An Overlay Routing Protocol for Video over sparse MANETs in Emergencies

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ABSTRACT

Video delivery over a mobile ad-hoc network that can be deployed by members of an emergency service in an incident zone is an appealing tool for emergency and rescue services, but has not be studied yet. In order to design and test a suitable solution, we have generated realistic evaluation scenarios by modeling fireman action plans and GPS traces from real situations. The Emergency Overlay Routing (EOR) protocol is a reactive protocol integrated into a store-carry-forward architecture. It selects ferry nodes to transport video data from a camera in the Incident Area to the Incident Chief's node, looking for the minimum delay, but reliable, candidate. The evaluation of EOR shows its superiority to the well-known DTN routing protocol, PROPHET, under this conditions.

Categories and Subject Descriptors

C.2.2 [Network Protocols]: Routing Protocols

General Terms

Algorithms, Design, Experimentation

Keywords

Emergency and Rescue, Sparse MANET, Routing, Video

1. INTRODUCTION

On the occurrence of an accident, fire or flood, emergency services are deployed aiming to protect population and goods, and, when possible, finish the crisis as soon as possible. These catastrophic events may happen everywhere and unexpectedly making it hard to establish effective preventive measures. One of the most useful tools for an emergency service on field is to have communication among members, but it is difficult to find reliable channels. For example, emergency dedicated public networks (e.g. TETRA, VHF or WiMaX networks) can be deployed to support fire extinction in the woods, although they imply high costs. However, they may be burned out or powered down under intense fire. In the case of urban environments, which already have communications infrastructure (e.g. cellular networks), it is proven that they often become collapsed by the victims, thus, useless for the rescue teams. Packet radio devices are traditionally used for voice, because of their reliability and acceptable range. However, their capacity is not enough for data transference at a minimum rate.

Mobile ad-hoc networking is a feasible alternative to provide data sharing in such an environment. Each member of a rescue team can be equipped with a terminal (e.g. WiFi) that establishes direct communication with their close teammates and uses them to reach further colleagues. From the network perspective, each device is both an end host and a router that forwards other's information. Since devices are mainly carried by people or cars, the network topology is dynamic. Other potential disadvantages of these networks arise from the uncertainty caused by the mobility (route changes, partitions) and the shared channel (packet losses, congestion). Nevertheless, their great advantage is their independence from an existent infrastructure and other networks. Thus, emergency services would have an instantaneous communication network, independent from others, reliable and secure, in other words, tailored from their needs. In many cases, this would mean the possibility of data transference where it was not possible before, although the communication range would normally be smaller.

Receiving video from the Incident Area(s) in the point where it is coordinated (command and control center where the Intervention Chief is located) is very appealing for the emergency services. Video would help them to foresee potential risks, analyze the situation and assign resources efficiently. Thus, emergency services can get a better performance of the deployed resources. For example, a fireman with a camera can send video of an accident in a tunnel, allowing experts to examine the evolution of the structures without entering in the area. Otherwise, this information would have to be just an oral description of the firemen, with unavoidable flaws. Sometimes they are able to get images using a mobile unit camera, and a helicopter as a repeater; which apart of being an expensive solution, it is not always possible in not open field situations (tunnels, underground caves, buildings). An ad-hoc network can be used to delivery this video, although the quality and especially the delay may be affected. A few firemen deployed on the Incident Area would form a sparse network with isolated network partitions, which will cause delay in the transmission. However, in these situations, the emergency services consider much better to have this video, even if it is delayed, that to not have it at all.

In this paper, we study video transport over sparse mobile ad-hoc networks (MANETs) deployed in an emergency situation where video recorded at the Incident Area must be delivered to the Intervention Chief. Limitations for such a system are the uncertain node movement, wireless multi-hop links instability and mobile device resources (mainly battery). In our previous work [1], we designed and implemented (in Java) an overlay network architecture (called MOMENTUM) that provides the store-carry-forward paradigm [2] over the standard IP architecture. Note that storage is not a big constraint due to the great capacity of devices compared with the video transmitted (e.g. 6000 seconds of a 500 Kbps, CIF, MPEG2 video ~ 240 MB). Our solution considered all nodes of the MANET as part of an overlay network that can be used to store and relay video. In other words, all the nodes have MOMENTUM installed and running. In addition, video was received and delivered as RTP in the end-point nodes, so it was possible to connect with standard servers (or cameras) and clients. Finally, the overlay network communicates with the standard network protocol OLSR, which allows crosslayer improvements, such as network topology awareness in the overlay routing decisions. The first experiments, carried out in random movement scenarios, proved store-carry-forward paradigm as a good alternative for video in these networks, but we detected the necessity of studying realistic scenarios to provide smarter routing decisions for the video packets. Therefore, we keep the core philosophy from our previous work and focus in this work on more realistic scenarios and propose better routing alternatives. For that reason, we have studied fire services, their protocols and collaborated with the Asturian Fire Service (Bomberos de Asturias/112). A simplified mobility model of an emergency scenario is presented and used to analyze our solution. Then, we propose a novel overlay routing protocol tailored for emergency scenarios. The goal of this protocol is to minimize the delay of packets in a probably partitioned sparse MANET. Our hypothesis is that we can benefit from the "a priori" knowledge of these scenarios to predict future movement, thus, to find the best nodes to store the video and eventually deliver it to the Intervention Chief. We compare its performance with the ideas behind PROPHET, a general purpose routing protocol for delay-tolerant networks (DTNs).

The remainder of this paper is organized as following. Section 2 analyzed relevant related work. In Section 3, we explain our model for emergency scenarios. The Emergency Overlay Routing protocol is described in Section 4. Section 5 gives details about the evaluation of the protocol. Its results are exposed in Section 6. Finally, Section 7 presents conclusions and future work.

2. RELATED WORK

There are several studies that can be considered relevant for the work presented in this paper. First of all, the dependence between node's mobility and applications running in an ad-hoc network is an important issue. Previous studies, like [3], emphasize the relationship between the parameters of mobility and the performance of routing protocols for ad-hoc networks. Therefore, part of the research community is trying to reproduce real life scenarios into mobility models [4]. Not only they make experimentations and repeatability easier, but also real world GPS traces are difficult to get. Emergency and rescue operations are not an exception and there exist proposals like [5]. This model, called the Disaster Area mobility model, takes into account different zones (incident site, casualty treatment area, transport zone and hospital zone) and defines the movement of units between them. We focus our research in the zone they call incident site, which in our opinion has not been modeled with enough detail by the state of the art. For that reason, the scenarios for this paper are built with the model presented in Section 3, which is, based on our experience, more accurate defining the personnel moving in the Incident Area.

Routing in ad-hoc networks has interested a lot in the last years. When it is possible to establish multi-hop communication, because devices are in the same network partition, proactive and reactive protocols have been proposed. While proactive solutions, like OLSR [6], try to keep an updated routing table, reactive ones, like AODV, only look for a network route when it is needed. Then, their main task is to detect topology changes produced by mobility or disconnections. When the network is aimed to transport video, congestion, packet losses and other difficulties emerge, see [7] for more details. Therefore, enhanced routing solutions for video in MANETs have been given. They are mainly based on multipath [8], hierarchical, or QoS routing.

Routing in a partitioned network is a different problem, which is defined in detail by [9]. First of all, a paradigm, like store-carry-forward [2], is necessary to transmit packets between nodes in different partitions. Then, the appropriate ferry must be found. In some cases, mobility is known in advanced [10], e.g. in space communications or networks using public transport. Then, routing is a matter of passing messages to the right node taking available resources into account. On the contrary, mobility is unpredictable in some situations. Hence, routing protocols have to guess the best ferry to transport the information to a different partition. In this area, there are some proposals based on epidemic routing [11] that spreads messages in the network whenever nodes' buffers support it. These approaches are not adequate for video delivery, due to the big amount of packets generated by a video source. PROPHET [12] represents a solid alternative in these situations. This protocol calculates a probability of encounter for every node in the network, which is updated depending on the contacts between nodes. Basically, PROPHET assumes that the node that contacts most with another has a higher probability of encounter it again in the future. A transitivity property is also considered. So if a node A contacts frequently with a node B, which also contacts frequently a node C; the probability of encounter between A and C also increases. More details on PROPHET are given in following sections.

The emergency and rescue situation may be seen, at first, like an unpredictable mobility scenario. However, there exist common behaviors of the personnel in most of the missions. Mobility could be considered in the middle of known and unknown situations exposed before. Movement is not completely free or random, but there are not previously defined movements. Consequently, we propose a protocol that considers previous contacts between nodes, but also takes into account the patterns encounter in the mobility in emergency scenarios, which other state of the art protocols do not consider.

3. EMERGENCY SCENARIOS

The design of a new technological solution for the emergency and rescue tasks requires a good understanding of the protocols followed by emergency services and their organization. This is more crucial in the case of studying MANETs deployed by these services, because personnel movement and location are very important. This information may help us to discover repeating patterns that eventually may be used to transport video smarter. For this purpose, we assisted to emergency trials ran by the regional fire department of Asturias in Spain (Bomberos de Asturias/112). We studied their action plan [13] and examined some GPS traces from their vehicles under different situations. We consulted other fire tactics manuals too, such as [14].

The human and material resources assigned to an emergency depend on the existence of victims, the areas affected and the potential risks for the population (such as intoxication in chemical escapes), among other factors. However, the methodology followed in them and the hierarchy assumed by the participants is very similar, just at different scales and with specific material and human resources. Next, we explain hierarchy described in the Asturian regional plan for emergencies [13]. Note that plans have the same general guidelines in every place, thus, this study could be effortless generalized. For each area, there are one or more teams, each of them with a team leader. They are commanded by an Intervention Chief, which is in direct charge of this zone. The Intervention Chief is normally located in a safe place at some hundred meters of the Incident Area. If several zones are affected, this structure is replicated in each. Coordination between zones and among different emergency services (police, fire departments, medical service, etc.) deployed in the area is carried out in the Advanced Command Post. This post is usually located a few kilometers away from the incident areas. Finally, the Central Command Post manages all the incidents occurring in a region and it is in charge of removing and assigning resources. Figure 1 shows a diagram of the emergency hierarchy. Information flows from the Incident Area to the Central Command Post, while Orders and Commands go on the other direction.

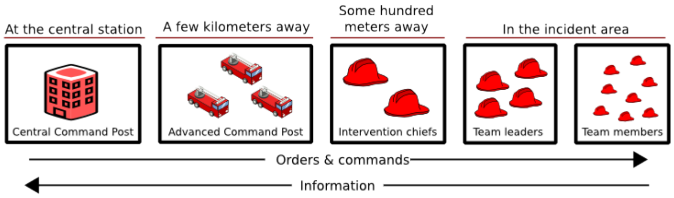

Figure 1. Hierarchy in an emergency and rescue scenario

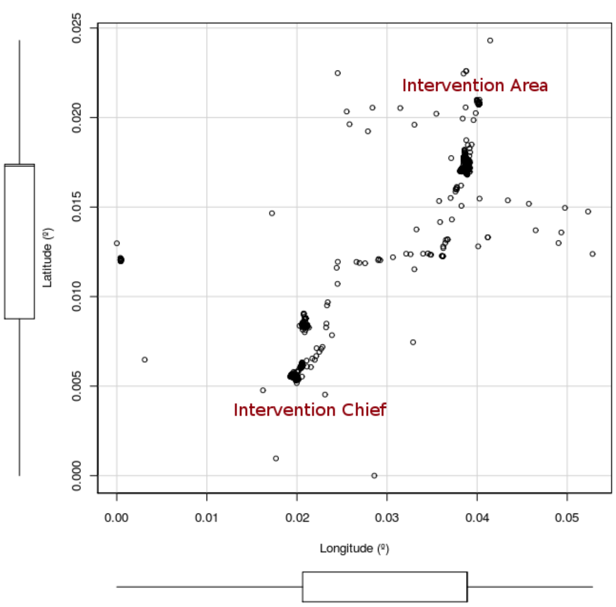

Figure 2. Firemen GPS traces in a chemical accident trial

The hierarchy of the personnel in the emergency is intimately related to position and mobility that they have in the scenario. In this paper, we focus on what happens between the Incident Area and the Intervention Chief, because it is where the deployment of a MANET is most meaningful. The other locations are static and may get easier access to communication infrastructures. They usually have easier access to power sources too, which is obviously relevant. Furthermore, most of the on field decisions are taken by the Intervention Chief, thus, it is important for him/her to have as much information as possible. We will consider simple scenarios with just one Intervention Chief, one Incident Area and one or more teams dispatched to that emergency. We have observed the following patterns relevant to the MANET deployment:

- Often direct connection between the Intervention Chief and the members in the area is not possible. They may be some hundred meters apart, which are too much for WiFi technology.
- Teams are dispatched for a mission from the point where the Intervention Chief is. Normally, they return there when the mission is finished to rest for a while.
- There are constraints for the time that a team stays in the Incident Area. These may be externally imposed, such as the autonomy of an oxygen tank, or related to their capacity and the intensity of work they have to accomplish.
- Normally, teams move together to and from the Incident Area. They are assigned a car and use it for that purpose.

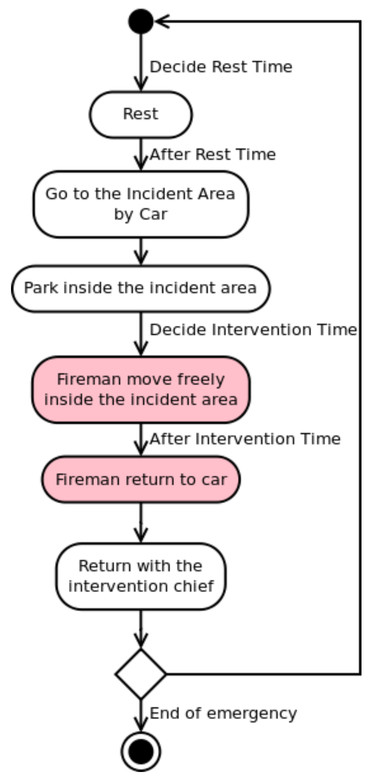

Figure 3. Team mobility activity diagram

Figure 2 shows the GPS traces[1] gathered mainly from vehicles in a chemical accident trial ran by 112/Bomberos de Asturias. Two different zones with people going back and forth are clearly made out. For this paper, we have modeled our evaluation scenarios mimicking this behavior. A rectangular zone is defined as the Incident Area and the Intervention Chief is located at a fixed position outside that zone (e.g. at a 200 meters distance). In each scenario, there may be one or more teams. Each team has a car and four firemen. Figure 3 shows how the behavior of each team is modeled. All teams are in the Intervention Chief area at the beginning of the emergency. Each team stays there for a random time (e.g. 5-10 minutes) and then move by car to the Incident Area. The car parks there and firemen start to move freely during a period of team, the Intervention Time (e.g. 10-25 minutes). Afterwards, they return to the car and come back to with the Intervention Chief. Each team repeats this process until the end of the emergency. Finally, there is a fireman with a camera that

[1] Latitude and Longitude have been modified for privacy issues

moves randomly inside the Incident Area. Our goal is to deliver the video recorded by this node to the Intervention Chief.

4. EMERGENCY ROUTING

From the previous section it can be concluded that the most common network in an emergency is a partitioned MANET. A network route from the camera to the Intervention Chief's node would be an exception. Based on the store-carry-forward paradigm, the movement of nodes can be used to transport video packets. These are called ferry nodes and how to select them is crucial for the successful video delivery.

The goal for a video delivery system under these circumstances is to deliver the video produced by the camera with the minimum delay possible and ensuring an acceptable quality. The Emergency Overlay Routing (EOR) can contribute by finding the best ferry nodes for the video, looking for the minimum delay option and taking into account transmission reliability. In other words, every node that has generated or received video packets must check whether there is a better ferry in its network partition to reach the final destination of the video. In our case, this destination is the Intervention Chief's node, but the protocol can be generalized for any video sink in the network. To make smart routing decisions, it should be beneficial to consider the "a priori" knowledge acquired from the emergency scenarios. This should be a big advantage over other general purpose routing protocols used in DTNs. In addition, topology information, like existent routes and neighbors, is extracted from the network routing protocol OLSR. This is done thanks to a cross-layer component present in our overlay architecture [1]. Finally, remind that all nodes in the network are considered members of the overlay; otherwise some of the protocol mechanisms must be modified.

Bearing this in mind, we have designed and overlay routing protocol tailored for emergencies. It relies in two basic mechanisms that may be performed by any overlay node. On the one hand, the ferry, or next overlay hop, selection, or next overlay hop, uses information gathered from different nodes in the network partition and also from the local node. This function chooses the best ferry from the nodes in the partition. Note that the node performing the selection may not find a ferry better than itself, and then it would keep the packets. On the other hand, there is the protocol itself, which is used by a node to request and answer others.

4.1 EOR Ferry Selection

The goal of this function is to identify the best ferry in a network partition. The input parameters considered in that decision may be:

- **The type of unit carrying the network device.** There may be different types of units that move at different speed or with known movement patterns. In general, a car is more reliable than a firemen for several reasons, i.e. less battery constraints, less probability of breaking the network device during the intervention, or more likely to go back to the Intervention Chief. In addition, they are often parked in the Incident Area, which may imply more stable links. The type of unit can be hardcoded in the devices. We have assigned 0 to the Camera, 1 to Firemen, 2 to Cars and 3 to the Intervention Chief's.
- **The time passed since a node last met the Intervention Chief.** For example, if we assume similar intervention times for all the teams, than those team members that arrived to the Incident Area first will be the first ones to meet the Intervention Chief. Note that PROPHET would consider that the last arriving will be the first to meet the destination. This parameter can be obtained from the routing table of OLSR. A timestamp is saved when a network route to the Intervention Chief's node exists in OLSR routing table.
- **The number of network hops to reach the ferry node.** The longer is the network route, the higher the risk of losing packets due to collisions in the multihop transmission. This is even more problematic if the information sent is not a single packet, but many of them. This parameter can be obtained from the OLSR crosslayer communication too.

In this paper, we consider the following equation to establish the value of a node as ferry. The higher is this value, the better the ferry.

ferry value = (seconds since last encounter · node type) / hops

4.2 EOR Protocol

The Emergency Overlay Routing protocol (EOR) is responsible to collect the information needed for ferry selection. It is running on top of OSLR and resembles to a large extent AODV. It is reactive, i.e., only if a node needs to forward video data it is looking the best ferry in the given partition. If the network partition has been stable since it forwarded previously video data it simply uses the same ferry as before. Otherwise it broadcasts an EOR Route Request (EORReq), which is answered with EOR Route Responses (EORRes). To do this efficiently EOR uses the nodes selected as Multipoint Relays (MPRs) by OLSR. Using a sequence number for each packet in the overlay network, already broadcasted messages are not sent again, avoiding network loops. It is important that all the nodes are members of the overlay, which means that they are able to perform this retransmission. Otherwise, the route request mechanism should be redesigned. EORReq contain the node type and the seconds passed since the last encounter of the node with the Intervention Chief node. Therefore, a node receiving such a message is able to calculate the ferry values of both the requester and for itself. Hence, EORRes are sent only if a node considers itself a better ferry than the route requester.

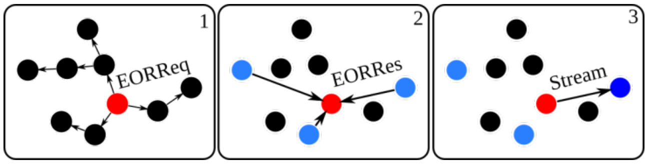

Figure 4. Overlay routing protocol overview

Figure 4 shows the message exchange of EOR. First, a node sends an EORReq (1). These messages are processed by the nodes as showed in the activity diagram of Figure 5. All ERRes received by the overlay route requester (2) are considered to perform ferry calculation. The finally step (3) represents the ferry receiving the stored video stream.

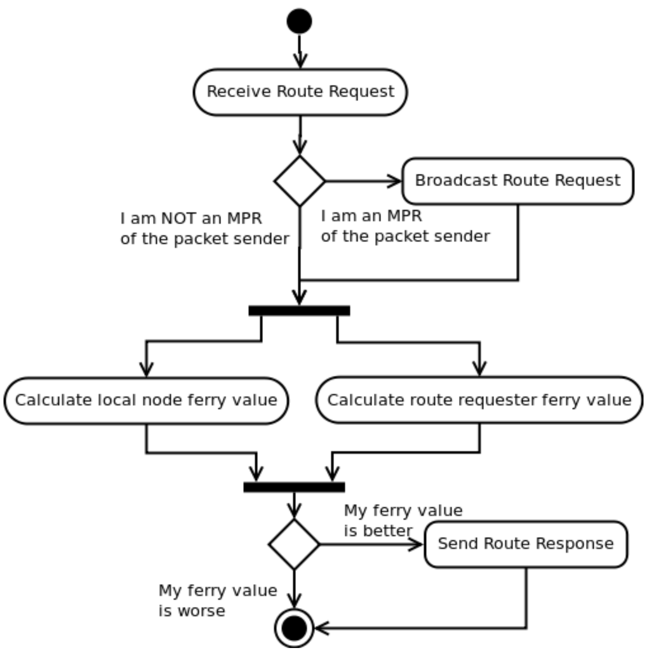

Figure 5. EORReq receiver activity diagram

There is an exception for this behavior: when the destination of the overlay route (i.e. the Intervention Chief) is detected in the partition, it is always selected as next hop. Figure 6 summarizes this in a state diagram for EOR.

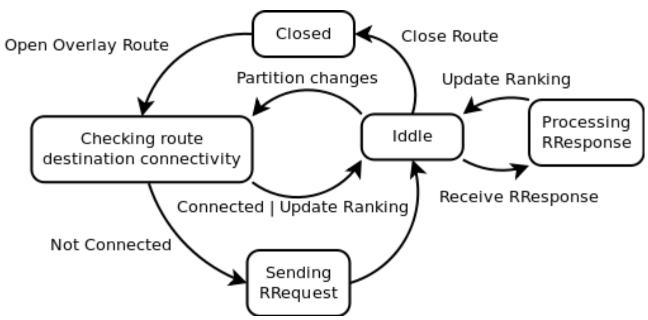

Figure 6. EOR protocol state diagram

In order to test EOR, we have integrated it in a simplified version of the MOMENTUM architecture [1]. The goal is to test its benefits in the system, thus, the rest of the systems provides the minimum required mechanisms to receive and deliver multimedia streams from video applications and to provide store-carry-forward transport. First, video packets are received from a VLC server (simulating the camera) in RTP format. These packets are distributed according to the decisions of EOR, which may select a ferry in the partition. Then, as much packets as possible are sent to it using the network route provided by OLSR until it becomes unavailable or a best ferry is found. A store-carry-forward transport layer is used for this purpose. The transport layer uses UDP as common transport protocol and there are not extra reliability actions (no acknowledgements). In addition, all packets are equally treated (FIFO outgoing and incoming queues). Finally, the architecture gathers information from OLSR with a crosslayer component.

5. EVALUATION

As it was mentioned previously, the goal of the evaluation carried out in this paper is to measure the benefits of the Emergency Overlay Routing Protocol in the store-carry-forward architecture of MOMEMTUM. For that reason, possible reliability or congestion control mechanisms have not be included in the architecture, although we are aware that a MANET is a harsh environment, prone to packet losses. A fully working system must take into account all these issues. To analyze the benefits of EOR against other proposals, we have selected PROPHET because it is a well-known protocol in the DTN community. Furthermore, PROPHET proposes almost an opposite philosophy for selecting ferries. For PROPHET, better ferries are those that contacted the destination recently, it is therefore very different to EOR. Next, subsection explains how it has been integrated in MOMENTUM for that purpose. Finally, subsection 5.2 details the experiments performed.

5.1 PROPHET

We compare the Emergency Overlay Routing protocol with PROPHET. PROPHET is a widely accepted probabilistic protocol for DTNs, which has been drafted by IETF DTNs Research Group[2]. They have also implemented PROPHET over their DTN architecture, but we did not find it suitable for our purposes. To make a fair comparison, using the same store-carry-forward mechanisms, we have implemented the next hop selection of PROPHET inside MOMENTUM. In other words, instead of using the ferry calculation from the Emergency Overlay Routing, MOMENTUM uses the encounter probability defined in PROPHET. The higher is the probability, the better the ferry. The others protocol mechanisms of the Overlay Routing Protocol (Route Requests and Responses) remain the same.

The encounter probability considers past encounters to predict future node connections. So each time the node (e.g. the Intervention Chief) is in the partition the encounter probability for this node is updated as:

$$P = P_{old} + (1 - P_{old}) \cdot P_o$$

Then, on each moment the probability is calculated:

$$P = P_{old} \cdot \gamma^{\text{time since last Pcalculation}}$$

Where P is the current probability of encounter with the given node (in our case the Incident Chief). P_o is a constant representing the initial probability. P_{old} is the value of last probability of encounter calculated. γ (gamma) is the aging constant and it is modified by the time passed since P was calculated the last time Values of gamma and the initial probability have been taken from the values recommended in [12].

$$P_o = 0.75$$

$$\gamma = 0.98$$

Finally, for simplicity we have not implemented the transitivity properties of PROPHET. We keep this in mind for future work, but since the Emergency Overlay Routing protocol is also suitable of adding transitivity and it is not considered in this version; we believe this is a fair comparison.

5.2 Experiments

Real time simulation over ns-3[3] has been used to make the experiments. Each ns-3 network node is connected to a virtual machine[4] through virtual network interfaces (taps). Each virtual machine runs MOMENTUM, which is implemented in Java, and an OLSR daemon, apart from the monitoring processes (tcpdump,

[2] http://www.dtnrg.org/

[3] http://www.nsnam.org

[4] http://lxc.sourceforge.net/

sar) or the video server (VLC) in the camera node. The configuration of OLSR is the default provided in its RFC [6]. The stream sent by VLC and captured by MOMENTUM in the camera node is a version of the Coastguard sequence taken from the Video Trace Library[5]. It has been encoded in MPEG-2 at 500 Kbps and repeated in a loop until the end of the scenario. All of this is run on a single machine with enough resources to carry out the simulations.

The ns-3 scenarios reproduce the mobility described in Section 3. Each MANET node has a device with the DSSS 11Mbps version of 802.11b. The Friss propagation model is used for losses and the Constant Speed propagation model for delay. To obtain realistic communication ranges the parameter RxGain of the WiFi physical layer was set to -16, which means a range of slightly larger than 100 meters. There is one node for the Intervention Chief and another for the camera. There are also nodes for the firemen and the cars. These are grouped in teams of 4 firemen and 1 car. Table 1 describes the two types of scenarios considered. In the Connected one, there may be network routes between the camera and the Intervention Chief. Two teams are deployed and a total of 12 nodes. On the contrary, a network route between the camera and the Intervention Chief is nearly impossible in the Sparse scenario. There are 4 teams, thus, 22 nodes. Times of Intervention and Rest were calculated as a uniform random variable of 5 to 25 minutes and 5 to 10 minutes respectively. The total duration of the scenario was 100 minutes. Each type of scenario (Connected and Sparse) was repeated using 5 different seeds for the random numbers selection. This generates 5 different mobility patterns and different time choices for nodes and teams. The Connected scenarios were generated using 1 to 5 as seeds. 6 to 10 were used for the Sparse ones. Each of them is repeated 3 times for each routing protocol.

Table 1. Experiments summary

Scenario Type	*Connected*	*Sparse*
Incident Area	200x200 m^2	1000x1000 m^2
Distance to the Incident Area	100 m	400 m
Teams	2	4
Intervention Time	U [300, 1500] s	
Rest Time	U [300, 600] s	
Node Range	~100 m	
Duration	6000 s	
Seed	1 to 5	6 to 10
Runs	3	

Two metrics are considered important: the amount of video packets delivered and their total delay. Both can be easily measured end-to-end using traffic traces. Their comparison should provide enough information to compare the two overlay routing protocols.

6. RESULTS

Figure 7 summarizes the results of the previously mentioned experiments. It shows the Experimental Cumulative Distribution Function (ECDF) of all the video packets in all the scenarios. They have been classified in four groups, depending on the overlay routing protocol and the type of scenario, so each line gathers information of 5 variations of the same scenario (using different seeds for the random number generation) and 3 runs for each variation. The delay of lost packets, i.e. packets that did not reach the Intervention Chief's node, is considered as infinite. Therefore, the figure represents delay and packet losses showing that EOR outperforms PROPHET in these scenarios when the two metrics are considered. Using the same transport protocols and architecture (MOMENTUM), our overlay routing solution is more likely to deliver a packet and to do it with a lower delay. The second important outcome is that the rate of packets delivered is extremely low (below 10%). It is even lower in the *Sparse* scenario, with delivery rates around 1%.

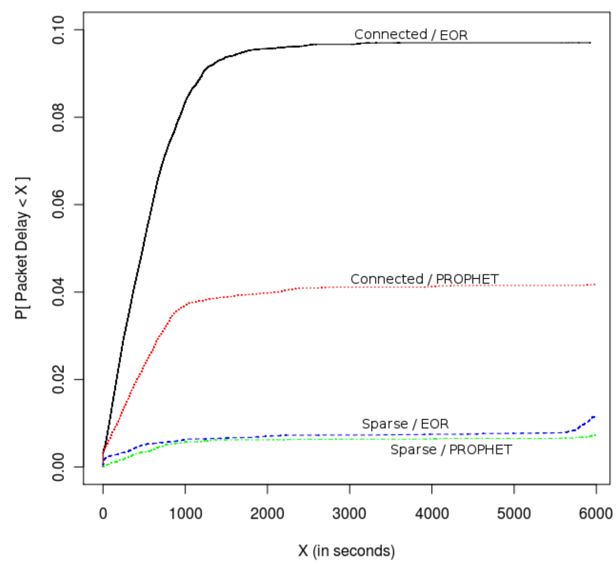

Figure 7. Video packets delay ECDF

Table 2. Numerical comparison

Overlay Routing	**Packets Delivered**	**Delivery Rate**	**Mean (seconds)**	**Standard Deviation**
Connected EOR	341341	0.097	552.0024	465.5865
Connected PROPHET	145118	0.041	587.5564	716.2637
Sparse EOR	40718	0.011	2389.3530	2561.5905
Sparse PROPHET	25891	0.007	1211.4365	1786.2271

Table 2 summarizes these results numerically, but only taking into account the video packets successfully delivered. They confirm that the EOR performance surpasses PROPHET in the *Connected* scenarios. In total number of packets delivered and delivery rate, EOR doubled the results obtained by PROPHET. Moreover, video packets are delivered, in average, one minute before. The standard deviation is lower too. However, numerical results for the *Sparse* scenarios are not so promising at first sight. Mean delay, and also its standard deviation, for PROPHET is lower. It is not possible to conclude a better performance of PROPHET, because it only delivers a bit more than half the packets of EOR. This just indicates that the extra packets delivered by EOR arrive slower than the others.

[5] http://trace.eas.asu.edu/

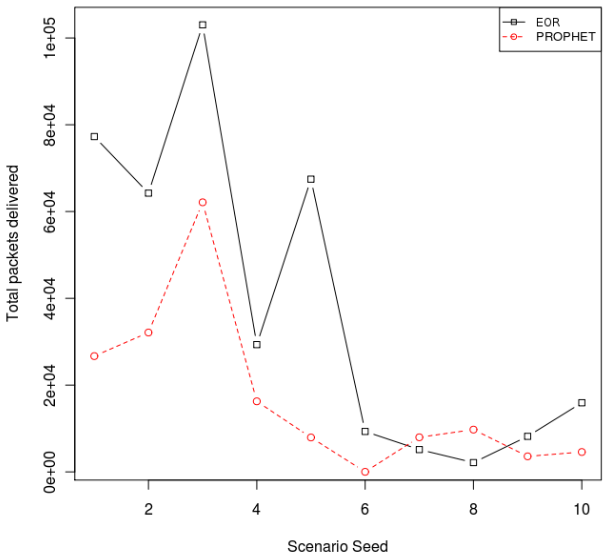

Figure 8. Video packets delivery in each scenario

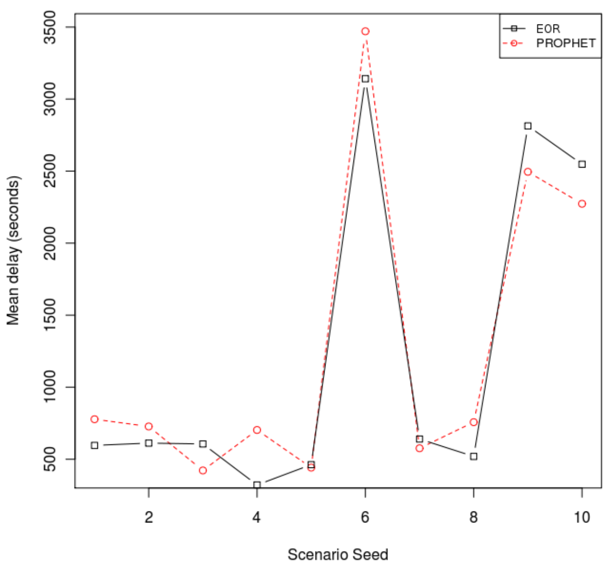

Figure 9. Video packets mean delay in each scenario

Ten different mobility scenarios have been evaluated, five of them *Connected* (seeds 1 to 5) and five of them *Sparse* (seeds 6 to 10). Figures 8 and 9 compare the performance of the overlay routing in each of them. On the one hand, Figure 8 shows the total number of packets delivery and packets from the 3 runs have been added. On the other hand, Figure 9 compares the mean delay averaging all the packets delivered in the 3 runs. In the *Connected* scenarios (seeds 1 to 5), packet delivery of EOR always outperforms PROPHET. Our solution is able to transport more than double the packets in some of them. Moreover, mean delay is lower or very similar. In the *Sparse* scenarios (seeds 6 to 10), the quantity of video packets received by the Intervention Chief's node suffers a significant drop for both approaches. EOR stills deliver more packets in three situations. Delay is also very similar in both approaches.

A more detailed analysis of the results reveals the reasons for the higher reliability and lower delay of EOR in the *Connected* situation and the not so good performance in the *Sparse* one. The former Incident Area size eases communication between the Camera node and the others in the area, including car nodes. Considering that the ferry calculation favors cars against other nodes (the have a higher node type value), EOR tends to select them as ferries. In the 200x200 meters Incident Area, the Camera node may find a 1-hop or 2-hop transmission with a car easily. Since cars are parked in the area, routes are more reliable. On the contrary, PROPHET ferry selection eventually turns out in less reliable transmissions, because cars are considered at the same level that other nodes. In the *Sparse* Incident Area is more difficult to find a these reliable transmissions between the Camera and cars. Both protocols send a lot of packets through transmissions between nodes more likely to move. Furthermore, there are more nodes (22) so large network routes are more frequent. Therefore, packet losses are higher than in the *Connected* case.

Although we consider these numbers promising, the overall performance of the system is still far from the desirable solution. The percentage of packets eventually delivered to the client is very low. Packets are not discarded by MOMENTUM, therefore, the explanation for this is in the lower layers and the lack of connectivity. Some well-known causes are:

- In many sparse scenarios, nodes connect infrequently. Therefore, sometimes it is just not possible for the camera to find a suitable ferry for every video packet generated. The delivery rate metric we have considered takes into account all the packets produced by the server, which includes those that the camera node was not able to forward too. Sometimes packets are not lost, but never sent by the camera.
- Packet collisions are common in wireless ad-hoc networks and RTS/CTS mechanism does not always perform as expected [15]. Moreover, MOMEMTUM nodes send packets continuously that will compete among them over multi-hop routes. This is also aggravated if several nodes try to send packets to the same node, which is a likely situation since it could be selected the best ferry in the partition.
- The information provided by the network routing protocol (OLSR) is not real time. This protocol carries out periodical queries in the network to discover neighborhood and routes. If a route changes or a node disconnects, it is not immediately detected. Of course, lower times for discovery broadcasts could be configured, but assuming the higher network consumption by OLSR. This impact has been analyzed by others [16].
- Independence of ARP and the routing protocol also contributes to losses. Packets sent during ARP resolutions are normally lost [17].

7. CONCLUSIONS AND FUTURE WORK

The work presented in this paper gives relevant insights about video delivery in MANETs for emergency and rescue situations. First of all, mobility in these scenarios is thoroughly studied and modeled with the purpose of building realistic evaluation scenarios. This knowledge is also used to design a tailored overlay routing protocol for emergencies. Results of the experiments show despaired performance in a connected and sparse Incident Area, but provide a promising outcome for future work. Although a few weak points have been identified, this first version of EOR outperforms PROPHET in the overall evaluation. Moreover, transport reliability has been identified as a key factor to build a successful video delivery system for MANETs. The extremely high packet loss rate found in all the scenarios make necessary to invest a great deal of future work in increasing this reliability.

Thus, future work in this area will consider two fundamental areas. On the one hand, the EOR protocol can be improved by considering other factors into the ferry selection. These could be related to the current network performance, such as considering the available bandwidth in the route to a node in a given moment. In addition, past successful transmissions between the ferry candidate and the Intervention Chief's node could be taken into account. If a ferry was effective in the past, it may be effective in the future too. On the other hand, it is mandatory to increase the reliability of the overlay.

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