and link sensitivity to different rates and capabilities. In many occasions, this lack of information leads ETX to select paths with lower rate and lower channel diversity. The Expected Transmission Time (ETT) metric ([27, 29, 30]) considers the different link capacities and overcomes the limitations of ETX. It can considerably improve the overall network performance, because it has the properties of the ETX.

However, the ETT is still not the desired effective routing metric in multi-radio topologies, because it was not designed to assign channels according to the intra flow interference and channel diversity of the link. A new routing metric, the Weighted Cumulative ETT (WCETT) ([27, 29–31]), is a noticeable improvement of the previously mentioned routing metrics and is designed to fit in a MIMC environment. WCETT is a metric that reflects the effect of channel diversity on throughput and targets at choosing high-throughput paths between source and destination. This metric is the weighted average of ETT with the additional feature of accounting intra-flow interference and thus augments the performance of ETT at MIMC environments. At this point, a drawback is that WCETT is not isotonic, and there is no guarantee for optimal and loop free paths to destination.

3. END-USER REQUIREMENTS

Emergency situations combine characteristics of high level of uncertainty with the need for swift and steadfast reaction. Therefore, emergency response has some special requirements from the supporting ICT solutions. The requirements for the network deployment are usually a very good match for the properties of wireless ad hoc networks, thus making them well suited for the purpose.

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Regarding the network requirements there is no specific model which seems to be the optimal solution for emergence response scenarios. Most emergence response scenarios are based on feedback received from first responders based on the needs of real world emergency events. Details on Emergency Response Ad Hoc Networks scenarios mainly based on real world emergency events are presented in [32] and [33]. The end-user requirements and the scenarios presented in the following paragraphs are based on the experiences and the real world needs as they are descripted during the interviews with representatives from the Hellenic Fire Brigade.

3.1. Tactical and communication requirements

The interview results confirmed that currently one of the main issues that First Responders (police, fire brigade, coast guard, port authorities, etc.) face in disasters is the lack of availability and/or the quite low rate of relevant information flowing both at the First Responder and the local manager level. Loss of communications and positioning information, lack of information concerning the environment (such as high temperature, hazardous gas, etc.), and low efficiency of the Human Machine Interface are the main issues that demand resolution. As a result, during the confrontation with the emergency situation, there is a time/synchronization gap between the First Responders' situation (positioning, health, etc.) and the (delayed) view their mobile headquarter or their coordination and operation center has; increasing the response time and respectively reducing the available action time. Communications is one of the areas identified as able to benefit from technological solutions, allowing enhanced intervention procedures to be faster, more efficient, and safer. In that respect, there is a need to enhance the communication among the First Responders on the field, the units and their Head Quarter by providing self-organizing, robust ad hoc communications in cases where the existing infrastructure may be compromised. Important to this communication is the ability of the Head Quarter to get a visual (video stream) on the first responders and unit in the disaster area see.

Our solution aims at reducing any delay in response, increasing the effectiveness and safety of First Responders by means of maximizing information gathering and communication with higher command levels, while simultaneously reducing risk and increasing chances of survival for both the rescued and the personnel involved.

3.2. Reference scenario

The reference scenario refers to a post-disaster area without fixed infrastructure (either not available at all or currently destroyed). We can visualize the deployment of first responders (e.g. Fire Brigade, or other rescue teams) to provide relief to disaster area. The network topology includes:

- A fixed command post (operational level)
- Mobile regional command posts (tactical level)
- Several teams deployed in the area (field level)

Figure 1 depicts this scenario. The fixed command post is required to have connection to external network. This can be realized by satellite links depending on the availability. However, our solution mainly targets at connecting the fixed Command Post with the lower level of commands: tactical and field level. In this case, WiMax technology can provide a feasible solution. At the tactical level, the Command Post is equipped with devices with dual interfaces. WiMax interface is used to provide connectivity with the operational level whereas Wifi (IEEE 802.11x) to communicate with the mobile teams. Regional Commands communicate with WiMax and they use an Ad hoc routing protocol. Regional Commands, mobile team leaders and rescuers (mobile nodes) use the same routing protocol and creating a mesh network. There may be cases in which a node in the field may be able to maintain connection with a neighboring regional command.

The network transmission requirements may vary from audio to video transmission in different qualities and for this reason we evaluate MANETs with both low transmission links (section 5) and high transmission links (section 6).

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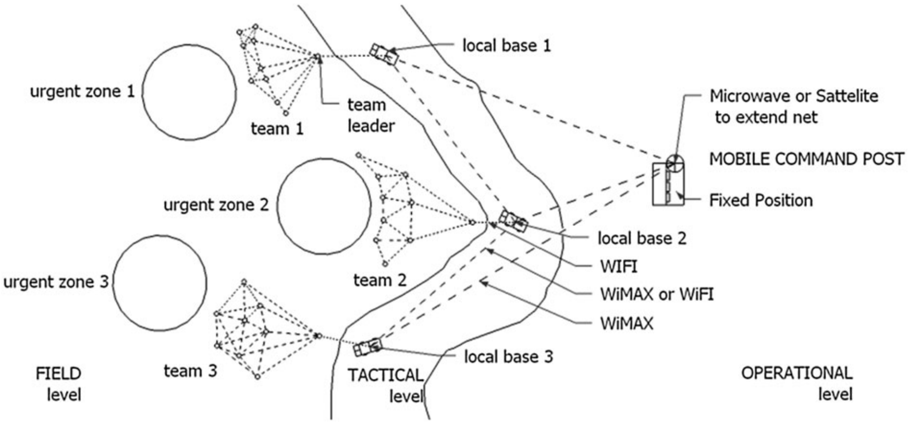

Figure 1. Reference scenario.

4. DESCRIPTION OF PROPOSED MIMC APPROACH

4.1. Node architecture

The proposed design is applicable for MANET nodes that can be equipped with multiple interfaces and can use multiple channels at the same time. As such, the networks nodes do not have the default mobile network architecture, but have an extended architecture to support MIMC. The default mobile node architecture and the mobile node architecture with MIMC support are briefly presented below.

- *Default mobile node architecture*. For the purpose of this work, the node architecture is considered to be the pretty much default node architecture of a mobile node, shown in Figure 2 (this figure is similar to a figure from the ns-2 tutorial, and is used here to show the difference between one and multi channel architecture, described below). It consists of a chain of modules, below the Routing Agent, that reach down to the wireless channel. Incoming packets proceed through the different modules (from the lower levels to the upper ones). Outgoing packets follow a reverse direction. The node has only one network stack and thus can utilize only one channel at a time. If another node in the proximity uses the same channel, the node's attempt to transmit will result in a collision.
- *Mobile node architecture with MIMC support*.The nodes equipped with MIMC follow a similar mobile node architecture, where the parts that relate to the multiple interfaces and the transmission in multiple channels are replicated as shown in Figure 3. Compared to the default schema, the main difference is that packets come through different interfaces (and different channels). In addition, the outgoing packets depart from the appropriate interface decided by the routing agent. A node supporting MIMC has multiple network stacks and thus can utilize more channels concurrently. If other nodes in the proximity use some channels, the node may transmit using a free channel. In addition, a node with MIMC can transmit or forward simultaneously more than one packet by using different interfaces and their corresponding channel.

4.2. Description of the proposed mechanism

The proposed mechanism is based on tracking real time metrics during data packets transmission.

- *Signal to Noise Ratio (SNR)*: Every node stores the value of the SNR for the channels attached to its interfaces used for transmissions. The stored value contains information for the signal strength and noise at the channels that are being used by the node. The intra-flow traffic is the traffic in the same path; the inter-flow traffic is the one performed by neighbors on different paths.
- *Channel Collision*: When the channel is 'busy' (i.e. there is a collision at the currently fixed channel), the MAC sends a signal to the routing layer at the corresponding node to check for switchable channels with better SNR value and less interference.

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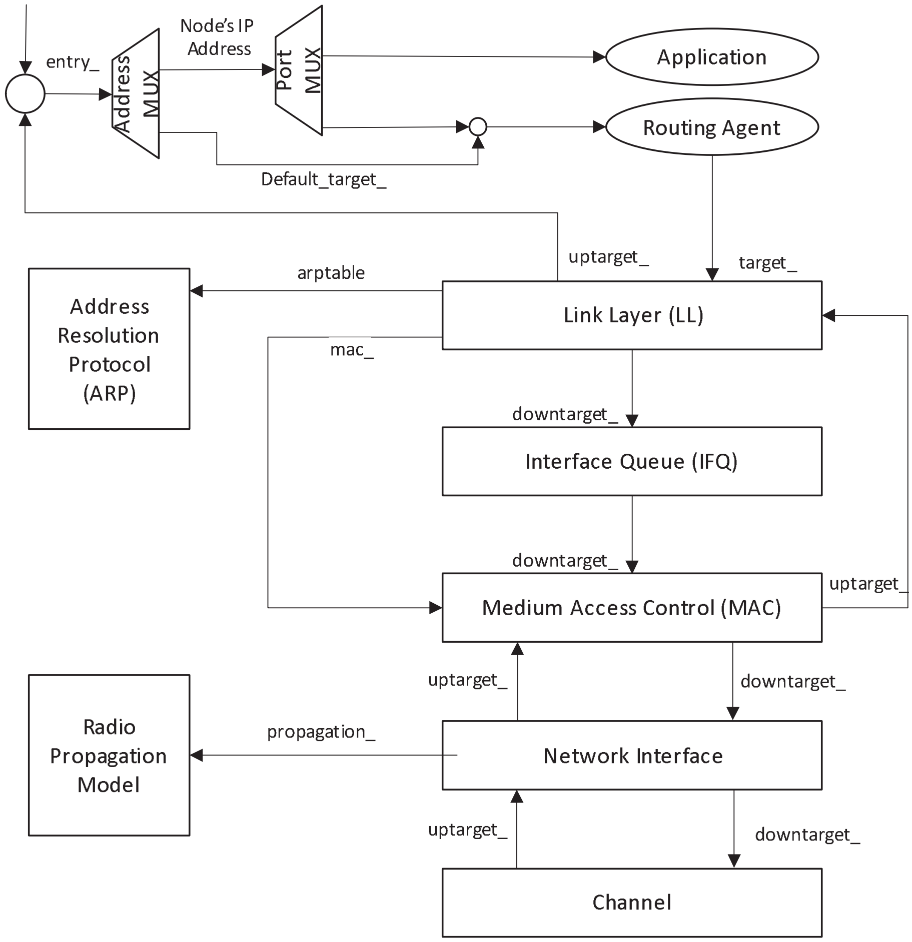

Figure 2. Default mobile node architecture.

These metrics are utilized to make the optimal channel selection for data transmitting through the currently created route between the senders and the receivers. When a collision takes place in a particular channel, the current state of the nodes forwarding or receiving is reevaluated and possibly another channel will be used to retransmit the frame. The aim is to offload busy channels.

The proposed approach is based on the concept of multiple channels usage for video transmission where each node is able to detect the best path and channel to send or forward packets. This means that according to current flows and packet traffic of the in-zone nodes, the sending node should correctly decide which channel to use. The model for usage of multiple channels and interfaces is described below.

The main bandwidth challenge in video transmission over a multi-hop route in MANETs is that no intermediate node can transmit when its previous and next nodes in the path are transmitting. This means that increasing the number of channels is not enough. For this reason, we insert in the current implementation an intelligent mechanism for channel switching. The intelligence added in every node is based on the data collected during broadcast messages and route path discovery process from each interface. Alongside this addition, the mechanism is also collecting data about its surrounding traffic of neighbor nodes and channel usage that affects the bandwidth of the used link of the current node. To achieve this, the routing table of each interface is updated every time a better path or channel is discovered.

Each node keeps different entries for each interface-channel in the routing table, and collects data on all the potential next hops to the destination. The node then analyzes the entries in the routing table for each interface and according to specific parameters it sets as gateway one of them. It should be noted that the system's packet scheduling mechanism is not altered. Only the

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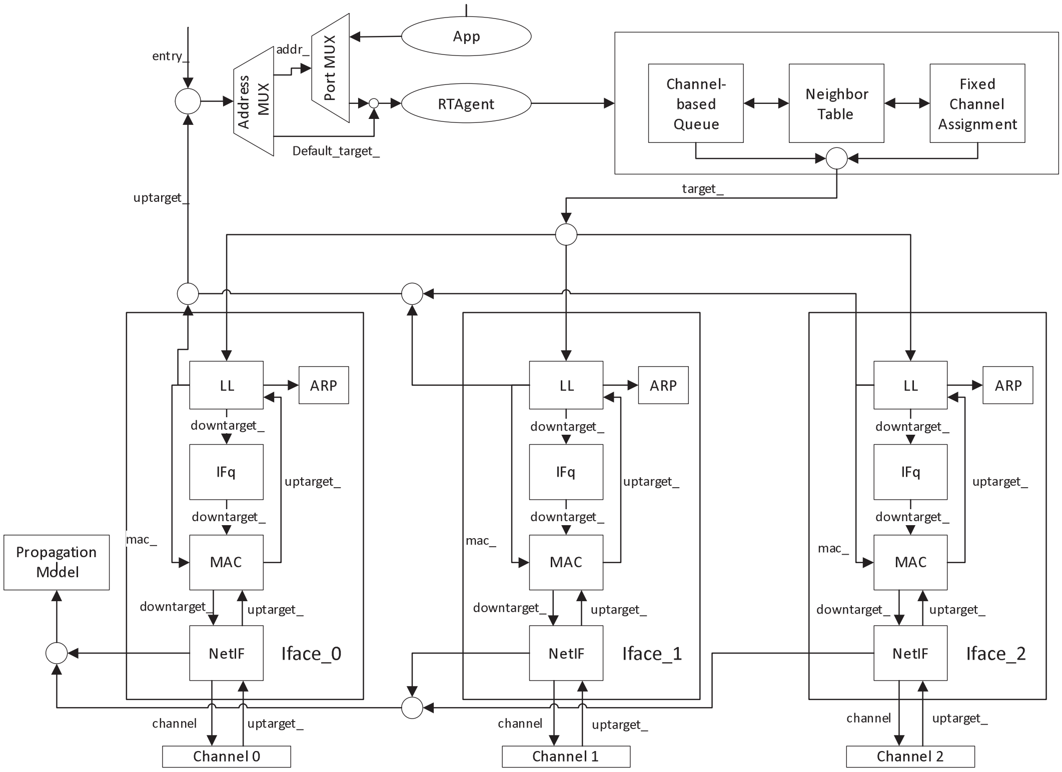

Figure 3. Mobile node architecture, with multiple interface support.

interface/channel selection procedure is altered, in order to change the interface that should be used for the next hop. Packets follow the default scheduling through the selected interface/channel. This also means that the mechanism does not require the exchange of additional routing messages, other than those exchanged by AODV alone.

The usage of multiple channels-interfaces improves significantly the packet end-to-end delay and data delivery ratio. Every added channel greatly extends the current total bandwidth of each link and enhances the operation of tactical teams. However, as a wireless topology expands and its density increases, the bandwidth of each link is affected noticeably and the wireless communication gets more complicated.

Figure 4 shows cases where only one channel is used, and thus the nodes are interfering with each other. In the displayed cases where the same channel is used by two links close in proximity, the average link capacity is half the channel. The situation is worst if more links are using the same channel. Combined throughput can go up to the channel's capacity.

Figure 5 shows cases where multiple channels and multiple interfaces are used. In the displayed cases two channels are used and there is no interference. Each link's capacity is the corresponding channel's capacity, and the combined throughput can go up to the cumulative capacity of the used channels.

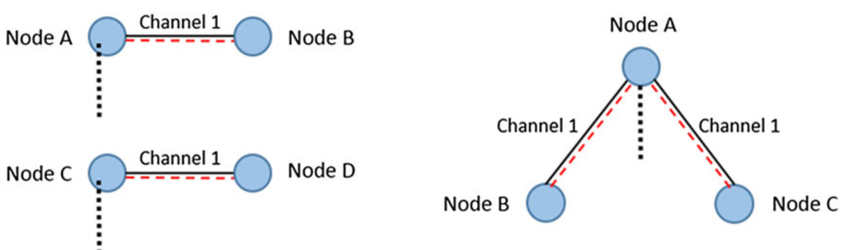

Figure 4. Usage of the same channel by multiple links.

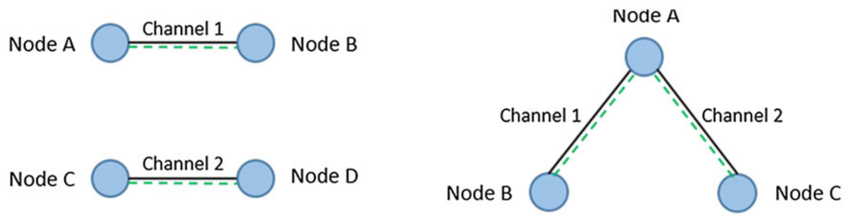

Figure 5. Usage of multiple channels and multiple interfaces for different links.

4.3. Interface switching mechanism

In the simulated MIMC MANET, nodes are configured with M interfaces and 1 channel per interface. The number of interfaces per node may vary and is configurable along with the simulation parameters. Every node sets a fixed interface for an active routing path and according to the number of interfaces, one or more switchable ones.

- Fixed Interface: The interface a node uses to send packets in the network. The corresponding channel of this interface is regarded as the fixed channel. Fixed interfaces are initially set to iface0, but during the transmission and according to the throughput needs, they can be switched to one of the switchable interfaces. The fixed interface of a node can be different for different paths crossing it, which means it can divide the channel utility in packet flow junctions. The designation of an interface as a fixed one actually means that it is the primary interface to be used for transmission.
- Switchable Interface: The remaining M-1 interfaces in idle state are referred to as the switchable interfaces. When a channel switch is necessary, the affected nodes should select a new fixed interface from their switchable interfaces.

Figure 6 shows four nodes and their interface-channel configuration. Node A is the source and its destinations are node C and D. Node B is the intermediate node and has a different fixed channel per route (red and green). All nodes can receive at chan-1, chan-2, and chan-3 regardless of their fixed interface. These channels are the ‘receive channels’ that are used in the proposed mechanism. Node B chooses this configuration in order to minimize packet collisions in the same channel.

The proposed mechanism uses the following data structures and concepts:

- NeighborTable [Nodes]: A graph adjacency matrix-like table containing the network nodes and their neighbors. This table is updated on hello messages and the interval is set by the AODV routing protocol.
- ChannelUtility[Nodes][Ifaces]: Stores the channel utility per interface for all the network nodes.
- FixedInterface[Nodes]: Stores the fixed interface per node.
- SwitchableInterface[Nodes]: Stores the switchable interfaces per node like a priority queue. Channels with less utility are placed first.

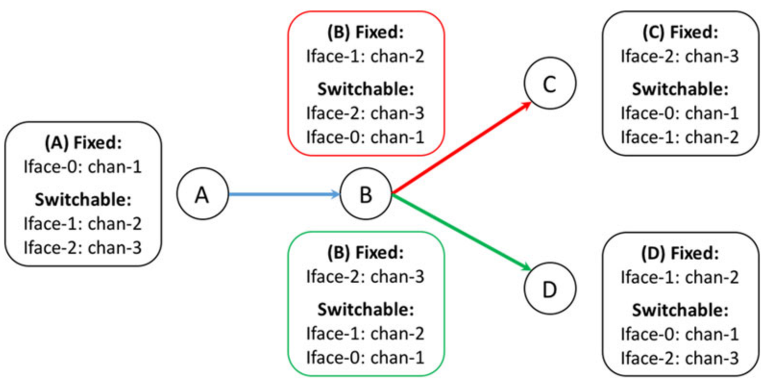

Figure 6. Fixed and switchable interfaces example for four nodes with three interfaces each.

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- ReceiveChannel[Nodes]: Stores the active channels per node. Active channels are used to receive packets. By default, all channels are active per node.

Figure 7 shows the basic components of the proposed mechanism. The MAC layer stores and updates the MAC state and SNR per used interface-channel for every node. This information is available to the routing agent of the index node forwarding data packets (cross layer data passing). Nodes are aware of the channels used by their neighbors (ChannelUtility), and they update the NeighborTable and ChannelUtility every time they receive a request (broadcast, hello, rrep, rreq message) or send (forward, sendrequest, sendreply, etc.) a packet. The interface switching mechanism is based on the channel utilization stored in the ChannelUtility and the packet collision flags that arrive from the MAC layer. The getWeakNode procedure returns the node in the neighborhood of the index node that should replace its fixed interface-channel.

More specifically, channel switching occurs after a few collisions are reported. This is done to avoid fluctuations between two ifaces/channels with equal utilizations, and to stabilize the algorithm. This still allows the algorithm to react in changing conditions. The specific value (i.e. number of collisions) for channel switching is experimentally obtained. For the experiments reported here this value is set to five hundred. A further improvement is to switch channels, not if the other channel's utilization is less but if the difference exceeds a certain threshold to make the change worthwhile. This is planned as future work.

Based in [34], assigning the fixed interface per node is performed in the following way:

1 When the route is up and forwarding data packets, the index node's routing agent processes the information sent by the MAC layer (SNR per channel, MAC state of the index node, and its neighbors) and uses the getWeakNode procedure to determine if it should change its fixed interface-channel. If the index node is the weak node, then it replaces its current fixed interface-channel with the head of SwitchableInterface structure.
2 Broadcasting is achieved by copying the packet to each channel's queue. These packets will be transmitted when the corresponding channel is scheduled for use. This will happen for all packets as the interface designated as fixed is going to change (i.e. the 'fixed' designation is going to be given to another interface), if there are packets queued for different interfaces/channels.

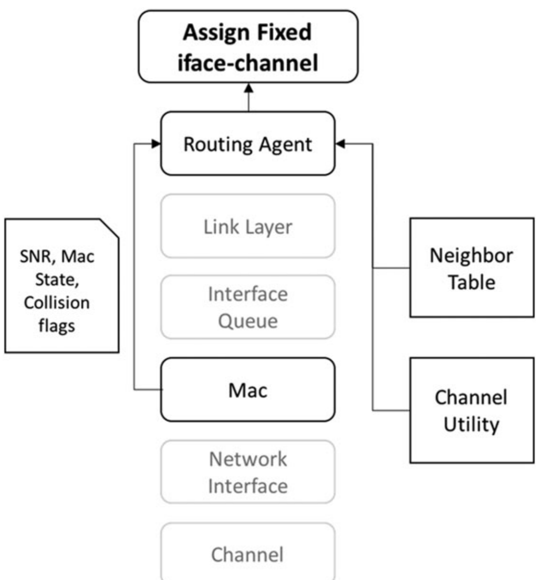

Figure 7. Interface switching mechanism.

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The algorithm in pseudocode follows:

```
Procedure forward()
 fixedIface[index] <- rt.rt_interface
 channel_in_use[index] <- channel[index][fixedIface[index]]
 if ( RREQ.packet_type == data )
  macList <- getMac_collision_addrs( channel_in_use[index] )
  snrList <- getSnr_channelList( channel_in_use[index] )
  ChannelUtility[index][channel_in_use[index]] ++
  weaknode <- getWeaknode( neighborhood(index) )
  switchableChannel[index] <- getSwitchableChannel( [index] )
  for ( neighbor i=macList.begin() to macList.end() ++neighbor )
   if ( is_neighbor( index, neighbor ) )
    collisionState[channel_in_use[index]] <- true
   endif
  endfor
  if ( collisionState[channel_in_use[index]] == true )
   collisionState[channel_in_use[index]] <- false
   channel_in_use[weaknode] <- switchableChannel[index]
   for ( iface i=0 to nifaces)
    if ( channel_in_use[weaknode] == channel[weaknode][iface] )
     fixedIface[weaknode] <- iface
    endif
   endfor
   if ( weaknode == index )
    rt->rt_interface <- fixedIface[index]
   endif
  endif
  if ( !broadcast )
   schedule packet at fixedIface[index]
  endif
 endif
Endprocedure
Procedure sendHello()
 if ( nifaces )
  for ( iface i=0 to nifaces )
   Broadcast Hello_msg on iface[i]
  endfor
 else
  Broadcast Hello_msg on iface[0]
 endif
Endprocedure
Procedure recvHello()
 NeighborList[index] <- add source node
Endprocedure
```

The source code that implements the above described mechanism is available at [35]. The current solution is in centralized form meaning that the information used by the mechanism is globally stored.

Another proposed mechanism, which can be implemented simultaneously with the previously described one, is a more efficient video data rate adaptation mechanism. When more than one video is sent from the source to destination, the used bandwidth of the wireless links between the nodes tends to reach or pass the limit. In such scenarios, a degradation of the videos quality leads to better results as more video packets are allowed to pass throw the link and reach the destination in time. Our proposed design can adapt the rate of the video sent and drops its quality efficiently so as maximum quality and minimum delay is achieved in the same time.

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5. PERFORMANCE EVALUATION OF MIMC IN AODV

During this simulation-based performance evaluation of the MIMC effect in the AODV MANET routing protocol, we follow the model of [24] to support MIMC technology in our simulations. The simulations concern an emergency response situation where a command & control center is setup and group or units are dispatched to different areas that require assistance. In each area, the group of units has a (mobile) local center and units are deployed locally to confront the situation. Each unit is a node in the network. There are 5–10 groups each group has (similarly) 5–15 units in it. The distance between the deployed units and the local center varies up to half kilometer, while the distance between the command & control and the group centers varies up to 10 km. In the initial simulations only one group is simulated, to study the performance of video transmission within the group and toward the local center.

The simulations are run for two different random placements of the group members in order to minimize the influence of the group member placement in the simulation results. The senders are three team members at the edge of the unit radius and the receiver is the team leader at the center of the unit. Transmitted messages from senders to the receiver may travel through up to 4 hops. The results were quite similar, so only the one case is presented below. In order to account for possibly bad conditions (which are expected in emergency response situations), the maximum data rate (bandwidth) of each wireless connection is set to 1 Mbit/s. In each simulation, three videos are transmitted. Each video is transmitted using variable bit rate (VBR) with a mean rate of 0.32 Mbit/s. This (when taking into account the protocol overhead) slightly saturates the wireless link at the receiving node and demonstrates the bottlenecks. The transmitted videos are uncompressed YUV sequences that are coded to MPEG-4 just before the streaming process and decoded back to their original YUV sequences at the end user. Their format is QCIF with dimensions of 176×144 and the fps is set to 25/s. The videos last for just less than a minute. The selected transport protocol is the TCP Friendly Rate Control (TFRC) [36] which supports rate adaptive transmissions. In the first set of experiments below, the TFRC does not use its rate adaptive algorithm. In the second set, the rate adaptation is enabled and a comparison of the two cases is made. For all simulations, the legacy IEEE 802.11 MAC protocol was used.

Figure 8 shows the videos' transmission rates of three simultaneous video transmissions without using MIMC per node. The rate of each video fluctuates a lot.

In addition, the average bandwidth for each video is slightly less than the mean bit rate, and thus the videos arrive with some delay. Figure 9 shows the delay for the three videos and demonstrates how it is accumulated. At the end of the videos this delay is almost 10 s. This transmission is impractical for a real video streaming as the delay accumulates resulting at some point to the command center receiving very outdated video.

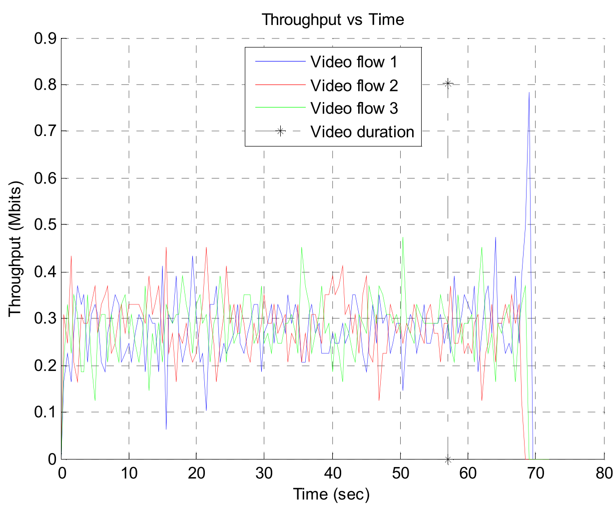

Figure 8. Bandwidth usage for three videos transmission without MIMC support.

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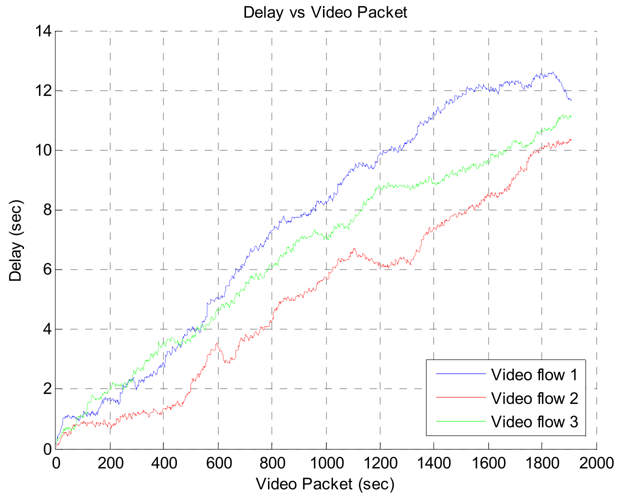

Figure 9. Delay for three videos transmission without MIMC support.

It should be noted that the situation is similar with only two or even with only one video transmission when the video transmissions are over three or more. When an intermediate node transmits neither its previous nor its next node can transmit at the same time. Thus, only one third of the bandwidth is usable at any time. It is clear that by using the same channel for all the wireless connections, the ad hoc network cannot properly support the transmission of even a few video streams. However, in order to utilize multiple channels, the nodes must be equipped with multiple wireless interfaces (so that each node can receive and transmit at the same time over different channels). This is not an unreasonable assumption for emergency response teams, as their equipment can be tailor made to their specific requirements. We repeat the simulations by equipping each node with two wireless interfaces and channels. The center node is equipped with three wireless interfaces as it is the sink of the video transmissions and needs to be able to receive over more channels.

Figure 10 shows the bandwidth usage of the three videos in the receiving node. All videos are transmitted at their intended rate (as they arrive at different interfaces over different channels), and there are no fluctuations other than those from the VBR encoding of the videos (which is very important during real time multimedia transmission).

Figure 11 shows that the actual delay is indeed negligible (please note that the scale is quite smaller than that of Figure 9, because the delay is very low).

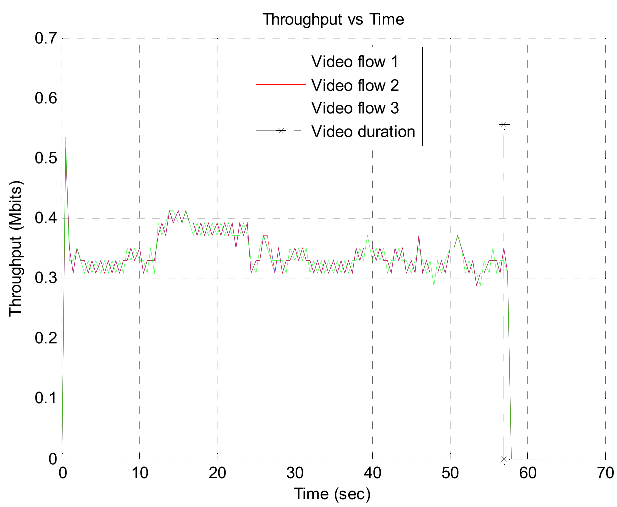

Figure 10. Bandwidth usage for three videos transmission with MIMC support.

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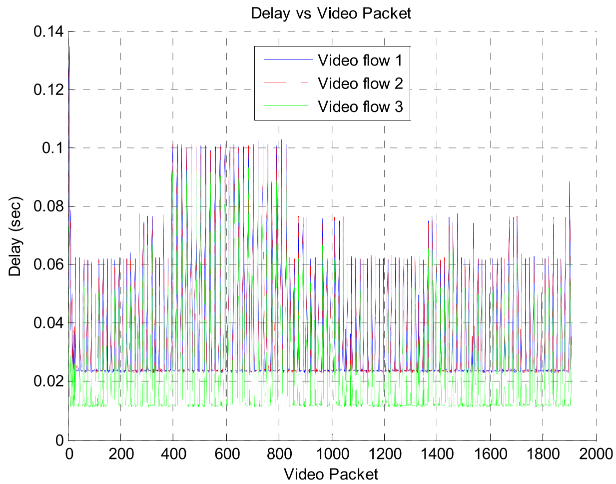

Figure 11. Delay for three videos transmission with MIMC support.

From the above results it is clear that simultaneous live video transmission can be supported by an Emergency Response Ad hoc Network, if the nodes are equipped with multiple wireless interfaces and use multiple channels. From the initial results it seems that for similar scenarios, two wireless interfaces per node are sufficient for the number of nodes and the number of videos expected to be transmitted within each emergency response team. This is concluded from the requirements given to us by the Hellenic Fire Brigade, in personal communications, because they do not require neither high resolution nor a large frame rate. However, the center node of each team acts as a sink for the videos and requires more wireless interfaces in order to be able to simultaneously receive all the videos. Another way to overcome the difficulties of transmitting multiple videos in such an ad hoc network is to use rate adaptation and reduce the video quality when the available bandwidth is less than the required in order to accommodate all videos (see e.g. [36]). This is clearly not the preferred solution, but it may be used if nodes are only equipped with one wireless interface. In order to evaluate this solution, we introduce rate adaptation in the video transmission. Thus, the simulations were also run with enabled rate adaptation.

Figure 12 shows the videos' transmission rates of three simultaneous video transmissions with rate adaptation. The figure is similar to Figure 8, with the three videos having rates that fluctuate a lot, but in this case the video rates adapt to the available bandwidth (by dropping the video quality by a small factor) and all video packets arrive close to their intended time.

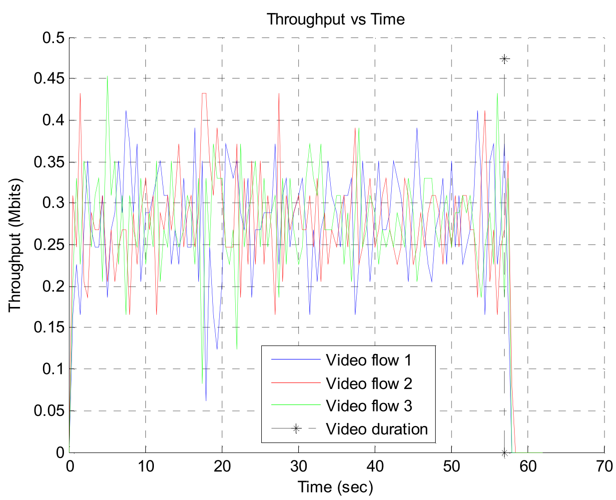

Figure 12. Bandwidth usage for three videos transmission with rate adaptation.

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Figure 13 shows the cumulative bandwidth (see). As this figure shows, the system is saturated and this explains the fluctuation as the three streams compete with each other for bandwidth. The cumulative bandwidth (see Figure 13) exceeds the capacity of one wireless link at all times (if we take into account the protocol overhead). However, this is to be expected as the total capacity is now two-fold for all nodes and three-fold for the center node. Therefore, there is available capacity to accommodate more video transmissions. Please note, that the videos arrive on-time with no noticeable delay.

Figure 14 shows that the delay of each video frame remains relatively small (compared to the delay in Figure 9), and, more importantly it does not increase with time. Contrary, as the system stabilizes, the delay remains less than half a second. This is not a big delay for the considered scenarios, and it is reasonable for live video streaming.

The drawback is that videos may have reduced quality during some periods. Figure 15 shows the PSNR of the transmitted videos.

Figure 16 shows the quality of the same video frame for different SNR values at the receiver compared to the original one at the sender. From the combination of Figures 15 and 16 it can be

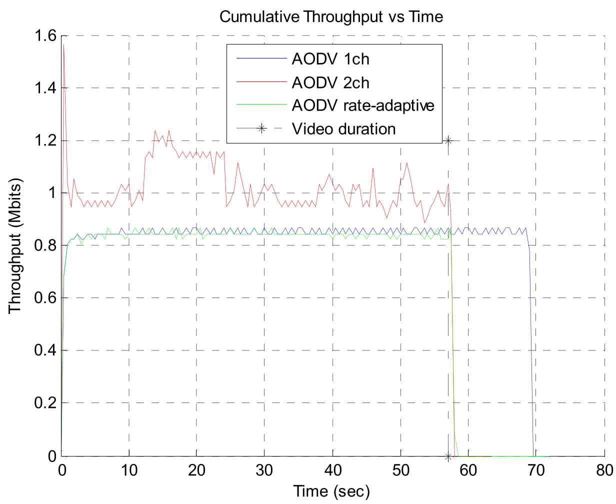

Figure 13. Cumulative throughput per second for the three cases.

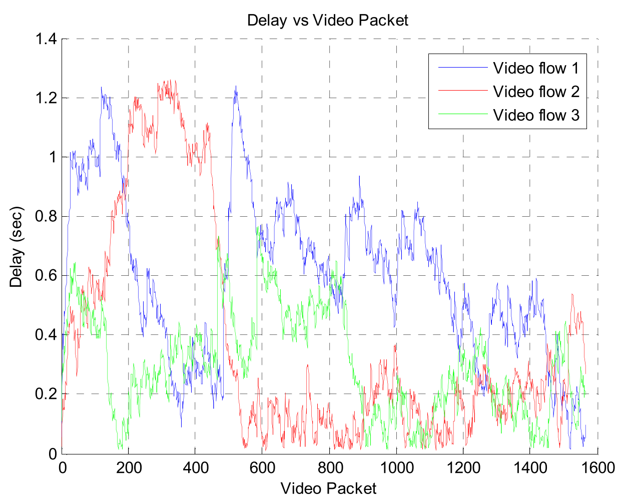

Figure 14. Delay for three videos transmission with rate adaptation.

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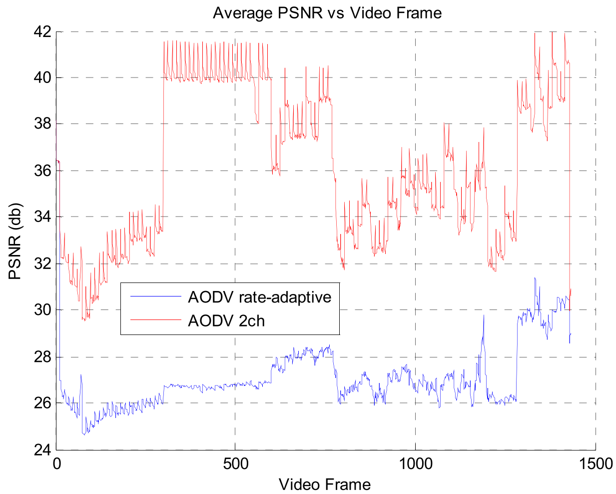

Figure 15. PSNR for three videos transmission with rate adaptation.

Original video frame video frame with SNR: 39.88db video frame with SNR: 26.77db

Figure 16. Same video frame for various SNR values.

concluded how the SNR values are mapped to the actual video quality at the end-user. The captured frames in Figure 16 belong to one of the transmitted videos during the simulations.

The PSNR of the received videos is quite low with rate adaptation when only one channel is used, and there is a noticeable lower quality. This is expected as the available bandwidth is not sufficient for better quality when having only one channel. However, when using MIMC, the received videos are clearly much better and are good enough for their intended purpose, i.e. to give the command center a clear view of the recorded operational field. Thus the reduction in quality does not introduce any vital information loss for the considered scenarios.

Figure 17 shows a delay comparison for each transmitted packet in the three considered cases (green: transmission with rate adaptation and no MIMC support, red: with MIMC support, and blue: with no MIMC support and no rate adaptation). When utilizing rate adaptation, fewer packets are transmitted as the video quality is reduced.

The comparison demonstrates that using MIMC should be the preferred solution for transmitting multiple live video streams in Emergency Response Ad hoc Networks. Rate adaptation should be considered only if the equipment for using MIMC is not available, or in addition to using MIMC. Clearly, deploying an ad hoc network without special considerations for video transmission is actually not an option.

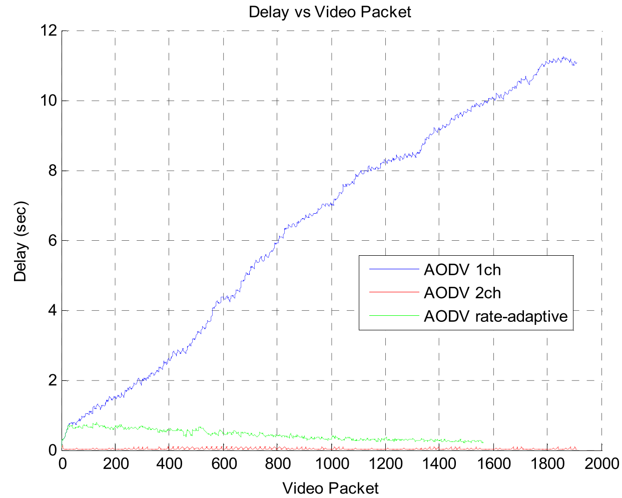

Figure 17. Comparison of the delay of each packet for the three cases considered.

6. COMPARATIVE PERFORMANCE EVALUATION OF MIMC IN EXISTING MANET ROUTING PROTOCOLS

In this section we present the results of the evaluation of the effects that MIMC have in the performance of various MANET routing protocols, i.e. the AODV routing protocol ([10]), the Ad hoc On-Demand Multipath Distance Vector routing protocol ([37]), and the Destination Sequenced Distance Vector (DSDV) routing protocol ([38]). Before presenting the results, we provide some information on the simulation settings.

For the performance evaluation of the above-mentioned MANET routing protocols and the effects of MIMC in them, we use the work of [24] as a baseline. The experiments are run in ns-2.35. For video encoding used in the simulations we enlist the use of Evalvid-RA v1.04_2 ([39]). For all simulations, the legacy IEEE 802.11 MAC protocol was used.

Our first studied topology has 13 randomly positioned nodes considered to be in group, as shown in Figure 18. There are four nodes that act as senders, namely nodes 0, 1, 4, and 6, and three nodes that act as receivers, namely nodes 10, 11, and 12. During the simulations there is a significant overlap in the paths used for transmitting the videos. For example, at some instance there are two four-hop paths, one three-hop path, and one two-hop path created. This represents a common stretched network situation. During the experiments, all nodes move continuously causing frequent changes

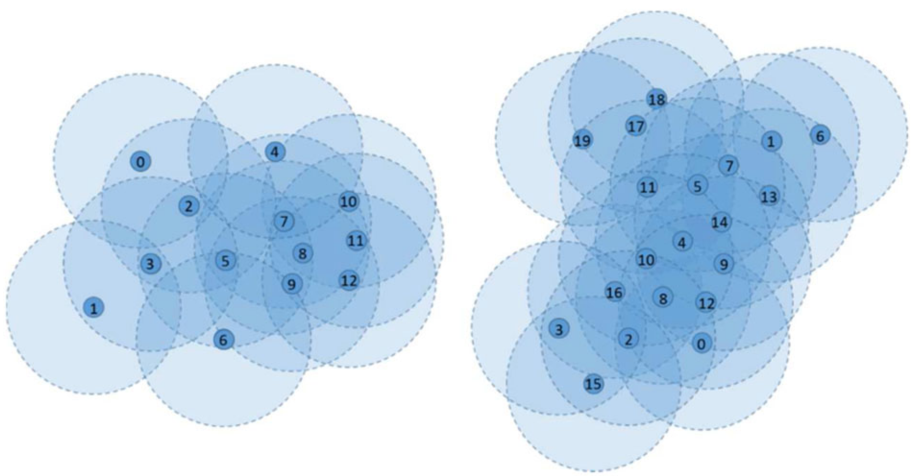

Figure 18. Topology 1 on the left and topology 2 on the right of the simulated MANET.

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to the routing table. However, the motion of the nodes does not cause complete disconnections between any sender/receiver pair. This allows the comparison of results from various experiments and does not cause problems in calculating the average delay. In the simulations, video transmissions are initiated only after a small initial time period in order to allow proper initial network formation. This initial time period is discarded, and time is considered to start at 0 when video transmissions fire. Transmitted videos have a duration of 80 s, a size of 352×288 pixels, and run at 25 frames per second (for a total of 2000 frames). They contain scenes with movement, in order to simulate realistic videos. The mean VBR of the encoding is set at 1 Mbps. The video transmission does not use rate adaptation in order to have consistently high transmission rates (i.e. high quality of the video). The network is set to operate at 16 Mbps.

The second studied topology consists of 20 nodes, and it is based on the group random waypoint model. In contrast to our first topology, this topology contains very intense movement which causes the disconnections of senders and receivers. The average node speed is 20 km per hour and nodes are moving as groups in an area of 700×700 m. However, the average network hops are decreased to 2 with a maximum of three hops. Video parameters remain the same as before and again no rate adaptation is used. The VBR rate is set to 0.8, and the network operates at 3 Mbps. The code used to conduct the experiments is available at [35].

6.1. Evaluation based on network metrics

This section presents the MIMC performance evaluation on the previously described MANET routing protocols based on network metrics and specifically the average delay which is presented in Figure 19 and the transmission rate which is presented in Figure 20. As Figure 19 shows, introduction of MIMC results to an important average delay reduction for all the above routing protocols. This is very important for video and multimedia communications in general. Figure 19 also shows that MIMC positive effects are greater for AODV and AOMDV. DSDV experiences less benefits from MIMC and performs better than the other two routing protocols in the absence of MIMC. As a result, DSDV is the weakest routing protocol during video transmission when using MIMC.

Figure 20 presents the transmission rate during the simulation. As someone can see in Figure 20, similar conclusions can be made for the transmission rate as well. As the above figure shows, the DSDV routing protocol has slightly less bandwidth utilization. Again, it is obvious that the DSDV routing protocol has the worst performance in transmitting video in MANETs with MIMC per node. From the above, video transmission takes longer when DSDV is chosen. This results to video streaming interruptions and delays (it takes approximately 100 s for the transmission of an 80 s video).

Comparison of the AODV performance vs. the AOMDV performance leads to inconclusive results. As someone can see in the above figure, AOMDV is slightly better at the first half of the transmission, and AODV slightly better in the second half of the transmission. Overall, AODV seems marginally better than AOMDV mainly because the video transmission in AODV is completed just before the AOMDV.

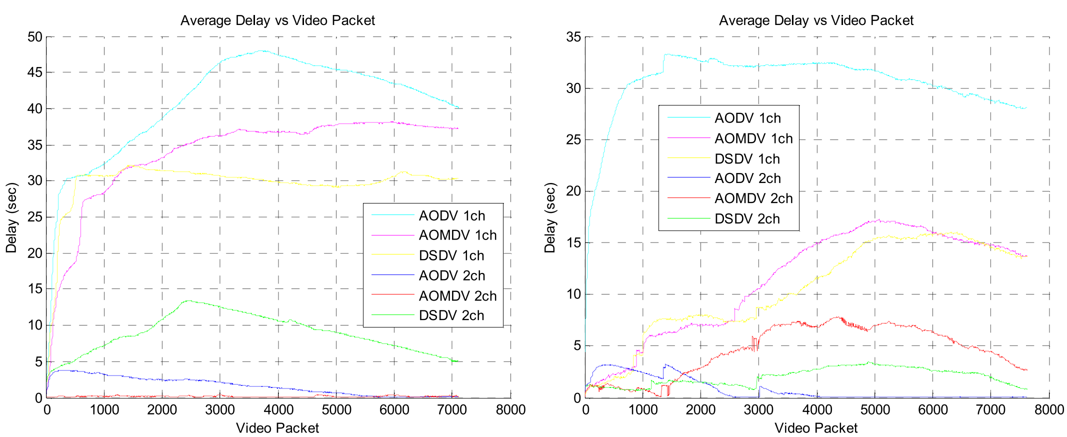

Figure 19. Average delay for topology 1 (left) and 2 (right).

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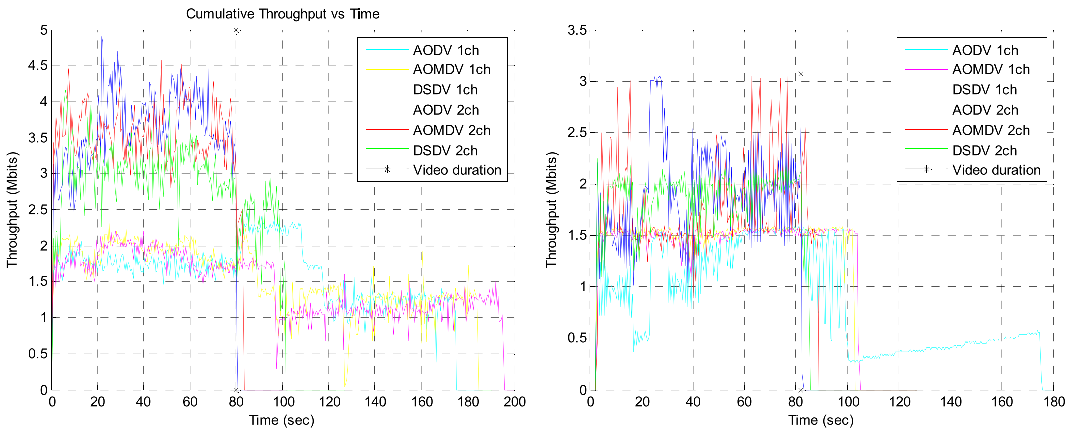

Figure 20. Cumulative bandwidth for topology 1 (left) and 2 (right).

It seems that DSDV has better performance (in terms of less end-to-end delay) when using one because of its pre-active nature. This same nature allows DSDV to have less fluctuation for the throughput, in all cases. However, the routing overhead incurred does not allow DSDV to have the highest throughput (though it is still quite close to that of the other protocols).

AOMDV has better performance than AODV when using one channel because of the multipath feature. The alternative routes allows it to achieve less end-to-end delay and slightly better throughput as there are less route disconnections and less rerouting overhead. However the dense nature of the simulated networks does not allow AOMDV to demonstrate better performance as the multiple paths still interfere with each other and a video stream cannot benefit by splitting between these multiple paths.

AODV seems to benefit more because the addition of MIMC, essentially, allows AODV to acquire some of the advantages of having multiple paths to the destination (as the MIMC means that there are multiple between neighboring nodes). While these paths are not node disjoint, but only edge disjoin, they allow AODV to ‘close the gap’ with the other protocols.

6.2. *Evaluation based on media metrics*

This section evaluates the effect of MIMC during multimedia transmission over MANETs based on video quality assessment methods and metrics. Initially, we present the video quality assessment methods and the metrics which were used during the evaluation.

There are two classes of techniques for surveying the receiving video quality as indicated by the human eye. The first class contains subjective video quality appraisal strategies which are defined by ITU-T in [40]. In the subjective video quality evaluation strategies, the apparent video quality is characterized through human reviewing in which the individual viewer decides the quality level.

The second classification is objective video quality evaluation systems which do not include human interaction and are grouped into three subcategories. In the first classification, the assessment is performed by looking at the complete decoded video arrangement toward the original transmitted video. In the second classification, the assessment depends on the examination of just a part of the components/measurements of the first video with the decoded video and not the entire video grouping. In the last classification, the assessment is not taking into account any correlation between the original and the decoded video toward the end client, yet is based just in the assessment of the decoded video toward the end client. The Video Quality Expert Group names the above described methods as the full, the reduced, and the no reference methods [41].

QoE prerequisites for video and audio ([42, 43]) might be founded on subjective assessment measurements, for example, the Mean Opinion Score (MOS). In the MOS assessment, various end users decide the video quality in an extent 1 to 5, where 1 is the lower video quality and 5 is the most

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elevated quality (Table I). MOS is a viable approach to quantify the QoE of any mixed media service for a user. On the other hand, MOS is considered as tedious and requires an extensive number of users to give dependable results.

Keeping in mind the end goal to defeat the above impediments, we base our assessment in the objective full reference test method and ascertain the Peak Signal to Noise Ratio (PSNR) [44] by specifically comparing frame-by-frame the original video sent by the sender with the decoded video at the receiver. During the video transmission we have calculate PSNR estimations of all individual video frames, and we have mapped PSNR values to the relating MOS value based on Table I. We have to highlight, that PSNR mapping to MOS values gives just a rough estimation of the apparent video quality by the end user.

The average MOS per video frame and routing protocol for topologies 1 and 2 respectively both without and with MIMC per node are appeared in Figures 21 and 22. Figures 23 and 24 demonstrate the normal PSNR per video frame and routing protocol for topology 1 and 2, respectively, again both without and with MIMC per node.

Table I. ITU-R quality and impaired scale [46] and possible PSNR to MOS mapping [47].

PSNR (dB)	MOS	Perceived quality	Impairment
>37	5	Excellent	Imperceptible
31–37	4	Good	Perceptible, but not annoying
25–30	3	Fair	Slightly annoying
20–24	2	Poor	Annoying
<20	1	Bad	Very annoying

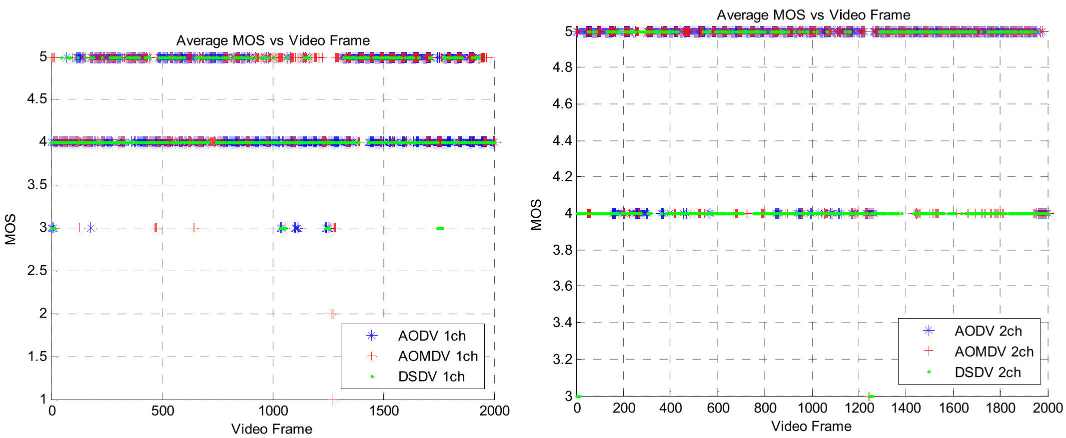

Figure 21. Average MOS without (left) and with (right) MIMC for topology 1.

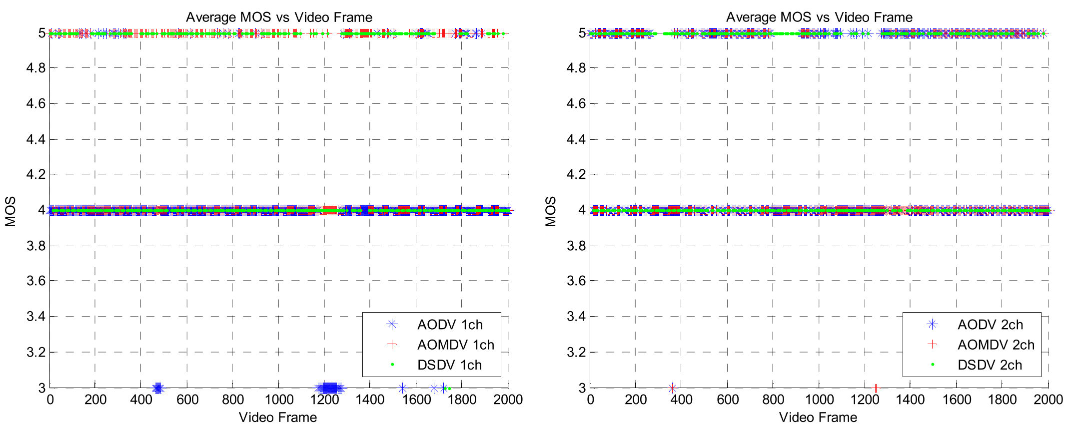

Figure 22. Average MOS without (left) and with (right) MIMC for topology 2.

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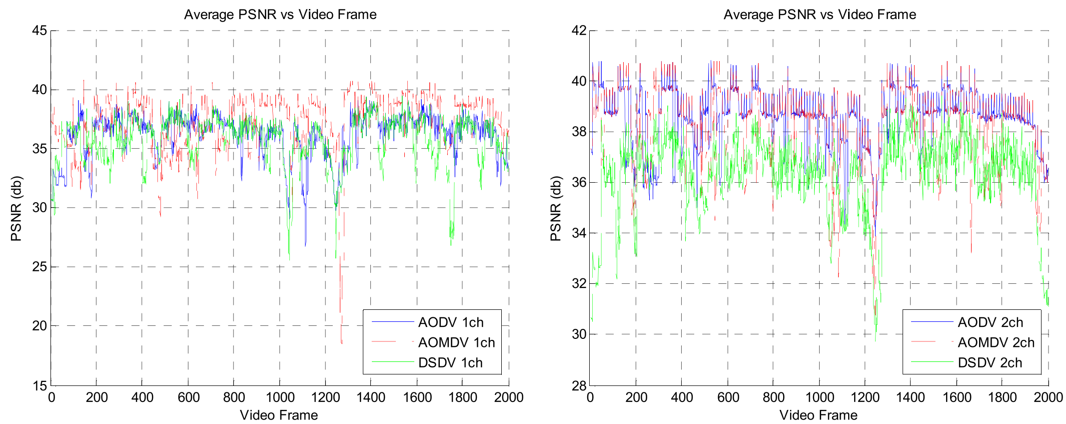

Figure 23. Average PSNR without (left) and with (right) MIMC for topology 1.

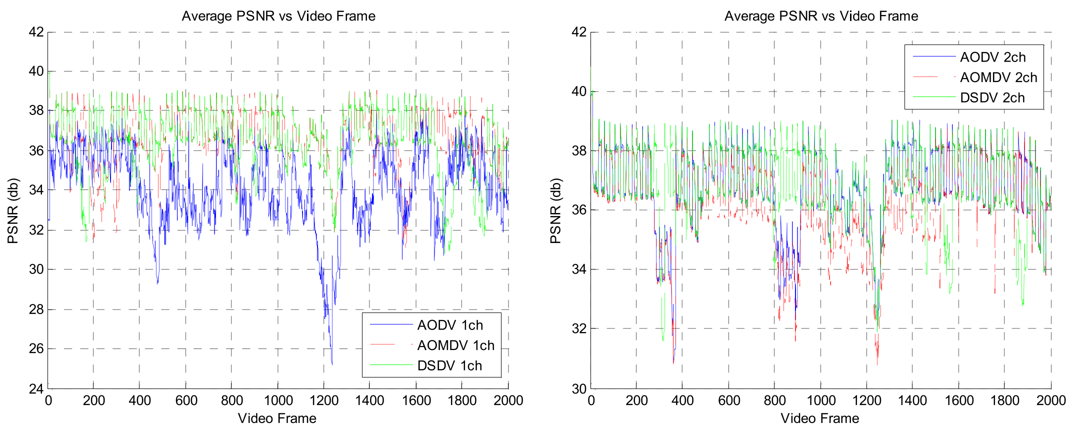

Figure 24. Average PSNR without (left) and with (right) MIMC for topology 2.

As should be obvious in the above figures, the quality of the received video appears to vacillate more on account of not utilizing MIMC. The above results show that while utilizing DSDV, the video transmission does not benefit from the utilization of MIMC per node, and its performance appears to stay at the same levels.

While using AOMDV, it appears that the utilization of MIMC noticeably improves the received video quality. For this situation, the received video quality vacillates less and stays at higher values more time than when not utilizing MIMC per node. This has accordingly a superior end user experience.

On account of the AOMDV routing protocol with MIMC, there are additional advantages in the received video quality and entirely comparable results with the AODV.

As observed previously, AOMDV seems to result in better PSNR than AODV, when using one channel, because the existence of multiple paths. However, the addition of another channel provides AODV with more routing options, and allows it to match the performance of AOMDV.

AOMDV results also in better PSNR in the case of topology 1, again because of the multiple paths. However, for the denser topology 2 this feature is enough to make a difference as the interference between the node-disjoint path is still quite high.

7. PERFORMANCE EVALUATION OF PROPOSED MIMC APPROACH

The evaluation of the proposed mechanism is made for a variety of topologies using the random topology creator BonnMotion [45]. The topology dimensions are set to 1000 m × 1000 m and the number of wireless nodes to 20. The bandwidth of data channels is set to 2 Mb, and the two-ray

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ground propagation model is selected. Nodes have radio range set to 250 m and top speed set to 20 km/h. For the MAC protocol, multi-radio and multi-channel is selected and each node has three interfaces and three channels. The simulations were implemented with data traffic set to Constant Bit Rate for common flows and TFRC [36] for video flows. Topology types are categorized based on the nodes density and speed. In most cases, when low movements and density were applied to the topology, the AODV with MIMC and the proposed mechanism performed in a quite similar way with the last one showing slightly better performance in throughput and delay. However, when applying higher density and more intense node mobility, the proposed design resulted to more efficient performance. The results are more intense and noticeable when video flows and TFRC are selected. In order to simulate a realistic topology with greater demands, we have implemented a topology with quite intense node density and mobility for five video flows with minimum hop count set to 2 and maximum set to 5. All five video flows are causing great interference to each other because at many points of the network they are meeting and sharing the same paths. Also, the node mobility creates extra interference and increased need to set optimal channel patterns to avoid collisions. Video flows 1 up to 5 start respectively at 10, 11, 12, 13, and 14 s and should end at 90, 91, 92, 93, and 94 s of the simulation. Starting and ending positions of the nodes are shown in Figure 25. The total simulation time is 120 s. For all simulations, the legacy IEEE 802.11 MAC protocol was used.

In this section, we present the proposed mechanism's performance results for channel assignment compared (described in detail in section 4) to the AODV with MIMC presented in [24] for the previously described topology.

Figure 26 shows the throughput for the five video flows in the case of using AODV with MIMC. In this case, three video flows out of five manage to reach the destination node within the desired stream time. The other two flows, video 2 and 3, are delivered with some noticeable delay that do not satisfy the end user requirements. Video flows 2 and 3 have some instability in the throughput because of the interference caused by the nodes that were initially outside the interference zone of these two flow paths, and after a period of time they approached the interference zone. The AODV with MIMC fails to see this interference change and does not switch to non interfering channels.

Figure 27 shows the throughput per packet in the case of using AODV with the proposed design. It is noticeable that the throughput is more stabilized and only one video is delivered with unpleasant delay, still considerably less than in the case without the proposed design. The proposed design monitors the changes of the interference caused by nodes with interfering channels that move toward the index flow and makes the decision to switch channels. The switchable channel is set based on the SNR of the channels in the flow neighborhood, and as a result the delay is maintained at desirable levels.

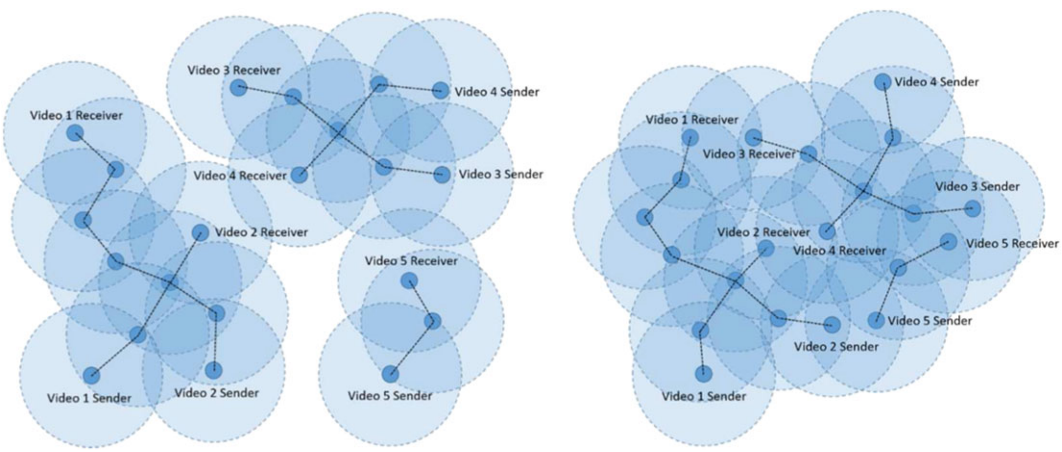

Figure 25. Starting (left) and final (right) positions.

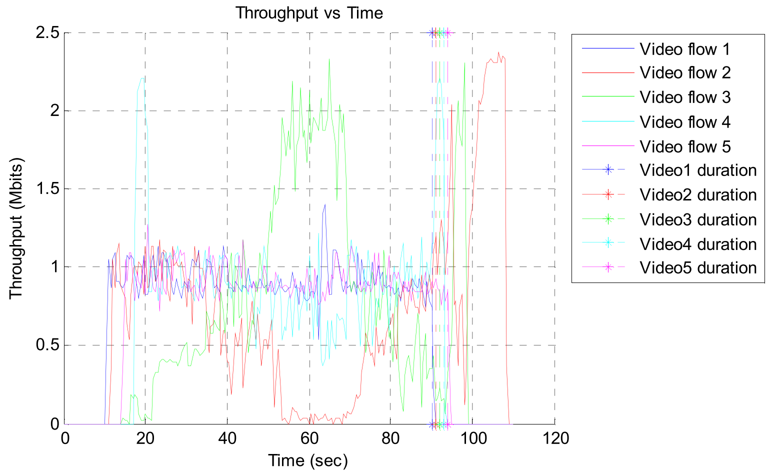

Figure 26. Throughput of the video streams in the case of AODV with MIMC.

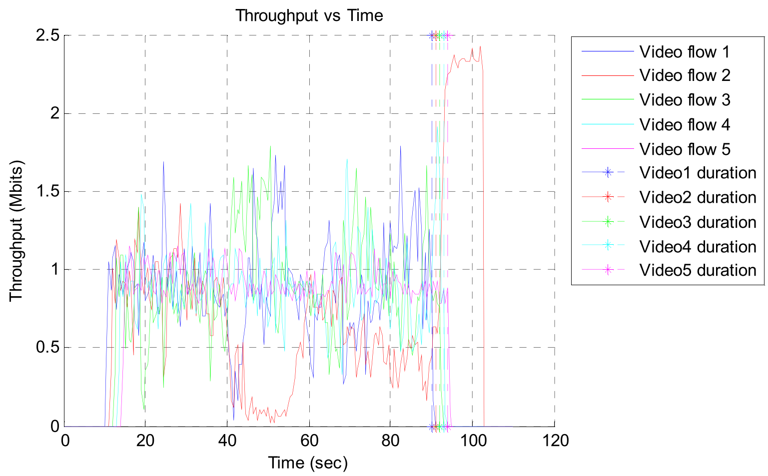

Figure 27. Throughput of the video streams in the case of AODV with the proposed mechanism.

The proposed mechanism largely improves the situation for video 3, which otherwise experiences a very slow start and a delayed delivery. With the proposed mechanism, video 3 transmits more normally, and finishes almost on time. It should be noted that there is large improvement also for video 2, which unfortunately is not delivered on time even with the proposed mechanism. This is because the frequent topology changes (at around one third off the experiment) cause video 2 to compete with several other videos and the existence of the three ifaces/channels is not enough to provide bandwidth for all the video streams. However, video 2 also gets some more bandwidth, and the final delay is much less than when the proposed mechanism is missing. This means that the inclusion of the proposed design improves the performance in the scenario at hand.

Figure 28 demonstrates the cumulative throughput for the two protocols. The cumulative throughput is better for the proposed mechanism for most of the period, and therefore transmission of the videos finishes earlier and with only one delayed video. This is obviously because of the fact that the proposed mechanism makes some proper choices when selecting the transmission channels and thus avoids causing much interference (i.e. cause less collisions).

Figure 29 shows the delay of each packet in the case of selecting the AODV with MIMC protocol. It is obvious that the delay for two video streams is noticeable and that these streams have a large delay for their final packets. This means that these streams cannot be played back without interruptions.

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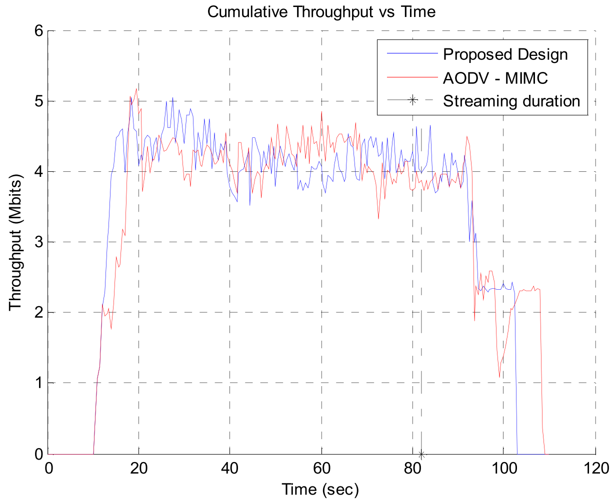

Figure 28. Cumulative throughput comparison with and without the proposed mechanism.

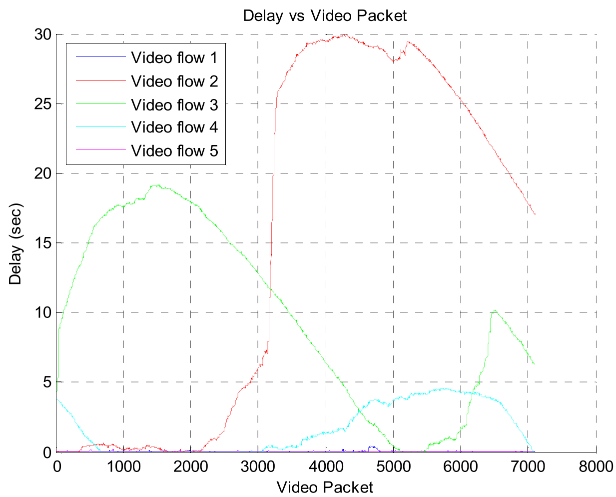

Figure 29. Packet delay of the video streams in the case of AODV with MIMC.

Figure 30 shows the delay per packet in the case of selecting the AODV protocol with the proposed design. The delay is much lower, and only one stream faces problems. This means that the proposed mechanism improves the video transmission. It should be noted that the proposed mechanism seems to keep the delays of the transmitted videos at an acceptable level, when possible. In the presented case, the delays for videos 3 and 4 are kept quite low at acceptable levels even if this means that the delay for video 1 has to increase at some periods (but still remaining at acceptable levels). Without the proposed mechanism videos 3 and 4 experience large delays (although video 4 catches up at the end), while video 1 experiences almost no delay. In all cases video 2 experiences large delays after the first third of the experiment, and while the proposed mechanism cannot lower it down to an acceptable level it nonetheless improves it. However, it seems that video 2 faces high competition and high interference from more than one neighboring links and cannot be transmitted on time in this case of using up to three channels. In order to solve this problem, it seems that up to four channels should be used in this case.

Figure 31 shows the average delay for the two cases. The results demonstrate that the proposed mechanism distributes the available capacity more efficiently leading to more smooth transmission of the videos and much less delays. It is obvious that the positive effect of the proposed mechanism in the delays of the video packets is substantial.

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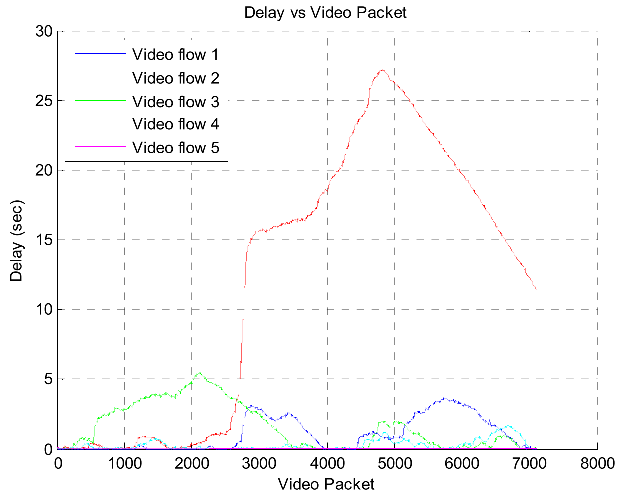

Figure 30. Packet delay of the video streams in the case of AODV with the proposed mechanism.

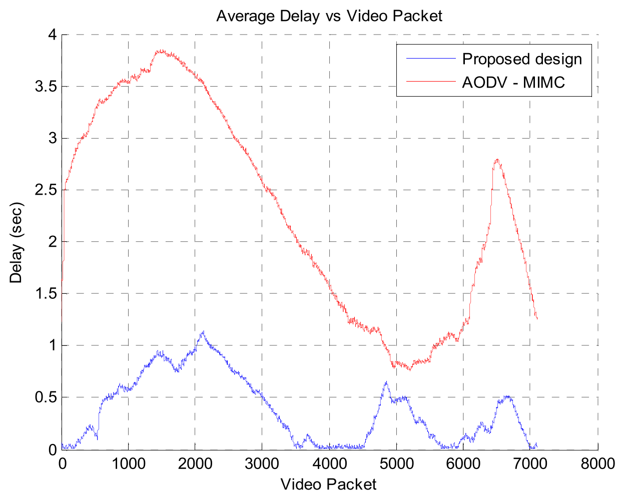

Figure 31. Average delay comparison per packet with and without the proposed mechanism.

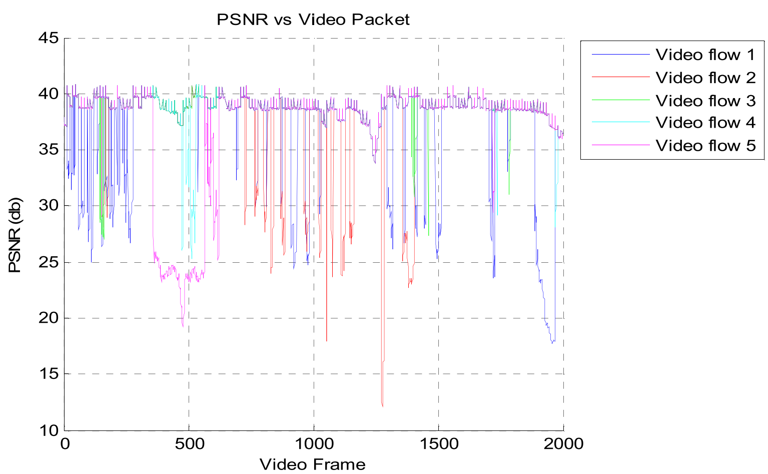

Figure 32. PSNR for each video frame.

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Figure 32 shows the PSNR of each video frame per flow for the proposed design. The results concerning the PSNR are exactly the same with the AODV with MIMC and are not presented. This however is to be expected, as the quality of the videos transmitted is not altered, and as packets are not dropped, they finally arrive at their destinations (even with a considerable delay).

From the above evaluation it is clear that the proposed mechanism has a positive effect on the video transmission and leads to better end user experience. Without the proposed mechanism, the video transmission rates are lower than the video playback rates, and this leads to interruptions. With the proposed mechanism, the transmission rates match the playback rates, and the video reproduction to the end user is smoother.

8. CONCLUSIONS AND FUTURE WORK

In this work, we evaluated the use of multi-interfaces and multi-channels for transmitting video in Emergency Response Ad hoc Networks. In addition, we evaluated the performance of AODV, AOMDV, and DSDV routing protocols with and without MIMC, and we proposed a simple channel selection mechanism that can be applied in MANETs when using MIMC. The simulation results indicate that video transmission using MIMC is better and offers many advantages in Emergency Response Ad hoc Networks. This means that the first responders should be equipped with special nodes that support MIMC and can transmit simultaneously in multiple channels.

In addition, the results show that, when introducing MIMC per node, different routing protocols show different levels of performance enhancement. There are a few benefits when using DSDV, but more when using AOMDV, and much more when using AODV. Therefore, in such MANETs, it is advantageous to use the AODV routing protocol. Finally, the proposed mechanism enhances the network's ability to accommodate more streams as well as reduce the delay that is experienced by the video streams' packets.

Future works includes further study of video transmission under multi-interfaces and multi-channels scenarios, as well as the proposal of appropriate changes in the most common MANETs routing protocols in order to get more benefits when using MIMC. More specifically, we plan to run more experiments for other cases/topologies and also for larger networks with more video flows. We also plan to introduce path selection and combine this mechanism with other mechanisms such as rate adaptation, to further improve video transmission in our studied class of MANETs scenarios. Moreover, we plan to implement a module for automatic selection of channel switching parameters based on specific network parameters. In addition, we plan to extensively compare our simple mechanism to others, found in the literature, in order to estimate if the additional implementation complexity of these solutions is justified, or if our solution can lead to adequate enough improvements. Finally, we plan to investigate how the proposed mechanism affects the energy consumption in the end nodes and what the performance is on real network testbeds.

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