An Offline Capable Communication Framework for Multinational Disaster Operations based on Self-aligning Wireless Gateways

Peter Dorfinger, Ferdinand von Tüllenburg, Georg Panholzer
Advanced Networking Center, Salzburg Research Forschungsgesellschaft mbH
Jakob Haringer Straße 5, 5020 Salzburg, Austria
{firstname.lastname}@salzburgresearch.at

Massimo Cristaldi, Giovanni Tusa
Intelligence for Environment & Security – IES Solutions s.r.l,
Via Vulcano 10, 95030 Gravina di Catania (CT) Catania, Italy
{m.cristaldi; g.tusa}@iessolutions.eu

Franz Böhm
Roofnode
10924 Bloomfield Street #2, North Hollywood CA 91602, USA
f.boehm@roofnode.com

ABSTRACT

This paper presents a novel communication solution for first responder organizations in large scale emergency situations. The system is able to use any existing network infrastructure and is able to combine it in areas where the network is down with an easy to install self-aligning wireless mesh network. Further the concept provides an integrated offline capability within the networked devices. Prototypes of a so called Communication Field Relay (COFR) and a Wireless Gateway (WGW) have been designed. The flexible approach is the basis for an ad-hoc information exchange between all the involved actors in emergency management.

KEYWORDS

Emergency network, self-alignment, mesh network, interoperability, communication

1 INTRODUCTION

The ability for first responders in the field to communicate with each other is getting more and more important. During the past years mainly voice communication within their own organizations was needed and used. Nowadays both data and voice communication between first responders of the same emergency organization or across different organizations, is crucial for an effective cooperation during disaster management. This is a clear change in the requirements of first responders where a clear focus in research is needed. Especially the automatic exchange of data offers the possibility to share relevant information across organizational and national borders, making the help more targeted and faster, thus saving more people.

One of the major problems right now is that after a large scale disaster the existing broad band network is often partially destroyed or overloaded. Even if the broad band network itself would be operational, power outage also disrupts the broad band network. So 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 are not experts in setting up communication equipment, nor is

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there a large number of IT experts available within their field staff, thus these systems have to be designed such that they are easy to setup and maintain.

The communication solution proposed in this paper is part of the European FP7 research project IDIRA (Interoperability of data and procedures in large-scale multinational disaster response actions) [1]. The main goal of IDIRA is to improve cooperation across responding organizations by enabling interoperability between different information systems that can mutually act as data sources or data consumers. As the most valuable information will come from on-site a core aspect is the sharing of information via connected devices used within the field, thus an existing communication infrastructure is crucial. The automatic exchange of all the gathered information lead to more efficient multi-national and multi-organizational disaster response actions.

Therefore IDIRA addresses this topic of interoperability at an organisational and a technical level. For the organisational part IDIRA examines possibilities to reach administrative coordination of multi-national disaster relief organisations with all their own specific workflows and procedures. On the technical side, IDIRA provides a complete communication system consisting of information systems, communication protocols, software interfaces, standard data formats on basis of a subjacent reliable network infrastructure. This communication system is an enabler technology to exchange disaster related information between administrative operators, commanders in the field, and other disaster management systems connected to IDIRA. The IDIRA system acts as central point for interchanging information related to the disaster. All information on incidents, resources, observations, and sensor data are collected by IDIRA and shared to mobile devices in the field as well as other information systems like existing command and control systems (C&C).

Disaster information is represented in a standardized and open XML-based messaging format known as Emergency Data Exchange Language (EDXL) [2]. Out of this suite of standards, the EDXL-CAP (Common Alerting Protocol) [3] data format is applied to data concerning occurred incidents 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 specialised rescue units or even power generators is shared by the EDXL-RM (Resource Messaging) [4] standard. The EDXL-SitRep (Situation Report) [5] messaging standard is used within the IDIRA context to exchange information on observations and situation reports sent by commanders in the field via their mobile devices.

The basis for the abovementioned information exchange is a working communication network so the described communication solution is a core part of the IDIRA system.

Based on the practical experience of the end-users involved within IDIRA the following core requirements are the basis for the design of IDIRAs' communication solution:

REQ1: Use any existing infrastructure which is still operational or brought by different units on site and is open to be used by all field units.

REQ2: The system has to be designed such that the installation of the communication infrastructure can be performed by non-IT experts.

REQ3: The usage of the system has to be allowed (almost) everywhere in the world without the need to apply for an allowance after the disaster strikes.

REQ4: The system should provide at least basic offline functionality.

REQ5: The technology used to connect the end-devices should be standardized to enable a lot of devices to interact with the system.

In the following sections we describe i) related work, ii) the system components of the IDIRA communication network, iii) the concepts for offline functionality iv) the prototypes developed and used within the IDIRA project v) the automatic establishment of the network and vi) the usage of the system and its results. Finally, we conclude the paper and show some further steps and ideas to improve our proposed solution.

2 RELATED WORK

Relief organizations rely on various technologies available for communication. Some of these technologies are everyday technologies like mobile phones others are more specific for action forces. In case of large scale disasters, affecting large areas and many people, power blackouts, damaged infrastructure and overload effect that the public phone network is not usable as a reliable communication infrastructure. In such cases radio communication like TETRA or even analogue radio technology is used. The components of such systems are constructed on a redundant basis and therefore operable in cases of power outages or if the infrastructure is partly damaged. 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. For bootstrapping a device COP needs about 10MByte of data as initial load. During operation data containing sensor information, incident information, observations, positions of field commanders, voice calls and information on resources and their activities are exchanged. All this leads to a bandwidth requirement of some Mbit/s for a seamless operation.

Especially for field devices a native app with lower bandwidth needs is developed. Despite of this, bandwidth provided by TETRA will not be sufficient to operate several end-devices in parallel.

Another communication technology used in large scale disasters is satellite communication which offers good qualities especially as uplink technology. Different satellite communication technologies such as BGAN [6], VSAT [7], or Emergency.lu [8] are available. 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 or several Internet Uplinks in the operational area. BGAN additionally has only a very limited bandwidth.

Other existing communication technologies available have drawbacks regarding operating licenses. E.g. for a WiMAX [9] communication system licenses are needed for the equipment to be operated. A system which provides broad band communication for PPDR (public protection and disaster relief) organizations is HiMoNN. According to the ECC Recommendation (08)04 [11] HiMoNN [10] operates with transmission power of 8W in the frequency band 5150-5250 MHz. It has a range of several kilometers and is able to transmit up to 28MBit/s but is only allowed to be operated in a small number of countries worldwide. Therefore it is not applicable for international deployment in emergency relief situation.

Another possibility is to use end-user devices such as mobile phones to build meshed networks. So it would be possible to use mobile devices of disaster relief forces to build up a meshed communication network using the mobile devices as communication hops to exchange data between forces which are not directly reachable. To have a practical solution there must be a full chain of interconnected devices between communication partners. Thus, in case of a large scale disaster it cannot be assumed in general to have a sufficient density of devices in the field to span a network across all of them.

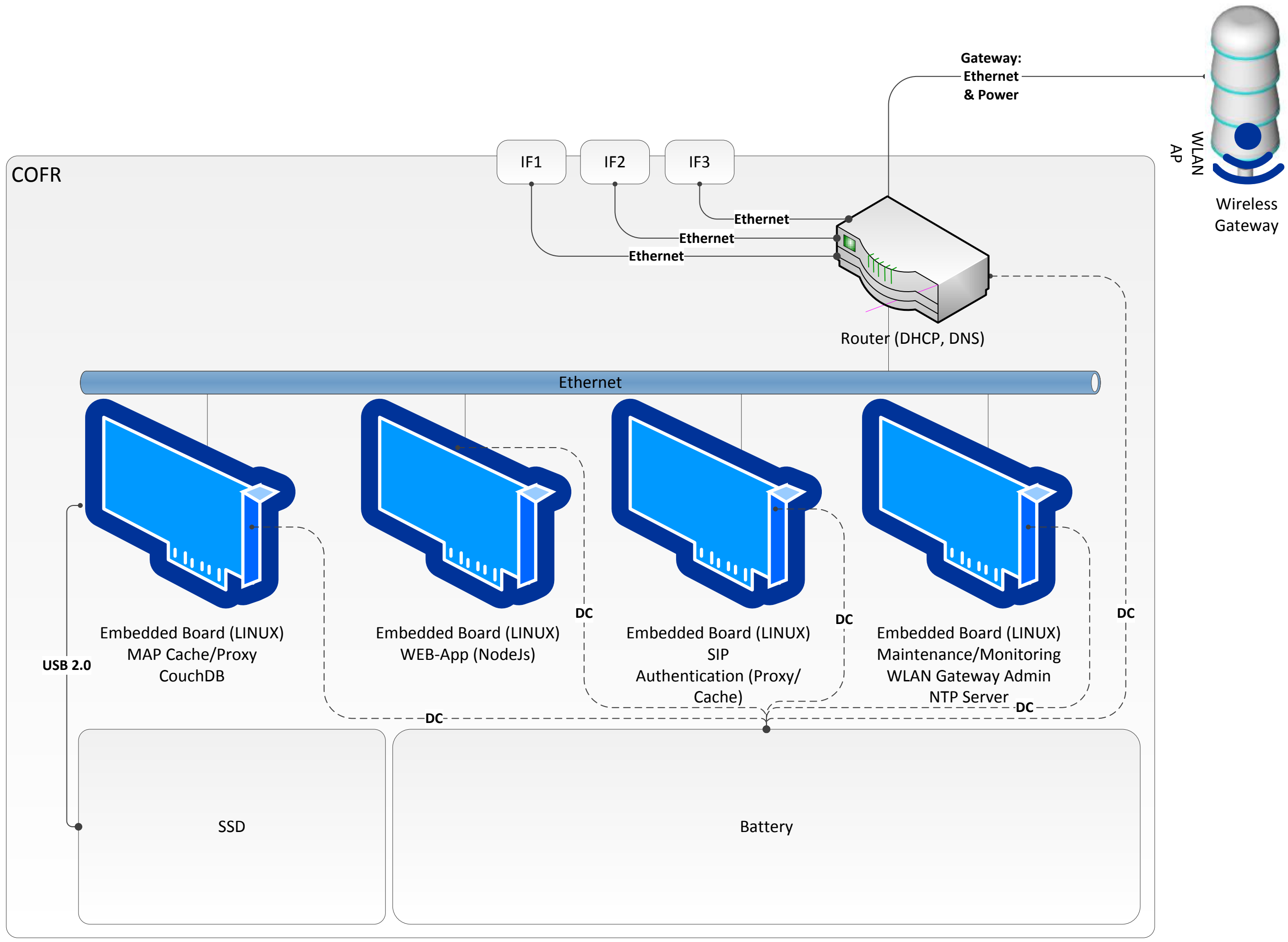

Figure 1. COFR building blocks

802.11 [12] technologies can be used all over the world without special licenses, but the possible distance between two devices is more limited as for WiMAX or HiMoNN. In our work we present a solution to extend the distance of 802.11 hosts by self-aligning directional antennas. As networking protocol upon the 802.11 hosts, we chose IP, which is a widely used and well known networking protocol. As routing protocol across the meshed wireless gateways we use the Optimized Link State Routing Protocol (OLSR) [13], which is optimized for constrained wireless LANs, based on multipoint relays which reduce the routing overhead on the network.

3 SYSTEM DESCRIPTION

One of the main design principles has been flexibility, thus the system consists of several building blocks which ensure a high degree of flexibility. This section will describe the main building blocks.

All the IDIRA services are running in the so called “Fixed Infrastructure” which is hosted in a cloud environment. From a network perspective the Fixed Infrastructure is running a VPN server which allows that other system

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components can interact with the Fixed Infrastructure in a secure manner.

The MICS (Mobile Integrated Command and Control Structure) is a mobile infrastructure which can be brought on site. The MICS hosts all the needed services and runs them local at the disaster area. This makes the need of an Internet uplink optional. Nevertheless if an Internet Uplink is present the MICS establishes a VPN connection to the Fixed Infrastructure. For the uplink any broad band communication technology existing at the MICS location can be used.

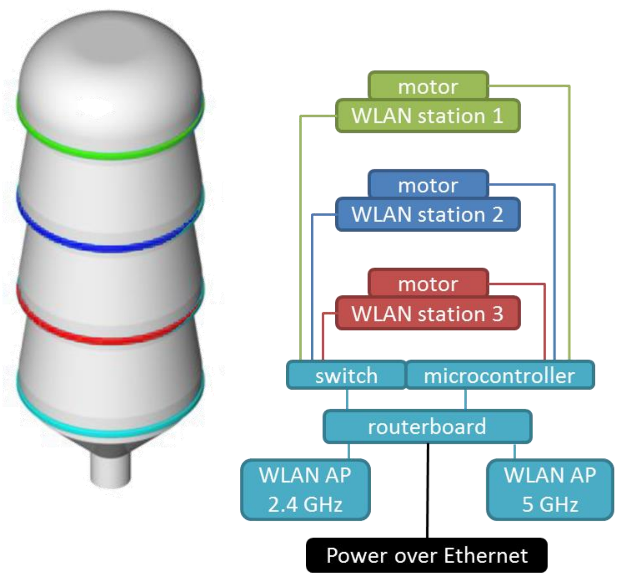

Figure 2. WGW building blocks

The COFR (Communication Field Relay) acts as local communication hub for the field commanders. The COFR provides network connectivity for the field commanders and offline functionality. Different uplink technologies can be connected to the COFR to ensure its interaction with MICS and Fixed Infrastructure. The COFR consists of several embedded linux boards running different services such as a SIP Server, webserver or proxyserver. The COFR is powered by a battery and for data storage a SSD is embedded. Further a router which on the one hand allows to connect different hosts via cable and on the other hand ensures the connection to the Wireless Gateway (WGW). The router also offers the possibility to connect different uplink technologies (via Ethernet Interface). A schematic diagram of the COFR is shown in Figure 1.

The WGW [14] establishes a meshed network with other Wireless Gateways using WIFI technology. It consists of the building blocks shown in Figure 2.

The WGW is a compound of various components assembled on four layers enclosed in a housing. In the top three layers, the WLAN stations are placed. Each of these identically constructed layers contains a wireless network interface with a directional antenna attached to it. With an electric actuator (motor) the antenna can be rotated by 360°. The configuration of the wireless network interfaces can be switched between a wireless access point configuration and a wireless client configuration, which is used to build up peer-to-peer connections between two WLAN stations of two WGWs by the self-align algorithm. The base layer contains a router-board which is an embedded system running the open source OpenWRT operating system. The router-board provides routing functionalities and runs the self-aligning algorithm. A switch on this layer connects the WLAN stations to the router-board. Also the COFR is connected to the router-board via this switch. The router-board consists of two further WLAN interfaces one operating in the 2.4 GHz frequency band and the other in the 5 GHz band. The 2.4 GHz interface is used to connect wireless end user devices while the 5 GHz interface is used by the self-aligning algorithm of the remote WGWs. Furthermore, on the base layer a microcontroller is included responsible for the rotation of the individual WLAN stations by triggering the actuators at the top three layers.

The field commanders are using tablet devices to access the different IDIRA services on the MICS or on the Fixed Infrastructure.

Figure 3 shows a potential network deployment of the IDIRA components. The network concept is fully flexible. The Fixed Infrastructure and the MICS can be connected by different technologies such as 3G/4G, BGAN, VSAT, Cable, DSL or any other broadband network technology providing Internet access. Also the COFR can use different technologies as Internet uplink. The tablet devices can use the COFR/WGW for its uplink or an existing 3G/4G network. If the Internet is used for data transport a VPN connection is used.

At the MICS a meshed network using the COFR and WGW can be established to provide network connectivity for the field commanders. Further also point to point or multipoint technologies provided by first responder organizations can be embedded into the network concept. For example for a farer away operational site a point to point WiMAX link can be integrated.
This fully flexible approach allows that in any circumstances a working network with the minimum feasible effort can be established.

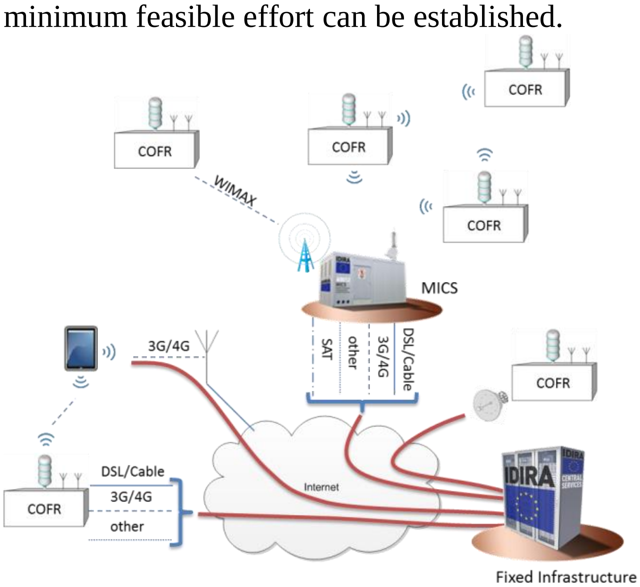

Figure 3. IDIRA communication network

The flexible approach allows using different pre-existing technologies to interlink the different components, thus fulfilling REQ1. The usage of 802.11 technology licence free spectrum ensures that the system can be used almost all over the world (REQ3). In the field the COFR and the WGW have to be plugged together, and the WGW has to be mounted on a pole. Everything else is performed automatically by the self-alignment algorithm, thus the installation of the system is easy and can be performed by non-IT experts (REQ2). For the connection to the end-devices 2.4GHz 802.11 WIFI is used, which is a standardized technology embedded in many end-user devices such as smart phones, tablet devices or laptops (REQ5).

4 OFFLINE FUNCTIONALITY

In case of a network disruption it is essential that at least some of the information can still be accessed. To support offline usage we have foreseen different concepts at different levels.

Within the Fixed Infrastructure all services are running and all the data is present. Further also external expert systems can be accessed. The MICS also has all services running and all the data is present at the MICS. In case of a network failure or in case that no Internet Uplink is feasible, the system would be fully functional. Only the access to an external expert system, which do not influence the core functionality of the system, would not be possible.

Further each COFR provides a copy of the static information such as a local map of the operational area. All the accessed information is cached on the COFR. Consequently all the information which has been accessed by a user at the COFR is available to all users connected to the same COFR. The design of the COFR also allows voice calls between individuals connected to the same COFR. Consequently the COFR provides basic functionalities to ensure offline operation.

Additionally a native Android Application for field commanders which provides static information like maps was developed. This App synchronizes all the data with MICS/Fixed Infrastructure when it is online. When it is offline it shows the local information and can be used exactly in the same way as it would be online. All the information entered by the field commander when the device is offline is cached and synchronized when the device is online again.

This flexible offline concept on different layers ensure that the system can even be used when the network is (partially) down (REQ4).

5 PROTOTYPE

The networking concept of IDIRA lead to two different prototypes for the communication network. The first prototype is the WGW shown in Figure 4.

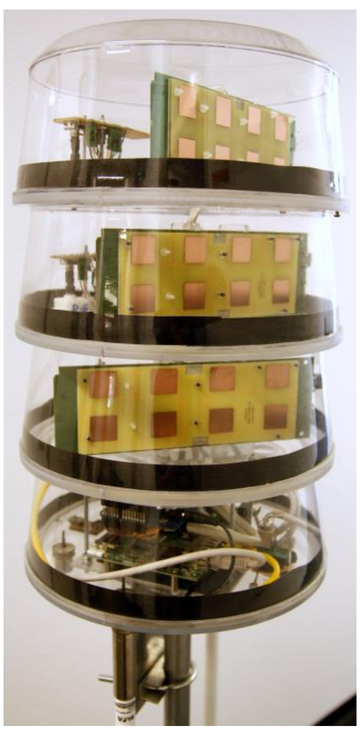

Figure 4. WGW prototype

According to the design pattern in section 3 for the WGW a modular plastic housing with four stacked layers of similar size has been built. An outer casing covers and protects all mechanical and electrical parts.

The WLAN modules in the top three layers are mounted to electrical driven turntables. Each of the turntables is equipped with a DC gear motor allowing a horizontal rotation by 360°. Consistent to the description in section 3 the motors are controlled by one central Arduino Leonardo microcontroller installed at the base layer.

The Arduino microcontroller is programmed to rotate one turntable individually of the others according to positions given by the self-alignment algorithm. As the microcontroller is not aware of cardinal directions it measures the angular displacement of each turntable to its home position. The microcontroller locates the home position of each turntable through a light-barrier mounted to it and a reflector attached to the housing of each layer. To determine the exact current position of a turntable a feedback signal from an incremental rotary encoder is used. This rotary encoder reads the output connector of the DC gear motor. The output signal provides a cyclic 2-bit pattern through two output signals. These signals (pulses) are used to increment or decrement a software counter. The value of the software counter can then be converted to a directional position of the turntable. Furthermore, this bit-pattern can also be used to detect the actual direction of rotation and the feedback signal also helps to detect mechanical problems like stuck or broken gear elements.

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The software inside the microcontroller is using the controllers' serial interface for reading and writing text messages. In context with the self-alignment algorithm inbound messages are interpreted as commands like rotate the top WLAN module to a specific position. Outbound messages can be seen as status information such as current positions of each turntable. After powering up an initialization process rotates all turntables to their home positions. During normal operation the Arduino controls the DC motor of a turntable and counts the pulses from the rotary encoders in order to calculate the turntables' current position as distance from its home position. In order to correctly calculate the angular displacement of a turntable regarding to a turntable's home position the current position of a turntable is stored in a non-volatile memory. The stored position also helps for fast recovery of connections in case of e.g. a power outage. As this position is recovered when the device powers up again and the homing procedure is finished.

As soon as a rotary encoder sends pulses while the motor is not in operation the software indicates a problem.

The microcontroller is connected via serial interface to the prototypes router-board at the base layer.

On each turntable a Nanostation M5 from Ubiquiti Networks is installed. The Nanostation M5 is a wireless networking equipment containing an 802.11n wireless interface operating in the 5 GHz frequency band together with a 16dBi directional, dual-polarized MIMO antenna. To connect the Nanostation to an Ethernet network it is additionally equipped with two 100 Mbps Ethernet interfaces.

To avoid useless space consumption within the WGW chassis the Nanostations' were installed to the turntables without their factory-provided protective cases. As the antenna built-in the Nanostation M5 has a non-symmetrical radiation pattern of about 42° azimuth angle and 15° elevation angle the horizontal orientation of Nanostations were shifted by 90°. The result is that the relevant radiation angle for the mechanical antenna alignment process is now 15°.

For interconnecting the three WLAN modules mounted in the top three layers and the base module at the bottom layer common and cheap Ethernet interfaces were used.

According to section 3 on the base layer a router-board is installed running the main logic of the WGW. The router-board is an industrial grade embedded board called Avila from manufacturer Gateworks. It contains an Intel IXP425 CPU and provides two 100Mbps Ethernet ports and 4 MiniPCI interfaces. We attached two Wistron NeWeb CM9 wireless cards to the board via MiniPCI. The CM9 is based on an Atheros AR5213A chipset and is able to operate optionally in 2.4 GHz or 5 GHz frequency band. We have chosen these cards as they are using the ath5k open-source Linux wireless driver compatible with the OpenWRT operating system. OpenWRT is the operating system of the Avila board.

Beneath the Arduino microcontroller and the Avila embedded board also a 5-Port 100Mbps Ethernet Switch is mounted to the base layer.

The switch is also capable of Power over Ethernet (PoE) functionality which we use as power supply for the Nanostation M5s. As power supply for the microcontroller, the motors and, the light-barrier sensor a 5V DC/DC converter is installed at the base layer.

As mentioned in section 2 OLSR is used as routing protocol. For that purpose the Nanostation M5s' firmware had to be changed to a version including OLSR routing. On OpenWRT at the Avila board also the OLSR package was installed. OLSR has been configured such that routes via Ethernet links are always preferred over routes via wireless links. This is done by the OLSR Link Quality Algorithm "etx_ffeth" and setting Ethernet links costs to 0.1.

The second prototype is the COFR. The COFR consists of two plastic housing which are installed at the foot of the pole. One housing is used for the battery-pack such that the battery-pack can easily be changed. For the battery we are using two Multipower MP18-12 lead acid batteries in parallel and a Kemo battery guard 148A set to 11V. The battery pack provides the power via a water proof Connex 12V cigarette lighter socket.

The second housing is used for the core components of the COFR. It can be powered by 12V (cigarette lighter plug) or 230V and includes the power distribution for 12V and 230V. In case of 230V power AC/DC converters for the different components are used. In case of 12V, a Cabstone 12V to twin USB converter is used.
As router a Mikrotik RB532 board is used. It features three 100Mbps Ethernet ports. The router is running the DHCP and DNS server for the network segment. One interface is used to connect to an uplink devices such as a VSAT terminal or 3G/4G router. The second interface is used to connect the WGW to the COFR. The third one is connected to a small 100Mbit/s 5port switch. One switch-port is used to connect LAN segments or remote p2p links to the COFR. To provide accessibility from outside Neutrik NE-8FDP are used. The other ports of the switch are used to connect to Raspberry PIs. The Raspberry PIs are used to provide the different services that need to run on the COFR. In the prototype two Raspberry PIs are acting as SIP server, webserver, proxy server and Map cache. A Transcend rugged 128GB SSD is connected to one of the Raspberry PI and caches all the data. The prototype of the COFR is shown in Figure 5.

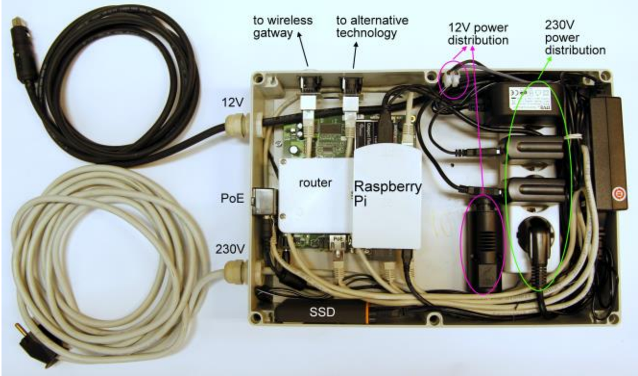

Figure 5. COFR prototype

The WGW and COFR system can be transported and installed by one single person. The system consists of the WGW unit, the COFR, the battery pack providing power capacity for about 12 hours, a tripod and a telescope pole of 6m height.

6 ALIGNMENT

The alignment algorithm is based on the state diagram shown in Figure 6. The state diagram shows the individual states of each of the three top layers of the WGW. The alignment algorithm is performed on the router-board on the lowest level of the WGW. Additionally to the state diagrams a central control instance is performed which choses which module is used when a request is received from a remote WGW and triggers the state changes.

Initially the modules are in state idle. From the idle state the control instance may trigger to perform a scan, trigger to connect to a remote WGW or being ready to be assigned to a remote node. In case a scan for remote WGW is performed the scan can be completed and returns into idle state. Further during scanning if a remote node is identified it will stop scanning and will be ready to connect to the remote WGW. If a remote request is received it will also stop the scanning and will be ready to be assigned to a remote node. If the remote node requesting the connection has been identified it will reconfigure the settings of the module and rotate itself towards the remote node and change the state to remote assigned. Once it is connected it will change the state to connected to module and regularly check if it is still connected. If the connection is lost it will change the state to lost connection to module and try to re-establish the connection for y minutes. If it fails to re-establish the connection it will change the state to reset.

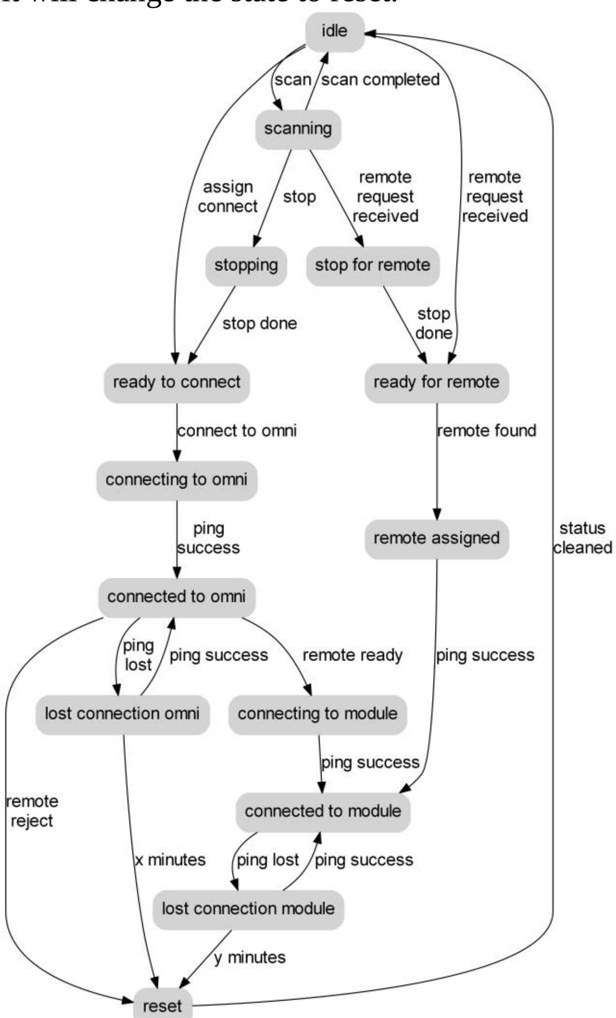

Figure 6. WGW state diagram

If a remote node has been identified without receiving a request from it, the parameters will be reconfigured to be able to connect to the 5GHz omni of the remote node (connecting to omni). Once it is connected (connected to omni), it will inform the remote node to establish a connection between two modules. If the connection to the omni is lost it will try to re-establish the connection for x minutes, afterwards it will change the state to reset. In the case that the requesting node answers the request in a positive manner the module will be reconfigured and a connection to the remote module will be established. If the module reaches the reset state the settings will be reset and the module returns to idle state.

7 SYSTEM USAGE AND RESULTS

For the applicability of the system we see four points to be crucial which have been analysed in more detail:

a) Distance between end-devices and WGW
b) Distance between two WGW
c) Easy installation
d) Able to cope with different technologies as Uplink

These aspects have been inspected in detail as they are crucial for the real world applicability of the system. For field units it is essential to know how far they can be away from a WGW/COFR and are still able to communicate. A study has been performed to have concrete values for this.

For the evaluation a Wistron NeWeb CM9 Wireless[1] miniPCI Card has been used. A WIFI-Link Omni directional antenna WLO-2450-09 is connected to the wireless card. The antenna has a gain of 9dBI. The wireless card is configured with a txpower of 11dBm such that the emitted power is within the regulatory limitations. For the measurements channel 1

1 http://www.hacom.net/sites/default/files/doc/CM9.pdf

has been used. The wireless card is installed on a Gateworks Avila Network Computer (Avila Board) running OpenWRT. An ASUS Netbook running Windows is connected to the Avila Board via Ethernet and used for throughput measurements to the clients. As WLAN client three different tablet devices have been used:

- Motorola XOOM MZ601
- ACER ICONIATAB
- SAMSUNG Galaxy Tab 8.9

The antenna has been mounted in a height of 6 meters. All the measurements have been performed with line of sight connection between the tablets and the Omni antenna. Figure 7 shows the WLAN signal strength measured at the different tablet devices. The field strength degrades with increased distance. The antennas embedded into the devices have different characteristics thus for example the Samsung Galaxy Tab outperforms the Acer tablet. Consequently an evaluation of the rugged tablet devices which will be used for IDIRA concerning their WLAN antenna and receiver sensitivity is needed. For example at a distance of 200m the ACER tablet receives a lower signal than at 300m, which decreases the performance in the range of 200m. The reason therefore has not been identified.

The measurements have been performed up to a distance of 350m between the WLAN access point and the tablet devices.

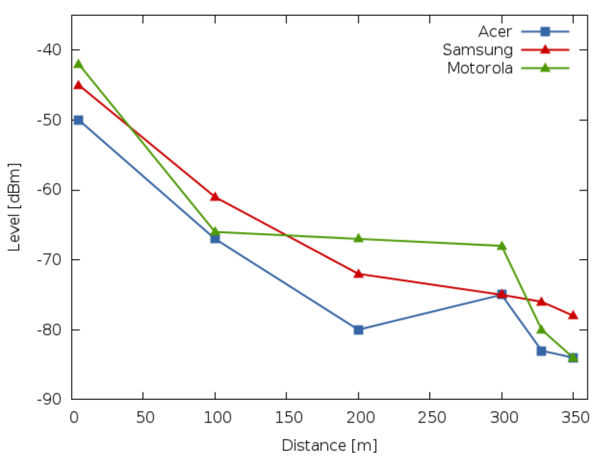

Figure 7. Signal Strength for Tablet devices

Figure 8 shows the throughput measured between the tablet devices and the Netbook (Upload). The throughput at the first 100m decreases very fast. Up to a distance of 300m the throughput is in a range where the speed is acceptable for IDIRA purposes. Only the ACER tablet at 200m (due to the low signal level received there) would cause problems due to the low throughput.

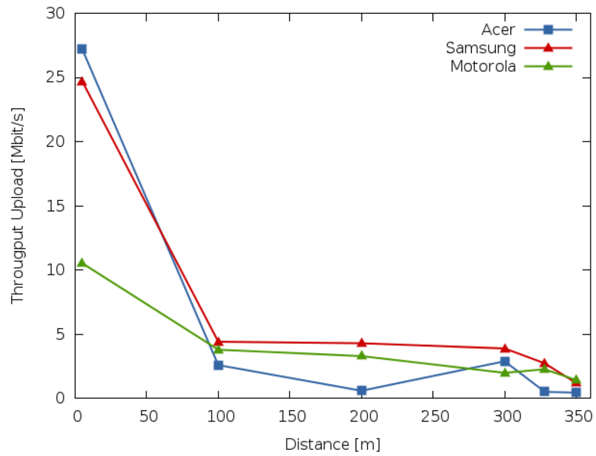

Figure 8. Throughput Upload

Figure 9 shows the throughput measured between the Netbook and the tablet devices (Download). The speed in the download direction is similar to the upload throughput, again distances up to 300m are feasible for IDIRA.

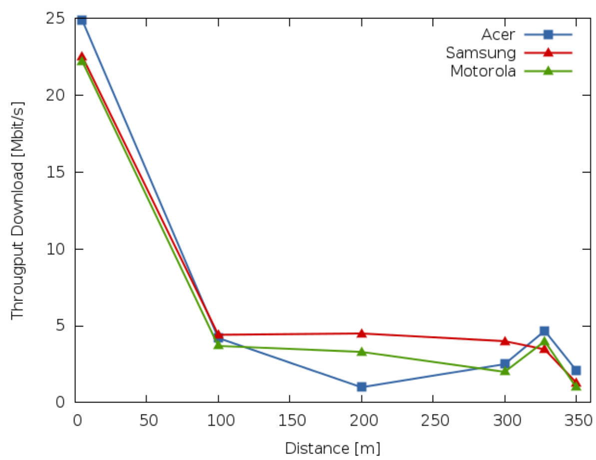

Figure 9. Throughput Download

To evaluate the possible distance between two WGW the setup shown in Figure 10 was used. The measurements have been performed between two ASUS netbooks directly connected to the WGW. To orchestrate the measurement the MINER software [15] has been used. The throughput measurements were done using iperf [16].

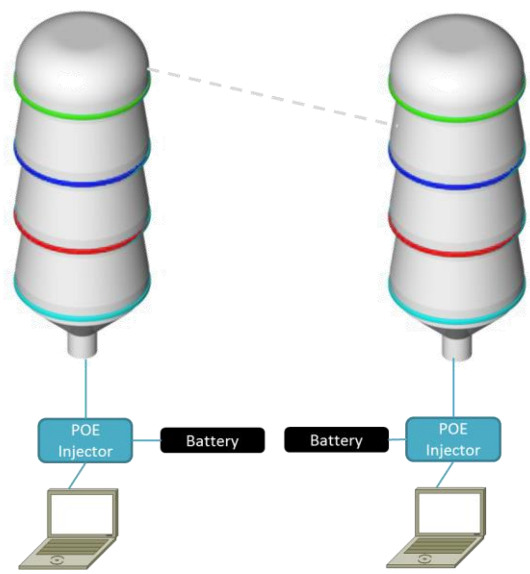

Figure 10. Measurement Setup

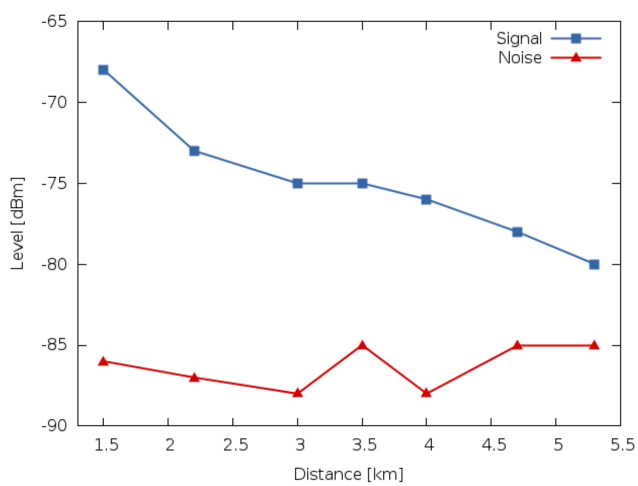

Figure 11. Signal Strength and Noise Level

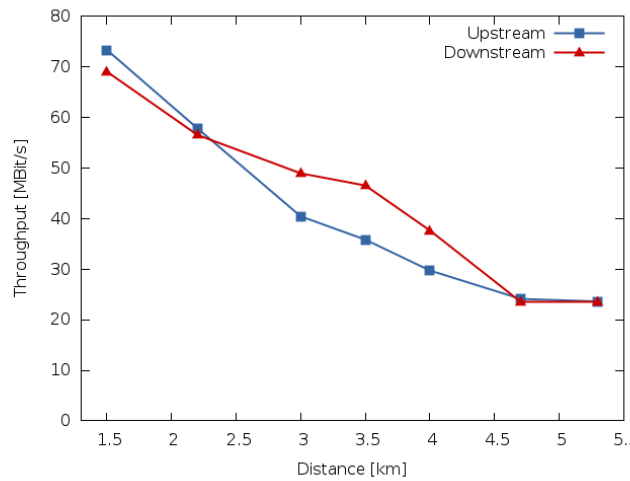

Figure 12. Throughput

Figure 11 shows the values for signal and noise levels in dBm and Figure 12 shows the measured throughput across the link. The SNR decreases from 18dB to 5dB. For distances up to 1.5km the throughput is close to the maximum speed of the Fast-Ethernet interface of the Nanostation M5. Even at a distance of about 5.5km the throughput has been in the region of about 20Mbit/s, which is sufficient for first responder communication needs.

The system has been extensively used during training and exercises within the IDIRA project. The system has been installed by different end-user organizations to show that the deployment is very easy and can be performed by field units of first responder organizations.

Different uplink technologies have been used during the real world deployment to show the applicability of the flexible approach. For the MICS WIFI, DSL and 3G network have been used. For the COFR 3G, Cable and DSL have been used as uplink technologies. The approach has shown its feasibility without any problems during these real world deployments.

8 CONCLUSION AND FUTURE WORK

This paper presents a flexible networking concept for large scale international emergency operations. The heart of the system are the Wireless Gateway (WGW) which establishes a self-aligning wireless mesh network using directional antennas and a Communication Field Relay (COFR) providing the possibility to use different uplink technologies and offline functionality.

The system requirements to be interoperable with existing networks, easy installation, allowed all over the world, offline capability and standardized interfaces to the end user devices could be fulfilled with the proposed solution. The system has shown its applicability during several training and large scale exercises within the IDIRA project.

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.

ACKNOWLEDGMENT

This work was partially supported by the IDIRA European FP7 261726 research project.

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