Delay Tolerant Streaming in Rescue Scenarios

Requirements Analysis and Resulting Industrial Issues - Version 2

Daniel Rodríguez Fernández[1], Stein Kristiansen[1], Morten Lindeberg[1],
Ovidiu Valentin Drugan[1], Sergio Cabrero Barros[2], Thomas Plagemann[1],
Vera Goebel[1], Ellen Munthe-Kaas[1], Xabiel García Pañeda[2] and Knut Omang[1]

[1] Department of Informatics, University of Oslo, Norway,
{dani, steikr, mglindeb, ovidiu}@ifi.uio.no,
{plageman, goebel, ellenmk, knuto}@ifi.uio.no,
[2] Department of Informatics, University of Oviedo, Spain,
{cabrerosergio,xabiel}@uniovi.es

Abstract. In emergency intervention and rescue operations, the coordination and collaboration of the rescue personnel is highly important for the success of the mission. Data networks formed between the devices carried by the rescue personnel can provide the means for collaboration and coordination on the operation scene. Unfortunately, the unforeseeable conditions and characteristics (e.g., size of the scene, availabilities of access ways for the rescue personnel, availability and status of the infrastructure) of the rescue operations can hinder (e.g., intermittently unavailable network infrastructure) and disrupt (e.g., network partitions) communication of data networks. Even in these adverse conditions coordination and collaboration need to be enabled between the participants of the rescue operation. In this technical report we analyse the usage of streaming services (data, audio and video) to improve coordination and collaboration tasks in rescue and emergency operations. We present a detailed requirement analysis for middleware services that support streaming of data, imposed by this application domain from a research and an industrial perspective. For this purpose, we present two rescue scenarios, which helped us perform the requirements analysis for supporting streaming in intermittently connected networks. Additionally, we also present an example from a middleware for streaming voice traffic within large organizations with multiple working sites. Although these examples might seem different, they have similar requirements considering the availability and awareness of network resources.

1 Introduction

The purpose of this technical report is to present background information and requirements analysis for the development of middleware solutions that support multimedia streaming (i.e., data, audio and video) in dynamic networks used during rescue operations. As basis for our requirements analysis we use example scenarios where we outline the need for middleware solutions which are aware of the underlying network infrastructure and use this information in order to improve the multimedia streaming. A central concern of our analysis is how such a system could react in the presence of network disruptions and how to provide delay tolerant mechanisms to the middleware. We address these problems from two different perspectives. First, we present an analysis of the issues faced by the middleware in order to enable streaming over delay tolerant networks. Second, we present issues faced by streams when crossing multiple networks with different security requirements.

Delay and disruption tolerant networking [1] is a research area that aims to develop protocols for "disconnected" networks, i.e., where at a given time there is no direct path from sender to receiver, but such a path may come into existence later. Application domains are sensor networks, vehicle area networks, first response for emergency and rescue operations, and also interplanetary communication networks. At a first glance, delay tolerant streaming seems like a contradiction in itself. In order to demonstrate its use and need, we use emergency and rescue as the case study for our project, but the results will be useful even for other application domains.

Rescue and emergency operations require a large amount of communication and coordination among the rescue teams and personnel. Today, much of this communication is done by face-to-face meetings, which consume valuable time. Audio Visual (AV) services, like Voice-over-IP (VoIP) and video conferences, would be much more user friendly, especially when being under stress and pressure. In the Ad-Hoc InfoWare project [2] and the MIDAS project [3,4], we are developing middleware services for information sharing to increase the communication efficiency in emergency and rescue operations. While the results of these projects are very promising, it should be noticed that middleware services handle discrete data only.

Many of the devices that are needed to realize AV services in ubiquitous environments exist already today, such as head mounted cameras, (wrist)-wearable computers, lightweight microphones, and screen projection in

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Research Report no.: 418
Department of Informatics, University of Oslo, Norway
ISBN: 82-7368-382-6, ISSN: 0806-3036
August 2012

glasses. However, the communication path between these devices, i.e., the network represents a hard problem. It is not possible to determine a priori which networking infrastructure will be available in such operations, because it might be partially or entirely destroyed. Therefore, a Mobile Ad Hoc Network (MANET) that is established by the rescue personnel's devices might be the only network. However, if additional networks are available they should be utilized, because AV services have non-neglectable resource demands and the end-users have certain quality demands. To meet these demands in heterogeneous, mobile, and unstable networks in which short and long term network partitions can occur, is very challenging.

The Delay Tolerant Streaming Services project (DT-Stream) [5] aims to provide new solutions that enable AV streaming services over heterogeneous, mobile, and unstable networks which are found for instance in emergency and rescue operations. In this technical report we identify four sub-goals to be achieved, which are addressed in four distinct PhD theses: (1) support for heterogeneity both at device and network level, (2) support for adaptation in dynamic networking conditions, (3) delay tolerant streaming transport, and finally (4) tools for development and performance evaluation. We present in Section 5 a complete requirement analysis where we describe the requirements addressed by the aforementioned PhD topics. Additionally, we analyse also other requirements for enabling streaming over networks prone to disconnections, which have not been directly addressed by the four aforementioned PhD theses. These requirements have been partially addressed by master theses related with the DT-Stream project.

During a rescue operation a stream may need to be routed by nodes belonging to different organizations, to traverse different networks (i.e., caused by disconnections), and cross different gateways between networks (i.e., pass through overlapping network gateways). This problem is similar to the problem faced by streaming of voice data in corporations which have offices at different locations and use of different network providers. The common solution for these problems is to discover the best possible routes considering both space (i.e., distance of intermediate paths segments) and time (i.e., availability in time of the path segments) connectivity. To do this one needs to describe the routes using different attributes which can describe the time/space evolution for different atomic segments of the routing path and of the available bandwidth, e.g., physical distance between nodes, number of hops, or length of hops, past and future availability periods of segments of a path.

The rest of this technical report is organized as follows: in Section 2 we present our assumption for devices, networking technologies, and node mobility in rescue and emergency operations. In Section 3 we present two possible accident scenarios relevant for the DT-Stream project. These scenarios are different in magnitude, area, and number of people that may be involved (see Section 3.1 and Section 3.2). After presenting the scenarios, we look at the commonalities and differences of the scenarios (see Section 3.3). We also present in Section 4 the two aforementioned industrial application domains: (1) audiovisual streaming services in rescue and emergency operations and (2) VoIP services for multinational corporations in the Internet. Then, in Section 5, we describe in depth the requirements for a delay tolerant streaming system. Finally, Section 6 concludes this technical report.

2 Assumptions

In emergency and rescue operations, rescue personnel cooperate to save lives and to limit the damages on, e.g., nature, buildings, and infrastructure. The rescue personnel has assigned tasks that they perform for saving human lives and minimize material damages, such as carrying injured persons to a safe place, providing food, water and blankets, doing examinations, perform investigations, etc. To organize such an effort, people involved in the operation need to communicate; they must inform each other about the performed, on-going and planned tasks, discuss what decisions to make, inform about decisions made, what to prioritize, make organizational decisions about usage of work forces, distribute work tasks, as well as exchange information and provide information to the public. If they cannot communicate directly, they can use mobile devices to exchange information, i.e., communicate through audio-video streams or data transmission. Sometimes audio streams are the best means of giving an order or provide feedback, while other pieces of information, e.g., a map and a photograph, cannot be communicated in the same way.

Communication: An important characteristic for a rescue operation is the heterogeneity of devices used, organizations, communication lines (i.e., information flows), applications, and the rescue operations themselves, which pose challenges to developing a middleware system for this kind of environment. Most communication (i.e., flows of audio-video and data streams) is hierarchical and takes place between the members of a group. In a larger group, the group leader is the main target for communication and his device may take the role of communication gateway with other groups. Additionally, group leaders of different groups communicate periodically with each other. This is similar to real life communication in rescue scenarios, i.e., team members report to the team/group leader, and group leaders coordinate their actions. This also conforms to the communication models, i.e., mesh and stellar, and the distribution of communication sources, i.e., random and alternate, described by Aschenbruck et al. [6].

Devices: The current handhold devices, e.g., PDA's and smartphones, have become real computing devices with extendible storage capabilities and enough processing power to run fully-fledged, multi-threaded operating systems. This enables them to run the set of potentially complex protocols and applications needed to be developed to satisfy the requirements of distributed emergency applications. In addition, they may have multiple wireless networking interfaces, which allows them to be used as multihomed devices, e.g., perform gateway tasks between networks, and by that improve the information exchange. Many mobile devices are now position enabled, i.e., with Global Position Service (GPS), which allows applications to become aware of the location of the devices. Unfortunately, localization services cannot work inside buildings or tunnels.

Network infrastructure: To make it easier to develop distributed emergency applications, middleware services are needed. The middleware must be able to enable the application to adapt to the underlying network conditions. These conditions can vary between the worst-case with no infrastructure available to an ideal and stable case where the network infrastructure is available and there is enough bandwidth available. Unfortunately, we cannot assume stable conditions of the network. In some parts of the rescue scene the devices may be in an infrastructure mode, others in ad hoc mode. In infrastructure mode, they may be connected to the 3G/GSM network or to base stations using IEEE 802.11 (WiFi) [7] or IEEE 802.16 (WiMAX) [8]. In ad hoc mode they can be connected using for instance WiFi [7] or IEEE 802.15.1 (Bluetooth) [9], and sensors can send data to a sink using IEEE 802.15.4 (ZigBee) [10]. In the absence of a network infrastructure nodes can be connected in ad hoc mode and can form a Mobile Ad hoc Network (MANET). On a rescue site there may be more than one MANET, and during the running of the operation there may be network partitions and merging. Devices may be turned off due to battery drain or they may be located out of range of other nodes or base stations. Unstable conditions are rather the rule than the exception. In these fluctuating conditions one cannot assume an end-to-end connection between source and destination. In such cases the applications must tolerate disconnections and delays in data transmissions. Another main challenge is limited resources, especially bandwidth. We can assume a high heterogeneity of devices (i.e., ranging from laptops to wireless sensors) on the scene and usage patterns (i.e., different roles in the rescue operation have different communications and usage requirements). Fortunately, in many cases mobile devices, e.g., laptops, smart phones or PDAs, have multiple network interfaces that allow them to be connected to different networks at the same time, i.e., are multihomed. These multihomed devices can take the role of gateways between the different networks and by this increase the connectivity in the rescue scene. An example of a network used in a rescue scenario, can be seen in Figure 1 where there are three disconnected MANETs using different network interfaces to communicate. Additionally, in some cases the only way to achieve connectivity is for devices to physically move between two networks.

User Mobility: The mobility of people and vehicles in an emergency and rescue operation changes from mission to mission. The type of emergency, the size of the hit area or the existence of victims are among the factors that determine it. Emergency services respond to many different types of events, such as urban or wild fires, traffic accidents, chemical escapes and so on. Different vehicles and tools are deployed depending on the emergency type. For example, water pumps are meaningful when there is fire involved, but not to rescue a victim trapped inside a car after an accident. Depending on the type of emergency, severity is measured with criteria such as the size of the area affected, the number of victims, the potential risks for population, and so on. The severity of the incident determines the amount of human resources deployed in an incident, as well as for how long they are deployed. More resources will be needed in more severe emergencies. The number and sort of units deployed in an emergency are crucial to determine the overall mobility of an emergency and rescue operation. Due to the heterogeneity mentioned, an exact definition of mobility for all emergency scenarios seems to be a complex task. Nevertheless, the analysis of GPS traces, emergency plans and emergency services' know-how reveals mobility patterns that are present in most situations.

Emergency services establish different zones and locations to organize themselves. One of the first steps in emergency response is the establishment of a Command and Control Center (CCC). If the emergency is severe, sometimes more than one are needed and hierarchically organized. If there are victims involved, there is often a point where they are attended, which may be far away from the CCC. These points are used for logistic purposes

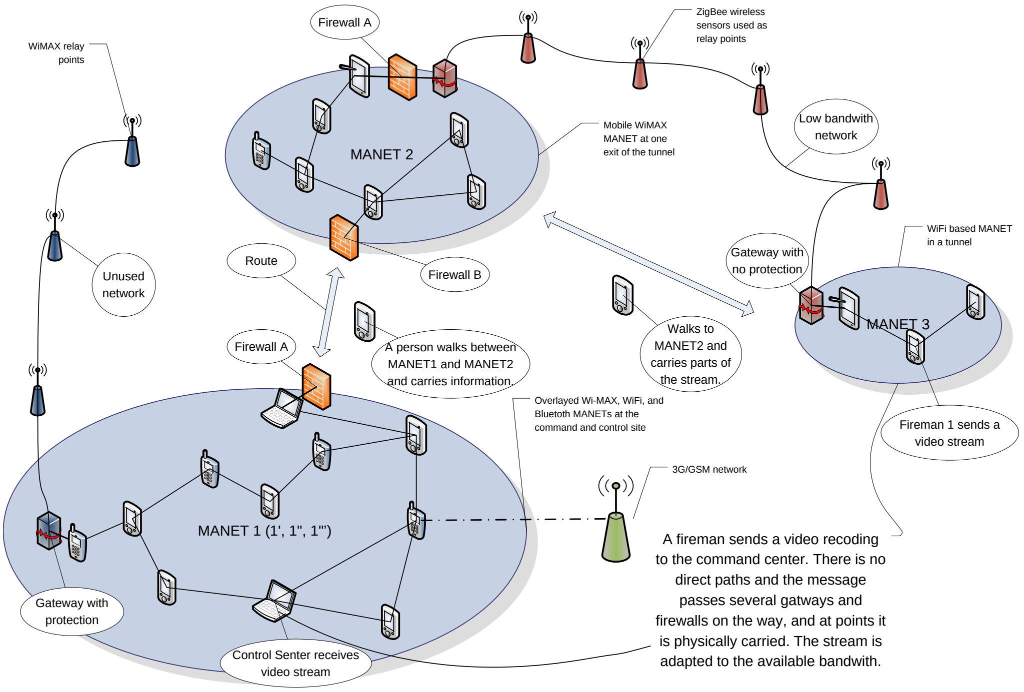


Fig. 1. A scenario of a delay tolerant network used in a rescue operation.

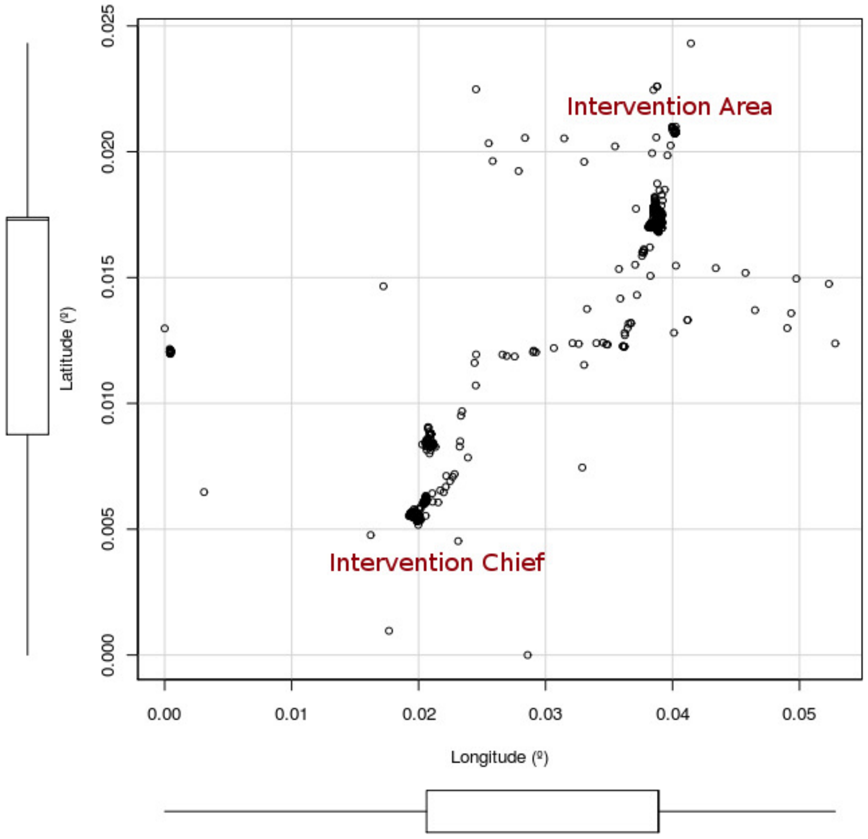


Fig. 2. Vehicle position during a chemical accident trial.

and always located in a safe area, hundred or thousand meters from the core of the incident. The division in zones of the affected area is confirmed by several sources, such as the Disaster Area Mobility Model by [11]; manuals for fire extinction tactics, e.g. [12]; and emergency plans like [13]. Sometimes the access to a zone is limited to the members of a specific service. For instance, firefighters are the only one allowed to go inside the incident area [13]. If a victim has to be evacuated from this area, the firefighters will carry him to a safe point where he can be collected by a medical service. Therefore, the personnel deployed move from one zone to another carrying out different tasks. Some of them do it in a deterministic way, e.g. ambulances evacuating victims, and some others more freely, e.g. firefighters going back to the CCC to rest. Finally, movement between zones and inside zones is sometimes done in groups. A team of people shares a vehicle and has a task that requires more than one person. The members of a team tend to move together for security and efficiency in their duty.

The chemical accident trial carried out by the “112 Asturias/Bomberos de Asturias” (Fire Department in Asturias, Spain) illustrates all these points. The event was a simulated escape of a toxic gas in a chemical plant that affected a wide area. Fire departments, police and medical services were involved. The incident area covered the place where the escape took place and the surroundings. Firefighters had to stop the escape and evacuate the victims. For that purpose they established a CCC a few hundred meters away from the escape, in a safe place according to wind direction. Figure 2 shows the GPS traces of some of the vehicles and firemen working in the gas escape and the CCC. Two separated zones are clearly observed. Firefighters move back and forth constantly. A few kilometres away there was a higher level CCC where the different emergency services met. Medical services established an ambulance parking point to collect intoxicated people that was gathered by firefighter vehicles. This trial is a clear example of the patterns mentioned, because there were clearly established zones, frequent movement between them and firefighters working in teams. Nevertheless, there are other situations where theses patterns are not so clear. For instance, we have analysed wild fires that last several days and where units are more static.

Fortunately for the study of emergency scenarios mobility, the usage of a Geographical Information System (GIS) is becoming common in emergency services. People and vehicles are being equipped with GPS devices that track their location. If this information is made available to researchers, the advance in this subject will be significant. However, the access to such traces is difficult due to administrative or privacy issues. When they can be obtained, some precautions must be taken in their analysis. GPS raw data is meaningless without the understanding of the emergency where it was gathered. Researchers should collaborate with emergency services to understand the traces. In order to extract relevant information, some facts are helpful such as the type of incident, the association of traces and units and the task it was performing. We have also found it very instructive to ask for a reconstruction of the full events from a officer.

In conclusion, user mobility in emergency and rescue scenarios is heterogeneous, but several important properties are present in most situations. The division of people in zones and the movement between zones have implications for the ad hoc network in these scenarios. The different areas can be large enough to provoke network partitions with technologies such as 802.11. However, communication between them is possible if the devices moving from one area to another are used to carry the information (following the store-carry-forward paradigm).

3 Scenarios

In this section, we describe from a “non-technical-perspective” two scenarios: a railway accident scenario and an underground transport accident. For each scenario we present our assumptions made about the communication and devices used during a rescue exercise. In Section 3.3, we examine the presented scenarios to find commonalities and differences useful in a requirements analysis for designing middleware to support delays in streaming (i.e., data and audio-video) in such scenarios.

3.1 Scenario: Railway Accident

A serious railway accident in inaccessible terrain can be caused by, e.g., landslides, technical failure, sabotage or collisions. If the accident is at a mountain pass, it will normally be in areas with limited infrastructure and scattered buildings. As every train can carry close to 500 passengers, such an incident will cause acute, extraordinary need for transportation, and an immediate need for transporting injured passengers from the accident site to a collection site for pre-hospital treatment, or directly to a hospital. The rescue service has established routines for this, and there are helicopters for airlifting patients out of inaccessible areas. In addition, there will be a need for transporting other (not injured) passengers to an appropriate collection place, and alternative transport bypassing the accident site has to be established for a period. There may also be requirements for assistance in delivery of equipment to the accident site after the evacuation phase. Relevant organizations and governmental departments have certain responsibilities and roles in connection with limiting damage of accidents as is described in Sanderson et al. [14]. The consequences of such an accident will have a great impact on the humans, economics and environment of the area (e.g., there may be a large number of casualties and local pollution, e.g., oil spill). In cases of trains carrying goods and passengers through (densely) populated areas, the consequences may be catastrophic, with a large number of casualties both injured and dead.

The railway accident in this scenario is located at the Rørosbanen railway, in a tunnel at a mountain pass. The area has weak infrastructure and a need for special services. The accident is caused by a landslide just outside of a tunnel; large blocks of stone are lying on the tracks. The landslide has weakened the ground beneath the tracks, and the tracks are partly broken. The temperature is minus 10 degrees Celsius, with deep snow in the area. A nearby mountain lodge can be used for collecting evacuated train passengers. The lodge can be accessed by a mountain road, which can be opened up for accessing traffic. The railway tracks cannot be used due to the damage to its structure and danger of repeated landslides, and the fact that it is blocked. A train between Oslo and Trondheim, carrying about 400 passengers, runs into the rocks when coming out of a small tunnel, it goes off the tracks and the train engine and some of the carriages are lying on their side. The train is partly inside the tunnel. The locomotive has gone off the tracks and is lying on its side, smashed. There are a number of casualties in the train. Some people in shock have walked out of the tunnel themselves. Others are still inside the carriages, some trapped under luggage and train parts due to the crash. One of the train carriages is completely crashed. The train has a diesel locomotive. Diesel cannot take fire unless it is already preheated to a temperature above a certain point (depends on the diesel, say about 60-70 degrees Celsius). Unless exposed to open flame or spark, it will not take fire until a temperature of 235-245 degrees Celsius, at which point it will light immediately without any spark or open flame [15]. This means that the diesel can ignite in this scenario either if nearby fire heats it up to its critical temperature, or preheated diesel catches fire from an open flame or sparks from a nearby fire or explosion.

After the incident, the train driver follows the appropriate procedure, and reports the incident and location to the train control center. The person on duty at the control center contacts ambulance and fire department through an emergency call, starts the internal emergency procedures for Jernbaneverket [16], and organizes for other trains on the same track to be kept on hold (waiting), stopped, or redirected if possible. The emergency central is alerted, and a rescue operation is initiated. The emergency central and participating organizations start gathering information about the area and available resources, e.g., maps of the area, weather condition information, available personnel and equipment, etc. All personnel get relevant parts of this information to their devices before/on leaving for the accident (briefing personnel). The incident is reported to the rescue service. Rescue Coordination Center (RCC) together with Rescue Sub-Center (RSC) launches/starts a rescue operation to evacuate those in need of acute medical treatment. Remaining and not injured, or slightly injured, persons are, due to weather conditions and terrain, also in acute danger and need attending by the rescue services.

The tunnel, rocks, and train carriages hinder communication. The mountain pass is a difficult accessible area, which puts extra demands and limitations on rescue operation, personnel, and equipment. The low temperature and the deep snow in the accident area create extreme conditions, which in addition to implications for the rescue operation also may have an impact on how well the rescue instruments and tools will function. There is also a danger of repeated landslides in the area. The lack of accessibility by road means that special vehicles, such as snowmobiles and helicopters, are needed for evacuation and other transport in/out of the actual accident area (both to the collection place and directly to hospital). As noted above, there is a high risk of fire, especially as the crash may have caused diesel from the locomotive to spread outside of the tank and this may have created a kind of “diesel fog”, consisting of very fine diesel drops and oxygen, which may ignite very easily. Also mentioned, diesel itself needs to reach a certain temperature before it will take fire. Thus, avoiding fire to spread close to the locomotive is very important. Sensors can be placed around the diesel tank and locomotive to monitor the temperature so personnel can be alerted in case of increased danger of fire or explosion.

The leader of the team arriving first has the role of temporary rescue operation leader or on-site-commander (OSC). Once the police arrives, the higher ranked police officer will take this role. The OSC sets up a place of command, and tries to get an overview of the situation based on information from the train control center, and the train driver, e.g., the number of wagons, passengers, any goods, etc. The OSC coordinates equipment and personnel as they arrive. As the fire brigade arrives, firefighters are going inside the tunnel. They are wearing sensors that monitor their heart rate and temperature.

All personnel are involved in evacuating people from the carriages, and they are moved away in safe distance from the wreck. Medical personnel start evaluation of medical state, register all persons, and mark each with a color tag showing the degree of injury and need for acute treatment (red: acute/immediate, yellow: not immediate, green: no injury). They are then transported to the mountain lodge for further treatment. Sensors are placed on patients in stable conditions to monitor their state (e.g., heart rate, oxygen flow, blood pressure, temperature, etc.). Team leaders receive information about the location of their subordinates. They may have received a task list and can check out the tasks as they are completed. This information is then sent to the work leader. The police start gathering evidence to investigate causes of the accident.

Communication during a Rescue Operation: Sharing information in this scenario may be very useful for personnel. In the absence of a working network infrastructure, MANETs can provide the needed infrastructure such that devices can communicate. If a MANET is to be used, nodes and routing daemons will have to be started up at the site to setup the MANET. The devices connect on arrival and become nodes in the network. Nodes inside the tunnel cannot communicate with nodes outside the tunnel, and because of hindrances, there is limited communication inside the tunnel. In addition, given the activity on site and possibly poor infrastructure in the mountain area, there may be frequent network partitions and a node may be disconnected from the network for periods. The possible frequent partitions in MANETs require adopting also solutions specific to Delay Tolerant Networks (DTN) [17] for communication between nodes in different partitions.

There are a number of possible communication flows in this scenario. We list three examples of such communication flows or possible audio-video streams here: The first is among team members from the same organization. For example, doctors can share registration and medical information about patients they are responsible for, or they can send audio streams that request feedback or inform about patients status to other medical personnel. Firefighters can share temperature information from sensors in the monitored area, or stream video with access paths and danger points in the tunnel. The second example is among members of task oriented ad hoc teams (can be cross-organizational or not), e.g., a team targeted for going through a certain train carriage to report situation, etc., consisting of paramedic, police, firefighter, possibly rescue dogs (to find people trapped or hidden in the wreck). Audio streams can be used when the firefighters inform the paramedics about the number of possible casualties in the tunnel. The third example is communication between different levels in the rescue operation organizational hierarchy, e.g., RSC and OSC, team members and team leaders, and team leaders and OSC. For example, firefighters can send an audio-video stream to the OSC with the situation in the tunnel and ask for feedback.

The landscape where this accident happened, has a big impact on the way the topology of the communication network is shaped; specifically it can create partitioned networks such as:

- Inside the tunnel, formed by devices carried by the rescue personnel and sensors placed in the tunnel (for example, in Figure 1 the personnel carrying the devices that form “MANET 3”).
- At the unblocked end of the tunnel where most of the teams may be situated and active (for example, in Figure 1 the personnel carrying the devices that form “MANET 1”). For example, first aid might be given to the injured here, the on-site commander center may be situated here, or resources needed during the rescue operation may be stored here.
- At the blocked end of the tunnel where personnel try to clear the tunnel opening.
- At the lodge where there is established a transportation hub for taking the injured to the hospital and distributing resources for the accident scene (for example, in Figure 1 the personnel carrying the devices that form “MANET 2”).

In such a network, data and audio-video streams must take advantage of all possible “transport” means and adapt to the current available bandwidth in order to be transmitted between network partitions. This requires finding the best way of using the available resources on the nodes to run services that help the rescue intervention. In addition, the mobility of the nodes must be used in order to transmit data between the network partitions.

3.2 Scenario: Subway Station Accident

The subway station accident described in this scenario is located in the Jussieu underground station of the urban metro system of Paris, France. It is based on a scenario description provided by the “Regie Autonome des Transports Parisiens” [18,19,20]. The area can be considered to have a good and well-maintained infrastructure. Certain communication services might be available in the metro station but may be missing in the tunnels between the stations.

There are two trains in the scenario: Train 1010 going east that is about to stop at Jussieu station, and Train 1020 going west that stops on the opposite platform. The driver of Train 1010 sees smoke coming out of car number 2. He immediately reports the fire to the operation control center (PCC) and tries to give supplementary information about the fire, such as where the fire is located. He requests the passengers to step out of the train. The PCC turns on the fire alarm and shuts down the traction power for the trains in the area of the Jussieu metro station. The fire alarm is automatically reported to other devices in the area, such as the mobile device of the driver of Train 1020. The PCC asks the passengers to evacuate the Jussieu metro station and provide traffic information for passengers on nearby stations. The PCC passes the information about the accident higher up in the hierarchy to the operation duty inspector (IPEX). The drivers of trains 1010 and 1020 take pictures with their mobile devices; these are automatically annotated with correct metadata, e.g., date, time, incident X, Jussieu metro station. The pictures are sent to PCC, which can use this additional information to decide which intervention procedure is most appropriate in this situation. Smoke removal systems need to be started, but for the Jussieu metro station the control is at Gare d'Austerlitz metro station which is notified by IPEX. Since the smoke will propagate through the tunnels towards the two adjoining metro stations (i.e., Cardinal Lemoine and Gare d'Austerlitz) need also to be evacuated. Communication with the local staff at these stations is also important. The IPEX calls for external support from different actors, e.g., fire department, ambulance, police, etc; and inform leaders, such as the Metro director. During this time, the passengers are evacuated from the metro station and the station is secured. The IPEX also localizes and calls the designated supervisor to the incident location. He acknowledges the receipt of the notifications and goes to Jussieu metro station to supervise and lead the operation. At the site, he/she will be briefed about the current situation. During the emergency intervention at Jussieu metro station IPEX centralizes the data received from the metro personnel involved. Additionally, each device needs to log all the actions of its user and information about the data exchanged during communications.

The emergency intervention involves the evacuation of three adjoining metro stations due to smoke at these stations. It also requires to extinguish the fire at Jussieu metro station, check the integrity and repair the infrastructure after the fire and reestablish traffic if possible through the metro station. The length of the operation can vary between one hour (i.e., for small damages at the train) to a day (i.e., for damages to the railway system, power system, or metro signalling system).

Communication during an Emergency Intervention Operation: Due to the existing security risks, the metro has a set of different emergency procedures, e.g., as with small accidents – secure the place, call for help, help the injured, etc. It also has a very precise hierarchy for the information flow, i.e., whom to inform, and what phone number to call (home/office/mobile), depending on who is on duty. All this information is context dependent and immediately available, which shortens the briefing phase. When an operation supervisor arrives at the scene, he becomes the incident manager. The incident manager receives information from the mobile agents at the site and sends reports to the control center. The IPEX can then inform agents at close by stations about the status of the accident, and ask them to evacuate the station. They may also send a personalized list about what to do, e.g., station evacuation, smoke removal system command, public information, help passengers, unblock validation line, etc. When a task is completed it can be checked, and this information is then automatically sent to the control unit.

The role of IPEX is central during the emergency intervention; during the start-up phase it ensures that all the actors are informed about the incident and all the necessary preliminary actions are taken. After the incident leader takes responsibility of the operation the IPEX will just centralize all the information about the status of the operation and redistribute it to the mobile agents. Additionally, at the end of the operation each device will provide its logs about the actions of its user and information about the data exchanged during communications.

Different groups of people are involved; train driver, people working at the station, emergency teams (e.g., paramedics, police, firefighters), and accident leaders from the metro department. In this scenario, the participants have mobile devices for communication and information sharing. They use ad hoc and relayed communication in tunnels/underground stations when 3G/GSM and WiFi are not available.

There are a number of possible communication flows in this scenario. We list three examples of such communication flows or possible audio-video streams here: The first is among team members from the same organization. For example, metro mobile agents can share the CCTV stream in order to assess if all the train passengers have been evacuated from the metro stations. The second example is among members of task oriented ad hoc teams (can be cross-organizational or not), e.g., a team selected to inspect the train to report situation, etc., consisting of firefighter and metro station personnel. Audio streams can be used when the firefighters inform the metro station personnel about possible fire damages to the train or railway. The third example is communication between different levels in the rescue operation organizational hierarchy, e.g., IPEX and incident manager, and team leaders. For example, when the incident manager arrives at Jussieu metro station he needs to receive the initial audio-video stream which reports the incident and the current CCTV stream closest to the train in fire.

In such a network, data and audio-video streams must follow a well-defined hierarchy and also allow quick feedback (e.g., acknowledgments and task reports). This requires finding the best way of using the available resources on the nodes to run services that help the emergency operation.

3.3 Commonalities and Differences

The scenarios described are quite different, e.g., with respect to the landscape, the size of the area of the accident, number of people involved, available resources, time span, etc. The subway station scenario covers a smaller area but involves more people. The available infrastructure may be better suited for video streaming and the rescue personnel can be deployed fast. On the contrary, the train scenario is more limited in time and space, possible involving less people, fewer casualties and rescue personnel, and the number of bystanders and non-organizational people involved will likely be much lower.

It is however important to emphasize the similarities between these scenarios. We use these to provide a basis for our requirements analysis for building a middleware. The differences may represent what needs to be configurable in such a middleware. The degree of heterogeneity, and to a certain extent the complexity, will in general increase with the size of the area, the time span, and the severity of the accident. In the following, we look into different aspects such as people involved, organizations, and ways of communication, in addition to similarities and differences in the two scenarios.

Many of the same organizations are involved in the scenarios, there are medical personnel, fire brigade, and police at both scenarios, and they have similar tasks:

- Rescue site leader (OSC): the main tasks are to set up a place of command, get overview of the situation, coordinate equipment and personnel, assign tasks, and report to the control center. In the railway scenario, examples of gathered information about the situation from the train control center and train driver are the number of wagons, passengers, any goods, etc.
- Fire brigade: The main tasks are to control fire and to monitor areas in danger of fire or explosion. Other typical tasks are to cut loose trapped people, help where needed, and place sensors to aid the monitoring of dangerous areas.
- Medical personnel: The main task is medical care, including registration of patients and evaluation of medical state. If sensors are used in aiding patient monitoring, medical personnel will place these on patients.
- Police: tasks include gathering evidence and securing the area.
- All personnel are involved in evacuating people and in general cooperating and supporting the rescue operation as needed.

Differences concerning organizations and personnel are related to the number of people involved; in general, the larger the incident, the more people, more volunteers, and different kinds of experts are involved. For instance, in cases of gas leaks or oil spills, people with the appropriate knowledge are required. In the train accident scenario, people from “Jernbaneverket” and the Norwegian State Railways (NSB) are involved, and in the subway scenario people to repair damaged infrastructure are needed, e.g., power and signaling systems.

Possible sources for information include both mobile devices carried by personnel, stationary devices, PCs in ambulances and rescue helicopters, and sensors. Another possible information source is an Internet gateway. The information from these sources can be shared, but there are cases when sharing of sensitive information is not desired. Examples of sensitive information are medical records of injured persons, environmental data, layout of buildings and installations, information about dangerous goods, collected evidence, available resources, and status reports.

Communication issues with respect to technical equipment may also differ. The train scenario is located at a deserted place, there is a lack of infrastructure, they need to put up their own MANET, and there are problems/challenges related to communication between people inside and outside of the tunnel. Weather conditions may also have an impact; devices may not work properly in extreme weather, e.g., temperatures well below zero in the train accident. In the subway scenario, the incident is located in the middle of the town and the infrastructure maybe in a better condition. There may be different means for people to communicate, either ad hoc using wireless devices, like laptops and PDAs or other pre-setup devices, metro and CCTV network or mobile phones.

Regarding the communication lines, there are many similarities, as the hierarchy in an organization is the same regardless of what kind of rescue operation. Possible communication lines include:

- among team members from same organization,
- among members of task oriented ad-hoc teams (can be cross-organizational or not), and

– between different levels in the rescue operation organizational hierarchy.

However, the bigger the operation, and the longer the time span, the greater the need for improvising. Thus, there may be differences concerning cooperation procedures and hierarchical levels depending on the size and kind of operation. For instance, the hierarchy in the railway scenario has few levels, creating a shorter way from top to ground personnel. It is also strict, in the sense that procedures are very detailed and people involved are drilled in the same manner. The size and type of operation will also have an impact regarding getting an overview and briefing personnel.

In large scenarios, it is important to get relevant information to the public, in order to save lives. In the train scenario, such information distribution is not so critical, except for redirecting people travelling, although informing families of the victims will still be important. In the subway scenario there may be difficulties concerning evacuating passengers, and avoid creating crowd panic. The main transportation needs in the train accident are to evacuate people and get supplies in to the area, while in the subway scenario access for the rescue personnel around the metro stations may be a problem.

4 Application Domains

In this section, we present two target applications: delay tolerant A/V streaming for rescue and emergency, and Voice-over-IP (VoIP) for multinational corporations involving multiple physical locations with different security requirements. Although the two applications are quite different, there are some similarities, which we discuss in Section 4.3. Together with the similarities between scenarios presented in Section 3.3, these form the basis for the requirements analysis in Section 5.

4.1 Delay Tolerant A/V Streaming in Rescue and Emergency

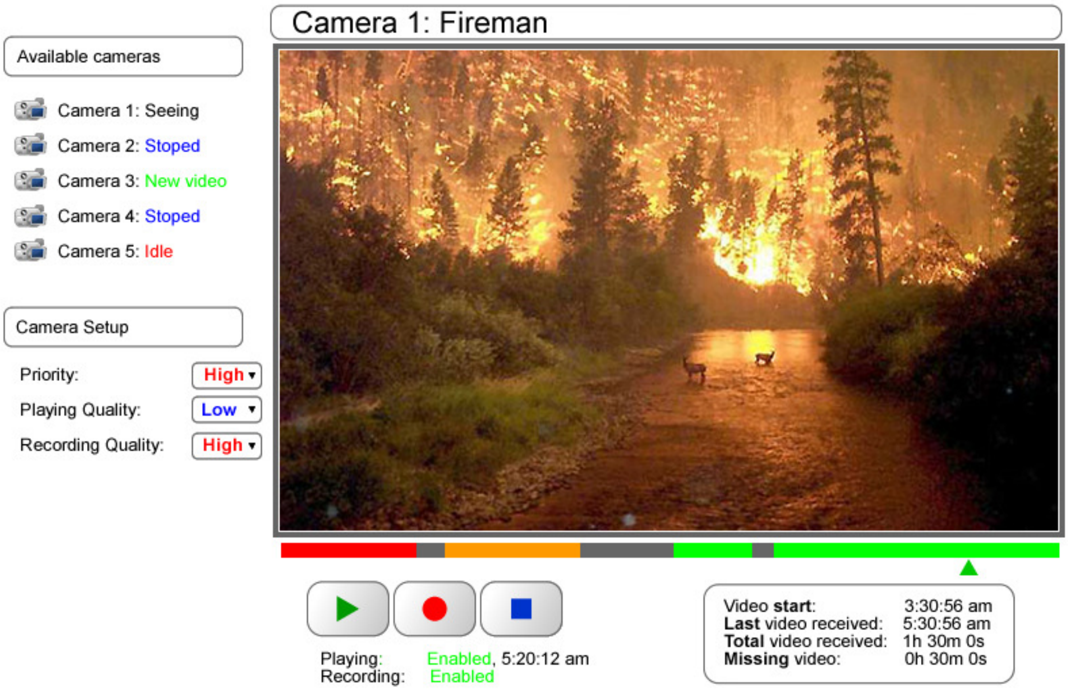
A delay tolerant streaming service requires more than a regular video player. Parts of the stream may be received disordered at the user end. The user must be able to visualize the received information when it is ready. In addition, the user must be able to setup service parameters, such as video quality properties, as well as managing the multimedia session (starting and stopping streams). If several cameras are deployed in the area, an appropriate user interface should provide means to control them all. All these features must be combined in an intuitive user interface. An emergency operation is a stressful situation by definition, so providing good user experience is important.

Figure 3 shows an example interface for that application. The screen is divided in several areas. The main part is the video player. Only one is shown in the figure, although the application could support more than one. Below the player, there is a bar that shows with a quick look the received video and its quality codified with colors. For instance, green represents high quality, orange, medium and red, low. A triangle points to the current reproduction time. It could be dragged by the user to go to other moments. Play, record and stop controls, camera status and other information can be showed below. On the left, a menu lists other cameras that are available in the network. Their statuses inform the user about events occurred, such as new video received. Finally, the user can change the session parameters of this camera. A target quality to watch and to record the video could be expressed for the user. The (overlay) network would use these preferences to define transport policies for the video streams.

We envision this multimedia application as part of a complete control panel. Ideally, officers would use a single application to access available information about the current operation. It would merge data coming from many different sources, such as sensors, geographical information systems and so on.

4.2 VoIP services and their need for network adaptation and delay tolerance

Delay tolerant and self-adaptive streaming services are appealing also from a commercial perspective. One interesting recent use case that shows this is effective routing of real-time media over IP in multinational corporations. A multinational corporation extending over multiple sites needs effective routing of real-time traffic, without compromising corporate security, data security, transmission quality and delay in the service. Figure 4 shows an example scenario. The corporate registrar service, which maintains the company wide database of phone/video conferencing user-ids is located inside a world-wide corporate network connecting together offices in different countries/places using VPN or dedicated lines. To allow communication with people outside an organization's firewall, the local registrar service instance can contact remote registrars services, e.g., via RealTunnel a Paradial



Camera 1: Fireman

Camera 1: Seeing
Camera 2: Stoped
Camera 3: New video
Camera 4: Stoped
Camera 5: Idle

Priority: High
Playing Quality: Low
Recording Quality: High

Playing: Enabled, 5:20:12 am
Recording: Enabled

Video start: 3:30:56 am
Last video received: 5:30:56 am
Total video received: 1h 30m 0s
Missing video: 0h 30m 0s

Fig. 3. Multimedia application user interface in the Command and Control Center

solution for firewall/NAT traversal. This can be both users registered within the company, i.e., locally or remotely, and users registered with a completely different registrar, e.g., hosted by other companies, somewhere else in the world. The path used for signalling, e.g., connection setup and maintenance, will often traverse several proxies and firewalls to ensure that all parties involved in maintaining the connection are informed about the status and the parameters of the path segments. However, the path for the media streams must follow the shortest (e.g., most efficient in terms of quality) path between the communicating entities. This optimal path may vary as physical links are more or less loaded and even in some cases broken.

Consider a case where client E is registered in the enterprise and is currently located at some external site. This client decides to set up a call to client C at another remote office of the enterprise. An example of such a network used in world-wide organization, can be seen in Figure 4. To route a call between the clients E and C, the software first needs to find a valid route between them. Such a path might include segments from the companies intranet and Internet, which have different characteristics (e.g., ADSL, WLAN, cellular networks or WAN). Current solutions will have to be statically configured to use one or another path. During the call certain paths segments might degrade and a replacement segment path should be found. It is clearly a situation where research on MANETs and adaptive communication protocols can contribute.

The example obviously lends itself well to improvements on adaptivity (i.e., during the setup of the call or during the call), but delay tolerance at the application level also has great potential. Currently, users do not have high expectations in this area, but it can be argued that this is to a great extent because they do not know better. DT-Stream aims at introducing innovative ways of hiding and minimizing effects of delay in situations where there is a temporary disconnection in the network. Even though such breaks are less likely in a normal urban area, typically consisting mostly of wired networks, packet delays (due to burst traffic or temporary network issues) long enough to cause jitter in voice communication is still a very relevant scenario. Being able to hide the effects of such delays, for instance by slowing down or speeding up voice or video to smooth the user experience, and innovative feedback and controls to manage longer delays are something that is very interesting also in commercial settings even though users are still not aware of the possibilities.

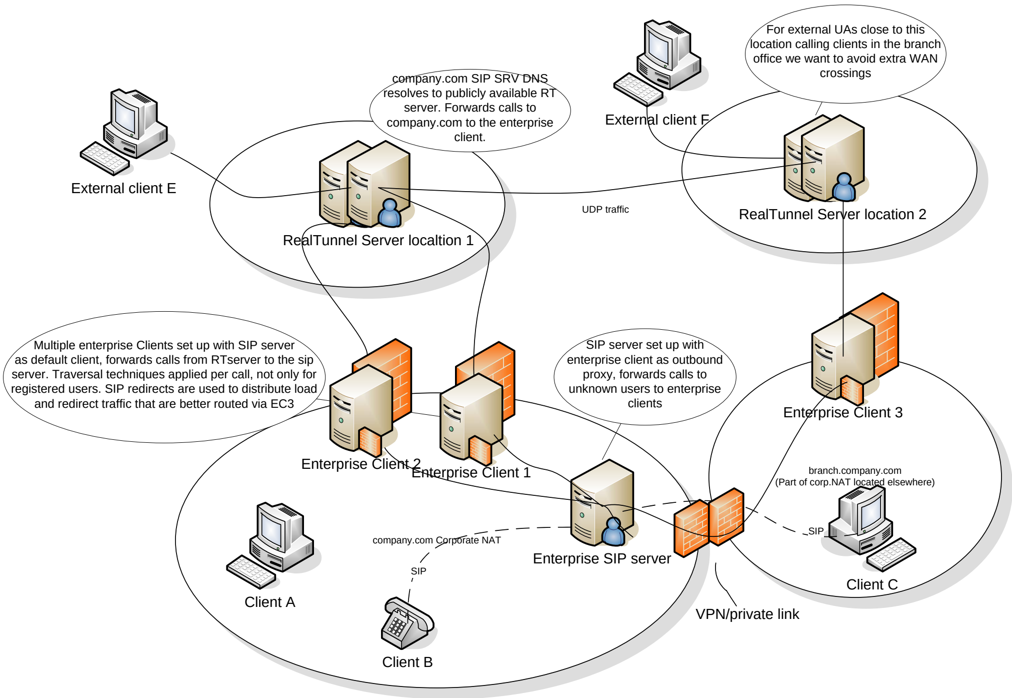


Fig. 4. A scenario of a multinational corporation with multiple communication paths.

4.3 Commonalities and Differences

The applications to support communication in emergency and rescue operations present common aspects with the VoIP application. An application to provide streaming during emergency situations needs to provide both synchronous and asynchronous communication. Passing between these paradigms should be done seamlessly and involve the user only if necessary. Consequently, the application itself must have a mechanisms to quickly react to changes in the network status and inform the user about possible alternatives.

The VoIP standard requires that both source and destination are available for communication at the same time and that there is a valid path between source and destination. This means that once the connection has been established there are two continuous streams (i.e., source-destination and destination-source). If there are short delays between consecutive IP packets the protocol will try to mask them for the application. Once the delays have reached a certain threshold the communication is considered interrupted and the streams are stopped. For example, if there are long round-trip propagation delays (e.g., 400-600 milliseconds in satellite communication) on certain segments of the path. It is obvious that by adding support for mechanisms to tolerate long delays and disconnections, VoIP communication can be enhanced and new applications could be developed. The current QoS requirements for VoIP stream are built around the concept of mitigating delay and jitter (variation in delays) during communication. Most enhancements added to VoIP address the recovery from lost or delayed IP packets. This is done either by attempting to use multi-path routing with error correction codes or by buffers to recover form losses. These solutions introduce delay tolerance mechanisms into the VoIP communications, but they can not cope with longer delays and disconnections in the network.

Application examples where VoIP needs to be delay and disruption tolerant are corporate communications, rescue operations and communications in remote areas. Applications for corporate communications need to provide tolerance to delays caused by long routes, dynamic changes of routes, user pauses in communications, congestions and limitations for different routes segments, or even temporary loss of connectivity. In case of delays or disruptions the users should receive all the traffic lost during the disruptions or by the delay. It would be the end-users' decision to listen to the missing parts or not. In the rescue scenario there might be partitions in the network. When such a partition occurs, ongoing communications between nodes in the different partitions will be interrupted. Even if data arrives later to the destination through the help of delay tolerant techniques the packets will be out of order and they will be discarded as stale by the VoIP application.

5 Requirements

The basic problem we aim to address is presented by the fact that AV streaming services would be very useful for emergency and rescue operations, but today's streaming protocols and applications are not able to work properly or not at all over the networks that we expect. This section analyses a set of requirements stemming from this basic problem, focusing on a set of underlying requirements addressed by four doctoral theses that are part of the DT-Stream project.

The first fundamental requirement is that the available networking infrastructure is not known a priori. This requires solutions that can exploit the availability of heterogeneous network technologies during run-time. As an example, transmit and receive packets via 3G/GSM if such infrastructure exist, if not switch to e.g., MANET technology. Requirements regarding support for heterogeneity is further analysed in Section 5.1.

A second general class of requirement comes from the fact that we expect a high degree of network dynamics. There might be no infrastructure existing in the emergency area, or the existing infrastructure might have been (partially) destroyed. Therefore, MANETs will play an important role in the first hours of the operation. However, MANETs are very dynamic and the available resources may be low and can change quickly. To cope with the dynamics, which also concerns switching between heterogeneous network technologies, it is utterly important that the solutions in DT-Stream are highly adaptive. This is further analysed in Section 5.2.

A third class of requirements comes from the fact that short and long term network disruptions may occur, thus AV applications have to be re-considered and re-designed to be useful in order to support the contradicting concepts of streaming and "disconnected", unstable networks. In essence, we must support data transport in presence of network disruptions. This is not supported by today's transport protocols such as TCP, and this is analysed further in Section 5.3.

A fourth class of requirements comes from the fact that performance evaluation is important to ensure that the DT-Stream solutions satisfy key performance requirements. The characteristics of the target scenarios impose certain requirements on the methodology and tools used to conduct such evaluations. Section 5.4 elaborates on these requirements.

In addition to the above-mentioned four classes of requirements, there are other requirements that must be addressed in DT-Stream. Firstly, requirements which concerns security. Secondly, we address other specific requirements through the works of several master students. Section 5.5 briefly outlines these works in terms of the requirements they aim to solve, and by what means.

5.1 Support for Heterogeneity

The scenarios described in Section 3 have in common that they have high heterogeneity in terms of the devices used to communicate, and in terms of the available networks. Even though this heterogeneity opens a lot of potential possibilities for communication, to take full advantage of them is a complex task for the applications. Hence, an internetworking framework is required. This framework should act as a middleware between the applications and the underlying heterogeneity. It should exploit the possibilities offered by this heterogeneity to provide the best service possible to the applications. Given that applications might have quite different preferences, a way to express their preferences is required. The adaptation to the changing conditions in both devices and networks is an important requirement of the internetworking framework. This relates with Section 5.2. The internetworking framework should take autonomous decisions without the need of human intervention.

Device heterogeneity: The devices are used to connect to infrastructure-based networks and/or establish spontaneous infrastructure-less networks. These devices are provisioned with different resources, ranging from high-end laptops to wireless sensor nodes, including PDAs or smartphones. One common characteristic of wireless capable devices is that they are usually battery driven. Device resources become especially important in infrastructure-less networks, since the devices themselves have to maintain the network. An efficient usage of the resources of the devices is a requirement for any internetworking solution. Additionally the internetworking framework should be aware of the resources available and their distribution in the network.

Multihomed devices, i.e. devices with access to more than one networking technology, are becoming increasingly popular. This allows devices to act as gateways between networks. To take advantage of device mobility and multihoming is a fundamental requirement for the internetworking framework. This requires a flexible mechanism to separate node identities from their network locations. Multihoming can be problematic, since it can cause an explosion in the amount of routing information [21]. The internetworking framework should consider this and be scalable.

Network heterogeneity: In the case of network heterogeneity, we have to consider not just the existence of different networking technologies, but also different networking paradigms. Networking technologies, such as 802.11, 802.15, 3G/GSM, Bluetooth, etc., have quite different properties and allows infrastructure-based and/or infrastructure-less communications. Furthermore, it is necessary to consider the differences between networking paradigms. IP-based networks are usually based on the end-to-end principle, while delay tolerant networking (DTN) is based on the store-carry-forward principle. The internetworking framework should select the best network to transmit the application data according to its preferences. For this purpose, the internetworking framework needs to be aware of the characteristics of the different networks. Thus, some kind of network description that describes the main properties of a network is required.

5.2 Support for Adaptation

The application(s) and the protocols part of the DT-Stream framework will face severe challenges due to strong variations in the amount of available network resources. These variations can be caused by several factors:

- *Mobility* can cause route breaks and/or network partitioning.
- *Limited battery* can cause that nodes suddenly shut down leading again to routes breaks and/or partitioning.
- *Heterogeneity* in the nodes resources and their status. Depending on their current computational tasks, their capability to forwarding network traffic might vary significantly.

To make the best out of the available resources, the applications and the protocols are required to adapt in real-time. Thus, a central requirement in the DT-Stream project is to facilitate adaptations of applications and protocols. Adaptations is performed in three general phases. First, sensing raw data from protocols or applications. Second, analysing this raw data to discover the current state(s). Finally, adapting the (protocols or applications) to the given states. In the following, we define general requirements tied to each of the three phases of adaptation in DT-Stream:

Data Sensing: By data sensing, we mean collecting internal data from protocols or applications. Determining accurate network states often requires data from multiple protocols. Collecting data from multiple protocols in today's IP-based protocol stacks is not a trivial task. Basically, the principle of layering prevents this in that protocols have well-defined, but very limited interfaces. Lower layer data is not visible to e.g., the application. In turn, this means that we in the DT-Stream project must break the general principle of protocol layering. Such approaches follow what is referred to as cross-layer design.

Data Analysis: The collected data must be turned into network state information. We envision the need for information describing two general network states in DT-Stream:

1. Route / link existence: Used to decide when to transmit or suspend packets on a route/link to avoid loss during network partitioning (store-carry-forward).
2. Congestion: Slow down transmission of packets, possibly discard packets of lesser importance.

A strict requirement is tools to facilitate the identification of these network states. Analysing data from protocols to discover these states requires explicit knowledge of the specific protocols that we obtain the sensed raw data from. This hard-wires the "adapter" to specific protocols and we loose an essential strength of IP. That is, IP supports well-defined but only a limited set of services to the protocols "above" and thereby hides the complexity of a large set of underlying heterogeneous protocols. An important requirement is to avoid such hard-wiring e.g., by making it possible for the "adapter" to obtain accurate generic network states. An component to facilitate such a mechanism must orthogonally span all layers of the stack. A final requirement is to ensure that the analysis of protocol data is carried out efficiently. That is, we do not want the computational cost to overshadow the benefits we get from the adaptations in the first place.

Adaptation Mechanisms: Having identified the accurate network state, the final step to carry out successful adaptations is to execute the adaptation mechanism itself. One obvious adaptation required in DT-Stream, is to avoid packet loss by suspending packet transmission for on-going streams (store-carry-forwarding). Another requirement is adapting the bandwidth needed by the AV services, to the available bandwidth in the network. Related adaptation mechanisms include techniques of video coding (compression) or methods of packet prioritization. As an example, drop or assign lower prioritization to packets holding less important video or lower prioritized frames, such as enhancement frames in many of today's video coding techniques. From a design perspective, DT-Stream requires a framework to distribute the identified network states to the "adapter", and possibly to some extent take control of the adaptation process. Carrying out successful adaptations does not only require identifying proper adaptation mechanisms, but also consider the holistic effect of the adaptations in an architectural manner. It has been argued that interaction, and thereby adaptations, across the layers can have undesirable consequences on overall system performance [22]. These negative consequences includes "spaghetti-like" code interactions, and adaptation loops, e.g., looping adaptation behaviour between two or more protocols. A strict requirement in DT-Stream is that we consider these consequences.

5.3 Delay Tolerant Transport

Streaming applications over connected networks requires low delay and high reliability in the transport layer. Streams are normally delivered using RTP/UDP, assuming enough available resources to achieve the desired quality of service. Lost or delayed packets are discarded because the user is reproducing the content when receiving it. The quality of the media reproduced is reduced by these failures, but it is tolerated by users if small. These conditions are difficult or impossible to meet in emergency and rescue scenarios. In general, transport layer requirements have to be more flexible.

As a first requirement, a transport protocol in the context of DT-Stream has to be flexible. MANETs are changing environments, their topology and available resources change more often than in the Internet. For that reason some transport protocols, such as TCP, fail to workout properly. A MANET is prone to packet losses due to collisions or congestion, like in regular networks, but also due to node disconnections, route changes or protocol underperformance, such as with ARP. These events produce single packet losses, temporal or permanent breaks in the connectivity. A transport protocol has to be flexible, detect and adapt to these different situations.

The transport protocol has to be able to support situations when end-to-end connectivity between video source and sink is not possible. When a MANET is partitioned, delay-tolerant networking techniques are needed to deliver the stream. In that case, other MANET nodes are used, for example to be used as carriers. Intermediate nodes are also useful to increase reliability when end-to-end connectivity is unstable. Therefore, a transport protocol must not assume end-to-end connectivity and support the use of intermediate nodes.

Emergency and Rescue operations may require that the media requested is received with a minimum quality. Media streams have packets that contribute in different grade to the resultant quality. Therefore, reliability in the transmission of packets can be flexible too. If reliability for all packets is not provided, at least the delivery of packets to fulfill the minimum quality required by the user must be ensured. Reliability implies mechanisms that add overhead to the communication, such as retransmissions or control messages. Since network resources tend to be scarce in a MANET, the overhead introduced by the transport protocol should be keep low.

5.4 Tools for Development and Evaluation

It is important to evaluate the performance of DT-Stream solutions both (1) to guide the research, design and development cycle, and (2) in order to accurately estimate their behaviour once deployed in the real world. The latter requirement is especially important when developing solutions for emergency and rescue, where it is critical that they behave and perform as expected. In order to enable such evaluation, the methodology, tools and models employed must be carefully selected and extended in order to account for the key characteristics of the target networks.

Approach and Tool: A DT-Stream network may potentially have large number of nodes moving across large areas. Full-scale experiments are required to properly evaluate performance, but it is too cumbersome and costly to perform evaluation by means of real world experiments. Instead, evaluation must be performed by simulation. Although a wide range of simulators are freely available, only a few are capable of accurately simulating the dynamic and heterogeneous networks required in DT-Stream. Popular general purpose simulators such as ns-2, ns-3, OPNET and OMNet++ fit our needs. They provide accurate models of the network stack and the wireless medium, and are designed for extendibility at all layers. The latter is important as solutions to adapt to dynamic environments often require cross-layer solutions. Finally, since these simulators are commonly used in the research community, they constitute a common ground for comparison between related works.

The Lack of Processing Models: As opposed to traditional networks composed of nodes that are specialized for a given task, nodes in a dynamic MANET must perform a diverse set of complex tasks. In addition, they are small and therefore constrained in computational and energy resources. This results in a situation where the nodes' impact on performance may become significant. Thus, in order to achieve accurate simulations for DT-Stream solutions, it is required to also simulate the impact of processing within nodes. General purpose simulators such as those mentioned above do not typically include such models. Although existing machine and processor simulators (e.g., SystemC) do allow for such modelling, they demand detailed knowledge of device internals which implies an unreasonably large modelling effort. The usability of these simulators is worsened by the fact that they are not readily integrable with existing network simulators. In addition, the high level of detail in the models means that they are not scalable.

Processing Model Requirements: One fundamental part of the DT-Stream project is thus the creation of the required processing models. A primary requirement is to realistically capture the overall node behaviour caused by resource restrictions. The models should capture the impact of nodes performing computationally complex tasks with limited processing power, including limitations imposed on throughput, and the added delay and jitter. Since networks interconnecting members from different organizations can consist of a highly heterogeneous set of specialized devices, it is important that the models are flexible enough to model devices of different types. The models must also be able to capture heterogeneous behaviour observed within one and the same device caused by different traffic streams traversing different sets of protocols.

At the same time, the modelling must not require detailed knowledge of the internal hardware in the devices. First, network researchers may not have the required competence to perform computer and operating system modelling at a high level of detail. Second, the required knowledge of the build-up of the device may be difficult or impossible to obtain, especially for commercial, hand-held devices. In addition, an important requirement is that the models are scalable for many-node simulations, which implies a sacrifice of detail according to the accuracy-scalability trade-off. Since today's hand-held devices are powerful enough to run fully-fledged, multi-threaded operating systems, the models must nevertheless be capable of capturing any significant effects the dynamics of multi-threaded protocol executions may have on performance.

A final, overall requirement is that the resulting models are integrable with existing network simulators, in order to re-use the large base of verified models available.

5.5 Other requirements

It is important to acknowledge that there are other requirements that we do not address in the four doctoral theses, thus they are omitted from the previous sections. Security, for one, is of great concern in the application scenarios. One can envision that the leaders of the emergency operators might exchange information regarding victims and the operation that due to privacy concerns should be secured from being accessible from the general public and the press. If we even envision emergencies caused by a hostile attacks, it is utmost important to leave any details of the operation secure from the enemies. Thus, security is important, and spans orthogonally all requirements. Due to resource constraints this has been left out of DT-Stream. Several master students have addressed other specific requirements within the DT-Stream project. The following outlines these works, some belonging to the application layer, and some belonging to the transport and network layer. Finally, we briefly outline some works that regards the issue of performance evaluation that spans the layers orthogonally.

Application Layer Requirements: At the application level, it is required to review the classical end-to-end approach followed by the Internet based multimedia applications of today. Applications in DT-Stream should be able to switch between "end-to-end mode" and "delay-tolerant mode" depending of the network resource availability. The absence of an end-to-end stable path can cause out-of-order and/or obsoleted data (e.g., video frames). The handling of such data requires sophisticated techniques of data management in the envisioned DT-Stream application. This requirement is partially addressed in the master thesis by Anes-González [23].

Another important aspect of the envisioned DT-Stream application is the fact that video transmission is costly both in terms of bandwidth consumption and battery drainage of the source node, and the node(s) forwarding the video stream. Keeping energy consumption and bandwidth at a minimum is a strict requirement in DT-Stream. Raw video can be strongly compressed by various means of video coding techniques, but there are also other mechanisms that can be used to convey the information within the original video. The thesis of Ullnæs [24] investigates the consumption of node energy and network bandwidth from several video conveying techniques such as video compression, key frame selection, and image stitching.

Another aspect of requirements belonging to the application layer is signalling. Signalling to establish and manage sessions is fundamental in multimedia systems. Basic primitives includes control operations such as "Play", "Stop" and "Pause". In the context of Delay Tolerant Multimedia Streaming, we are required to reformulate the semantics of traditional signalling. It is also necessary to review the end-to-end concept of sessions to also manage video or metadata temporally stored in intermediate nodes. These requirements are addressed in the master theses by Dybsjord [25] and Alonso-Martín [26].

Transport and Network Layer Requirements: In DT-Stream, we cannot rely on TCP since we expect network partitioning. Thus, as addressed in Section 5.3, we require different means of transportation. A number of master theses have attempted to address this requirement. Fundamentally, we need to store packets temporally during periods of disconnection. The thesis of Sentis-Rodríguez [27] compares the effect of storing packets only at the source to storing packets along the route for each hop . Since some packets are more important than other, and for this purpose Carus in his thesis [28] investigates different mechanisms of sorting packets in temporal storage.

An additional concern is routing in presence of network partitions. Section 3 describes node mobility in disaster scenarios. An important finding is that when partitions exist, it is likely that certain nodes travel between them. If this is the case, such nodes should be exploited in actually carrying data between the partitions (store-carry-forwarding). This requirement is addressed by the thesis of Haavet [29]. The work more specifically investigates mechanisms to discover and utilize such nodes.

Additional Requirements In Performance Evaluation: During design and implementation, simulations are used to understand how design decisions affect the behaviour and performance of the system. The amount of information required to be collected from simulation runs to capture this behaviour is usually very large. Therefore, proper visualization is required to convert the information into a visual format that is possible for humans to comprehend. The tool must be capable of presenting intuitively key aspects of the envisioned networks, including node mobility, routes and links between nodes and data buffered at carrier nodes. This is addressed by Santirso-González [30] and Dabed [31] in their master theses.

Mobility of the scenarios is important during performance evaluation. Many efforts rely on the use of synthetic mobility models, but they do not always reflect reality. Thus, GPS traces or manually built scenarios are very useful in order to increase realism. In doing so, the use of a special purpose-built editor reduces the workload required to create and analyze them. The basic required functionality is addressed by the MASS [32]. In addition, MASS has been extended through the master thesis of Cima-Granda [33] to extract metrics and by the master thesis of Díaz-Solares [34] to generate synthetic mobility models through a graphical interface.

6 Conclusions

The DT-Stream project aims to enable multimedia streaming in emergency and rescue operations. The deployment of multimedia streaming services in such operations present many challenges from the networking perspective, since it is not possible to predict the availability and status of the networking resources. In such dynamic networking scenarios, network disruptions may occur breaking the end-to-end principle of the classical Internet. This technical report presents the requirements analysis for multimedia streaming in intermittently connected networks. For this purpose, we include the necessary background information about devices, networks and mobility in such operations. Furthermore, the requirements analysis is supported by the complete description of two example emergency operation scenarios. Apart of the rescue and emergency application domain, we study similar problems found in corporate communication systems. We compare the two application domains identifying their commonalities and differences. In the requirements analysis, we have identified four sub-goals, which are the main focus of the four PhDs theses that result from DT-Stream. In Section 5.1, we study the requirements introduced by giving support for node and network heterogeneity. For this, it is required to take advantage of node multihoming and consider the resources management. The support for adaptation in such dynamic networking environments is presented in Section 5.2. The transport requirements for streaming in delay tolerant networks are described in Section 5.3. Finally, we describe the requirements of tools for development and performance evaluation in networks composed by resource constrained devices in Section 5.4. In addition, we complete the requirement analysis with other requirements that are partially addressed in master theses related with DT-Stream, such as delay tolerant multimedia streaming application, multimedia signalling in DTN, etc.

Acknowledgements

This work has been funded by the VERDIKT Programme of the Norwegian Research Council through the DT-Stream project (project number 183312/S10) and by the Spanish National Research Program (FUTURMEDIA Project TSI2007-60474).

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