A Flexible Self-Aligning Communication Solution for Multinational Large Scale Disaster Operations

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***Abstract*—This paper presents a communication solution for large scale multinational and multi-organizational disaster operations. The work is motivated by real world requirements depicted from well experienced forces in disaster management. The core design principles for the solution are flexibility and easy installation. The solution has proven its applicability during several training and large scale exercises, such as floods or earthquakes. With our solution we present a communication infrastructure for connecting mobile devices of relief forces in large-scale disaster operations to Command, Coordinate and Control Systems. The infrastructure can be set up by one single, non-IT-expert person.**

Keywords—Emergency network; self-alignment; interoperability; communication; wireless coverage simulation.

I. INTRODUCTION

Communication is one main building block to enhance interoperability between multinational and multi-organizational disaster relief actions. To provide targeted and fast help, relief organizations are highly reliant on the possibility to share important information across different organizations and national borders.

Compared to former days, when mostly voice radio communication was used for information interchange, modern broadband communication technologies can now provide a clear added value to the cooperation in large scale disaster actions. For example, some of the most valuable disaster information is gathered by relief forces directly at incident locations. Sharing these information between relief workers and management could bring a clear benefit to find the best supporting measures shortly. To get out the best, all the information should be made available in an automated way to all relief organizations and personnel involved in the disaster response actions.

With broadband communication, automatic exchange of relevant data between relief organizations as well as voice communication will be possible. One main research issue is now, how to bring broadband connectivity to almost any arbitrary location in a large scale disaster area.

The presented communication solution is part of the European FP7 research project IDIRA (Interoperability of data and procedures in large-scale multinational disaster response actions) [1]. IDIRA has its overall objective target in enhancing and streamlining the cooperation between relief organizations by enabling interoperability of information systems used for disaster management.

IDIRA addresses this interoperability topic twofold. First, at an organizational level, IDIRA shall examine possibilities to reach administrative coordination of multi-national disaster relief organizations, with all their own specific workflows and procedures. Second, on technical side, IDIRA shall provide a complete solution consisting of information systems, communication protocols, software interfaces, and standard data formats. This solution is the enabler technology to exchange disaster related information between administrative operators, executive personnel, and other disaster management systems connected to IDIRA. With IDIRA, information on incidents, resources, observations, and sensor data should be collected and shared to various other information systems like, mobile devices and command and control systems (C&C). To reach the required level of interoperability and automatic information exchange, IDIRA has a strong focus on a flexible, reliable, and easy to deploy communication infrastructure.

One of the major problems, we address with our proposed communication infrastructure is, that after a large scale disaster, the existing public broadband network is often partially destroyed, overloaded, or at least hit by power outages. Consequently, first responders cannot rely on any pre-existing infrastructure which may fail as consequence of the disaster.

As the communication network is essential for a better and more efficient collaboration between first responders, there is a critical need for the fast setup of alternative communication means. In such a case, another issue arises: First responder organizations neither are experts in setting up communication equipment, nor there are a large number of IT experts available within their field staff. Thus, easy setup and maintenance is heavily required for such systems.

This paper is structured as follows: Section II gives a brief overview on related work, Section III describes the system requirements on the IDIRA communication network, Section IV presents our proposed solution; the results of the systems' usage is discussed in Section V. Section VI concludes the paper and outlines further steps and ideas to improve our solution.

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II. Related Work

Communication technologies used by relief organizations is manifold. Beside everyday mobile communication technology like 2G, 3G, 4G, or even standard voice radio, there are numerous technologies which are more specific to action forces or disaster relief organizations. Some of these technologies are designed to be transportable and independent of any pre-existing infrastructure like satellite communication. Satellite communication systems like BGAN [2], VSAT [3], or Emergency.lu [4] are specially designed to provide data and voice communication in remote areas. As such, it can be used as communication uplink in large-scale disasters, if the pre-existing infrastructure is damaged or not usable due to power outages. Drawback of most satellite communication technologies are the high expenses for data exchange, so making them not the number one solution for commanders in the field, but a feasible approach for one Internet uplink in the operational area. BGAN additionally has only a very limited bandwidth.

In the case of a disaster, affecting many people and large areas, the public landline and mobile phone networks are often affected by overload, power blackouts, and damaged infrastructure. Consequently, these networks are often unusable as reliable communication infrastructure. Among others, this problem was addressed by TETRA. TETRA allows both, range limited direct device to device communication without usage of a fixed infrastructure and range unlimited indirect communication via a fixed infrastructure. To be more protected against power outages and damages, the components of the fixed infrastructure are constructed on a redundant basis.

A disadvantage of these technologies is the provided low bandwidth for data exchange. IDIRA heavily depends on data exchange between multiple components - for example for user interactions via IDIRAs web interface, the so called Common Operational Picture (COP). Here, data are exchanged between web clients of tactical personnel at the command & control center and field commanders. The bandwidth provided by TETRA will not be sufficient to operate several end devices in parallel.

Other available communication technologies have drawbacks regarding operating licenses. E.g., licenses are needed for operating WiMAX [5] communication equipment. Highly Mobile Network Node (HiMoNN) [6] is a communication system specific to public protection and disaster relief (PPDR). In compliance with ECC Recommendation (08)04 [7], HiMoNN operates with transmission power of 8W in the 5GHz frequency band, and is able to transmit data over a distance of several kilometers with a bandwidth of 28Mbit/s. Shortcoming of the HiMoNN technology is the lack of international operating permissions, which make it not the best choice for an international deployment.

The authors of [15] propose to use end-user devices such as mobile phones to establish a mobile ad-hoc network (MANET) between first responders. The devices use their 802.11 wireless network interfaces, to automatically build up connections to other devices within their transceiver range. During operation, first responders sending data via this MANET to a central host located in a command center. Special routing protocols are employed for routing the network traffic. To have a practical solution, a rather dense concentration of devices is needed, so that MANETs are only usable at limited incident areas of less than some 100 square meters. As a general communication solution, this approach seems not to be sufficient, as it cannot be assumed to have an adequate density of devices in the field to span a network across all devices.

The solution proposed in this paper uses 802.11 [8] technologies, which can be used all over the world without special licenses, but the possible distance between two devices is more limited than with WiMAX or HiMoNN. As routing protocol we use the Optimized Link State Routing Protocol (OLSR) [9], which is optimized for constrained wireless LANs. OLSR is based on multipoint relays which reduce the routing overhead on the network.

Within IDIRA, disaster information is represented in a standardized and open XML-based messaging format known as Emergency Data Exchange Language (EDXL) [10]. Out of this suite of standards, the EDXL-CAP (Common Altering Protocol) [11] data format is applied to data concerning occurred incidents. These incidents are registered e.g., by a sensor system and shared with some central C&C system. Information respective to availability, demand, and status of resources, such as specialized rescue units or even power generators, is shared by the EDXL-RM (Resource Messaging) [12] standard. The EDXL-SitRep (Situation Report) [13] messaging standard is used within the IDIRA context for exchanging information on observations and situation reports sent by commanders in the field via their mobile devices.

III. Requirements

The proposed networking solution is intended for multinational and multi-organizational large scale disaster operations. The work is part of the IDIRA project. Consequently, it has to fulfill both the generic requirements brought in by first responder organizations and the needs pushed by the IDIRA framework on the communication solution.

Within the IDIRA project several end user organizations are involved and more than 20 organizations are part of the end user advisory board. The requirements concerning the communication solution for first responders in emergency situations were conducted within IDIRAs' end user advisory board.

As nobody knows where the next disaster will strike the communication solution has to be allowed for usage (almost) all over the world. This allowance has to be given in advance, as asking for e.g., WiMAX frequencies in a disaster area right after the disaster strikes, is not an applicable approach (REQ1).

Whenever open broadband communication networks are at least partially operational, the emergency network should be able to use or interact with the existing network (REQ2).

For end device connectivity, the network should use open standards to ensure that different end devices can easily be added to the network and can interchange information with the emergency network (REQ3).

After a large scale disaster, only few human resources are available to setup a communication network. Especially IT-staff is a scarce resource. Thus, the setup of the communication network, especially of the remote nodes, has to be easy. There must not be the need for an IT guy to setup a remote communication node (REQ4).

Even in case the network is down, the information, that was already in the system when the connection was lost, should be available to the end-user (REQ5).

The interaction with the system should be the same when the network is down, as it would be if the network is up - for sure with a limited number of functionalities (REQ6).

The result of a survey within the end user advisory board was that REQ1, REQ2 and REQ4 are the most important ones and are thus crucial for the applicability and acceptance of a proposed solution.

The main design principle of IDIRA is to use standardized interfaces. Standardized interfaces, as for example the XML based EDXL standards family, often have the drawback to increase the communication overhead. Consequently the bandwidth needs within IDIRA are higher than they could be in case the design would have been performed with the bandwidth as main scarce resource. The IDIRA communication network will be used to access the Common Operational Picture (COP). The COP is a web application which presents the needed information in a Geographic Information system (GIS) manner to tactical and strategic personnel. For bootstrapping a device, COP needs about 10MByte of data as initial load. During operation data containing sensor information, incident information, and information on resources and their activities are exchanged. All this leads to a bandwidth requirement of around 2Mbit/s for a seamless operation of the COP. For field commanders (operational commanders) a dedicated Android App has been developed, where specific attention was given to reduced bandwidth consumption. This operational app needs less than 100kBit/s to be operational, if voice communication is used the needed bandwidth is in the range of 200kBit/s. Depending on the number of clients a few Mbit/s of bandwidth are required to support the IDIRA needs (REQ7).

IV. SOLUTION

Core of our proposed communication solution is a set of multiple communication nodes, called Wireless Gateway (WGW). The WGWs are used for both, to build up a backbone network and to provide end users access to this network.

Based on the requirements presented in section III, 802.11 based technology was chosen as the main communication solution used in the WGWs. The usage of 802.11 ensures that it can be used almost all over the world without the need to apply for licenses (REQ1). Within the proposed solution for the backbone network the 5GHz frequency range is used. 802.11 technology also is used between WGW and end devices. We are using the 2.4GHz frequency band to connect to end devices. This technology is widely used in end devices such as smart phones, netbooks, tablet devices or laptops. This ensures that a large number of commodity hardware will be available to be used as end devices (REQ3).

To overcome the limitations of the limited distance between two 802.11 endpoints we are using directional antennas. The disadvantage of directional antennas is that they have to be aligned to each other. As this is not a task which can easily be performed by first responders, it was decided to develop a self-alignment algorithm. The proposed solution consists of three directional antennas at each WGW which are automatically aligning themselves to build up a meshed backbone network with a maximum number of three direct links to other WGWs.

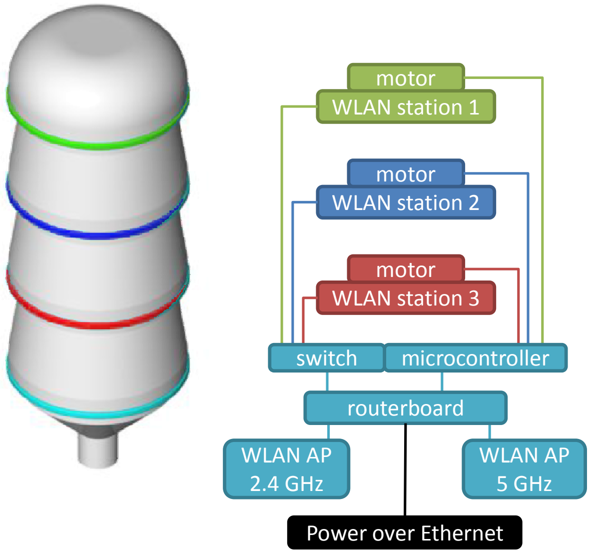

Figure 1. WGW building blocks.

Figure 1 shows the main building blocks of the WGW. The upper three layers are built identically. They consist of a WLAN station with a 16dBi directional antenna and a motor to rotate the antenna. In the bottom layer, a switch is mounted to connect the WLAN stations to a router-board. On the router-board the self-alignment algorithm is running, which controls to which remote WGW the individual WLAN stations are connected. A microcontroller is connected to the router-board which is responsible for performing the rotation of the upper three layers. In addition, the router-board is equipped with two miniPCI WLAN cards, where the first one is configured for the 2.4GHz band, and used for the connection to the end devices, the second operates within the 5GHz band and is used for the self-alignment algorithm. Details on the self-alignment algorithm can be found in [14]. The WGW will span a meshed network automatically, and each WGW is working as relay node for other WGWs.

The installation of the system is quite easy, it is just needed to mount the WGW on top of a pole and connect the cable and the Omni antennas for the 2.4GHz and 5GHz access points. Thus, the installation can be performed by non-IT experts, bringing us closer to REQ4. Nevertheless, an easy to setup network is only half of the job. In advance, it has to be decided where to set up the communication nodes.

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To support the first responders in positioning of the WGW, a simulation environment has been developed. The COP visualizes incidents, resources, tasks and other relevant information for disaster management on a map. Based on this information the incident areas are known, where field commanders need a working communication infrastructure to interact with the IDIRA system. Within one single incident area there may be preferred positons for WGWs (where they are able to communicate to each other) and positions where a WGW should not be placed. For first responders, it is not an easy task to identify accurate positions for the WGWs. We have embedded into COP a highly accurate simulation model based on digital elevation and digital surface model with a resolution of 1/10 of an arc second. This allows visualizing together with the tactical information also the communication feasibilities. Both used together allow an accurate positioning of the WGWs within the operational area, which allows the field commanders to fulfil their tactical needs and being able to communicate to each other. More details about the simulation can be found in [16].

Figure 2 shows such an example output. The simulation output shows clearly where it will be possible to install a WGW and where it is not possible, based on the simulation result for a remote position.

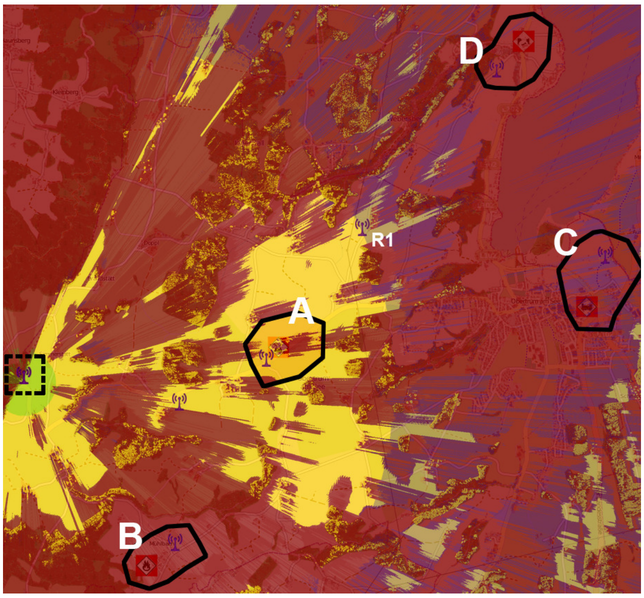

Figure 2. Simulation results.

The figure shows four incident areas (A-D) where communication coverage is needed. A central WGW has already been installed on the left border of the picture showing its simulation results. The lurid green color indicates the area where communication between end devices and the WGW will be possible. The yellow color shows areas where the installation of a remote WGW would be possible. The simulation results shows that for incident area A, the positioning of a WGW would be possible, but not for B, C and D. Consequently in a next step, a WGW will be positioned within area A and a simulation will be performed to show the coverage of the WGW positioned in that area. The aim is to find locations at the areas B, C, or D which are reachable from the WGW at location A. In doing so, it is possible to connect incident areas over multiple hops to the central WGW. For example, at position R1 on the map, a WGW is used as relay node to build a multi-hop-connection to incident area C.

The self-alignment algorithm of the WGW together with the simulation model allows the positioning and installation of the WGW by non-IT experts, thus the solution fulfills REQ4.

To be flexible to also integrate other technologies each WGW is using a so called Communication Field Relay (COFR). The Communication Field Relay is positioned at the foot of the pole on which the WGW is mounted, and it is connected to the WGW by Ethernet LAN. Furthermore, the COFR offers the ability to connect wired end devices such as desktop computers to the network. It provides all the needed networking services such as DHCP or DNS server for the machines. This link can also be used to integrate other layer 2 technologies, such as WIMAX, to the network. An additional link of the COFR is configured as DHCP client. On this link, different Internet uplink technologies such as DSL, Cable, 3G, 4G or anything else using an Ethernet interface can be connected. This Internet uplink can be shared by all clients connected to this COFR, to the local WGW or, to any remote COFR or WGW. The route is distributed by the OLSR dynamic gateway plugin.

Beyond networking, the COFR has a responsibility as power supply for the COFR/WGW compound. The COFR can be connected either to a 230V power socket or, to be independent of an available and working power grid, to a battery via a 12V cigarette lighter socket. The COFR provides power to the WGW via the PoE enabled Ethernet wire.

The IDIRA system consists of two more components the so called Fixed Infrastructure and the Mobile Integrated Command and Control Structure (MICS). From a networking perspective, the Fixed Infrastructure operates an OpenVPN server. As the COFR and WGW should work in different network environments two VPN configurations are used. One is using the default setting of an UDP VPN server on port 1194. The second one (overcoming some firewalls) is using a TCP VPN server running on Port 443. Moreover, the Fixed Infrastructure is running a DNS server. All the COFRs using an Internet uplink to connect to the IDIRA network will establish a VPN connection to the Fixed Infrastructure.

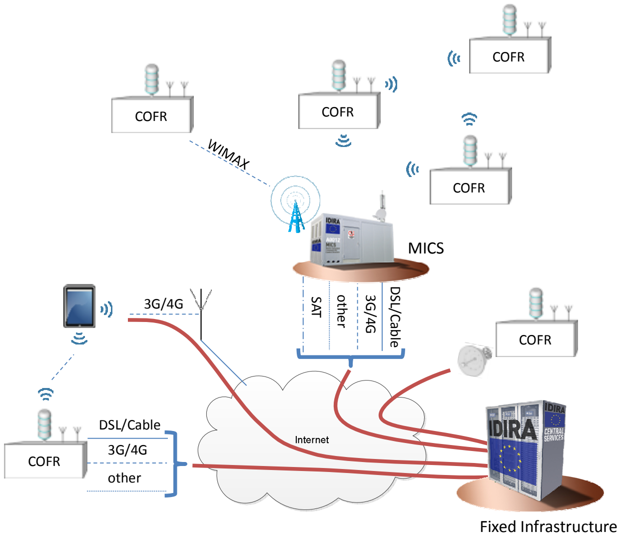

Figure 3. IDIRA communication network

The MICS allows shipping all the IDIRA services on site. This is of importance if a major network disruption occurs. When using the MICS, no Internet uplink is needed as all the services are running inside the MICS. All WGWs and COFRs will connect to the MICS. In the case that an Internet uplink can be established the MICS will setup a VPN connection to the Fixed Infrastructure and consequently, also hosts using the Internet can access the MICS. The flexible approach which allows using also existing networks to connect the COFRs to the Fixed Infrastructure and using other layer 2 technologies to interlink two COFRs ensure that also still existing network parts can be easily integrated into the network (REQ2). Figure 3 shows a deployment of the IDIRA communication network.

The proposed solution offers a speed of several Mbit/s which is sufficient for the needs of IDIRA (REQ7).

To fulfill REQ5 and REQ6 different steps on different components have been designed. When the system is fully operational, all the services can be accessed also including external expert systems which are running somewhere in the Internet. If the clients are only able to access the MICS, all services will be accessible, only the access to external expert systems will not be possible. When the connection between a COFR and the MICS is lost, the COFR will provide static information such as a map. Furthermore, all the information that has been viewed by a user before the network failure has been cached at the COFR and can be accessed. Also Voice over IP calls between end devices connected to the same COFR will still be possible. Finally, a native Android App has been developed to be used by the operational staff. All the data is synchronized between the MICS/Fixed Infrastructure and the Android App, so when the network is down all the information is still accessible by the users.

V. Results

The presented communication solution has been used during several training actions and large scale exercises within the IDIRA project. Here, we will describe the setup used during two large scale exercises. The first exercise represents a disaster response operation after intense rainfall conditions. As a result, it came to severe flooding around the city of Görlitz at the Polish/German border. Due to the heavy rainfall, it came to landslides and building collapses. The exercise consisted of two parts - incident 1 and incident 2. At the incident 1 location, several people had to be rescued from the water. At the incident 2 location, (several kilometers apart from incident 1) some people had to be freed, as they were buried under a collapsed building.

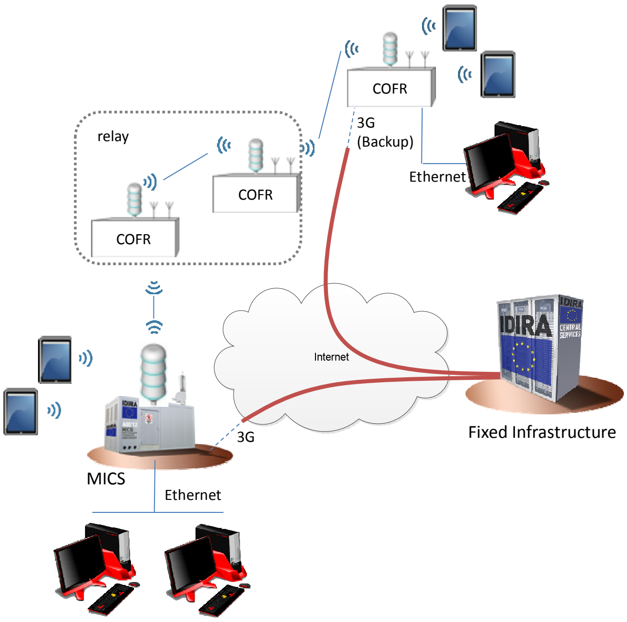

Figure 4. Real world deployment for first large scale exercise

Figure 4 shows the deployed infrastructure for the first large scale exercise. Incident 1 took place in close proximity (some 100m) to the on-site deployed MICS infrastructure. To provide connectivity to mobile end devices used at incident 1, a Wireless Gateway was used as access point and wire-connected directly to the MICS. Several workstations were connected to the MICS via Ethernet LAN.

Also at the location of incident 2, mobile end devices should also be connected to the MICS infrastructure via wireless LAN and a WGW access point. The problem here was, that incident 2 took place at a location 3.5 km distant from the MICS installation, separated by hills, dense forests and even urban area. To span a point-to-point WLAN connection over more than 3 kilometers, and to bypass obstacles (hills, trees, buildings, etc.), it was decided to install two relay nodes to provide the needed communication coverage at the incident 2 location. All four WGW nodes – the one at the MICS location, the two relay nodes, and the one at the incident 2 location - were separated by distances

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between 200m and 1.3 km. Except for the WGW located at the MICS, all relay nodes were installed by a unit of the Austrian Red Cross.

In addition, at location of incident 2, a mobile command and control vehicle was connected to the MICS using the Ethernet LAN connection offered by the COFR. The connection was used to access and operate the COP.

At location of incident 2, we decided to prepare an additional 3G uplink. This uplink should provide backup connectivity in case of a lost WGW point-to-point connection and could have been used to connect mobile devices over 3G to the MICS Infrastructure - even though with a very limited bandwidth and performance. These bandwidth and performance limitations are further exacerbated, as the MICS itself uses only a 3G Internet uplink due to a lack of availability of other broadband connections like DSL.

Both, the 3G uplink and the WGW point-to-point connection were tested during the exercise.

Figure 5 shows the deployment as it has been used during the second described large scale exercise. The exercise scenario was about an earthquake and fire disaster. As a result of the earthquake (which had its' epicenter in the area of Attica, Greece), it came to multiple blocked roads, collapsed buildings and fires. The exercise consisted of four incident areas, which were spread over an area of several kilometers in square.

In contrast to the first exercise, where end devices have been connected only via WGWs and 802.11, at one incident location, tablet devices have been equipped with 3G SIM cards to use the existing 3G network. Similar to the backup solution at incident 2 in the first exercise, we also used a 3G uplink for the COFR/WGW compound at one incident location. In contrast to the first exercise, the on-site deployed MICS could be connected to a DSL uplink. Several PCs have been directly connected to the MICS via Ethernet. A remote PC was using a legacy WIFI network which is normally used for cameras, and a COFR/WGW network has been established to be fully independent in two disaster areas. Also the Offline functionality with the Android App has been tested by switching off the data connection on the tablet device using the SIM card.

Again, the installation of the wireless communication infrastructure was done by a unit of the Austrian Red Cross.

The deployments in both exercises have shown the flexibility of our solution in combining existing networks with COFR/WGW networks (REQ2).

All over the exercises the communication infrastructure was installed by different personnel of various first responder organizations. The setup of the system has been proven to be easy and can be fulfilled by non-IT experts (REQ4). During the trainings it was shown, that battery, pole, tripod, COFR and WGW were able to be transported and installed by one single person.

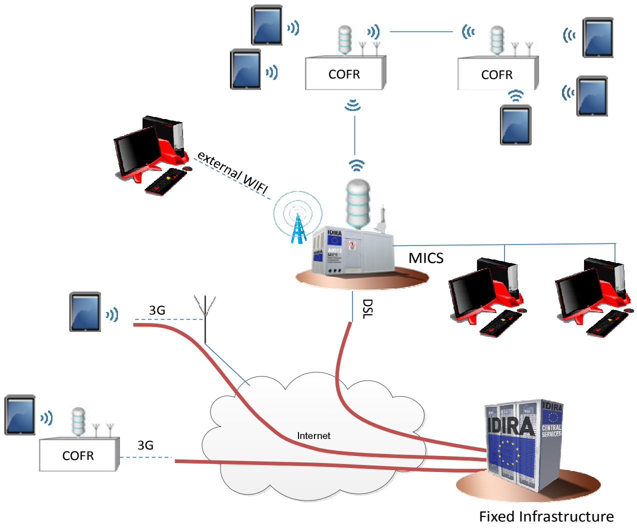

Figure 5. Real world deployment of the IDIRA communication network

Furthermore, the assessment of the communication system was part of surveys, which collected the views of all relief forces using the IDIRA system. A majority of those questioned about the communication infrastructure are of the opinion that the communication solution would be helpful in real deployments and the communication quality and coverage was (very) sufficient for the use with the IDIRA system.

VI. CONCLUSION AND FUTURE WORK

This paper presents a flexible, communication solution for large scale multi-national and multi-organizational relief operations. The concept complies with several requirements which have been introduced by action forces of relief organizations, such as easy installation and transportation, interoperability with existing communication systems and, international operation permission. The core of the system consists of the WGW/COFR compound. The WGW are able to automatically build up meshed wireless networks, using self-aligning directional antennas. The COFR provides power supply and Internet uplink technologies to the compound. During several trainings and large scale exercises, the system was able to prove its workability for the use within the IDIRA system.

For the future it is planned, to mechanically enhance the prototypes to fulfil the mechanical requirements of robustness for being used in real world large scale disasters.

Furthermore, we plan to integrate a MANET based approach similar to the one described in [15] to expand the communication coverage created by the proposed WGW solution.

ACKNOWLEDGMENT

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