Aerial Base Stations with Opportunistic Links for Next Generation Emergency Communications

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The authors focus on describing the main outcomes of the ABSOLUTE project in terms of network and system architecture, regulations, and implementation of aerial base stations, portable land mobile units, satellite backhauling, S-MIM satellite messaging, and multimode user equipments.

Abstract

Rapidly deployable and reliable mission-critical communication networks are fundamental requirements to guarantee the successful operations of public safety officers during disaster recovery and crisis management preparedness. The ABSOLUTE project focused on designing, prototyping, and demonstrating a high-capacity IP mobile data network with low latency and large coverage suitable for many forms of multimedia delivery including public safety scenarios. The ABSOLUTE project combines aerial, terrestrial, and satellites communication networks for providing a robust standalone system able to deliver resilience communication systems. This article focuses on describing the main outcomes of the ABSOLUTE project in terms of network and system architecture, regulations, and implementation of aerial base stations, portable land mobile units, satellite backhauling, S-MIM satellite messaging, and multimode user equipments.

Introduction

Terrestrial communication infrastructures can be annihilated or partially damaged during disaster scenarios or temporary events [1]. In such scenarios, the necessity of re-establishing the communication system or deploying temporal infrastructures is a crucial requirement of public safety and disaster relief (PSDR) officers to provision essential services, aid, and reconciliation for communities in affected areas. Therefore, the ABSOLUTE project [2] designed and demonstrated an innovative rapidly deployable network architecture, which is capable of providing broadband multimedia services and dependable connectivity for large areas affected by unexpected disasters or temporary events.

Aerial and terrestrial rapidly deployable platforms are the key components of the ABSOLUTE system. They are required to deliver wide-area radio coverage with many applications, embedded in easily and rapidly deployable equipment, suitable for inhospitable areas (e.g., after a disaster). In addition, innovative concepts such as standalone Evolved Packet Core (EPC), cognitive mechanisms for dynamic spectrum management, network reconfiguration, as well as opportunistic and cooperative networking mechanisms maximizing ABSOLUTE system availability and dependability were developed.

This article focuses on explaining and describing the main outcomes of the ABSOLUTE project in terms of innovative research and real implementation. In order to achieve a representative overall validation of the proposed solution, a system demonstrator integrates major functionalities of system components such as:

- Long Term Evolution-Advanced (LTE-A) base stations embedded in low-altitude platforms (LAPs) enabling wide coverage for broadband services
- Portable land mobile base stations interoperable with conventional public safety networks
- Advanced multi-service professional terminals for first responders
- Satellite communications for both broadband backhauling as well as narrowband ubiquitous messaging services

As design guidelines, the demonstrator takes into account to a great extent the PSDR user requirements, and more precisely the 101 individual requirements detailed in [1] on the basis of technical perimeters identified after the system engineering phase.

The rest of this article is organized as follows. The PSDR communications requirements are explained. The proposed network and system architecture are presented, respectively. Then we concentrate on implementation details while also dealing with regulation aspects. Finally, we conclude this article.

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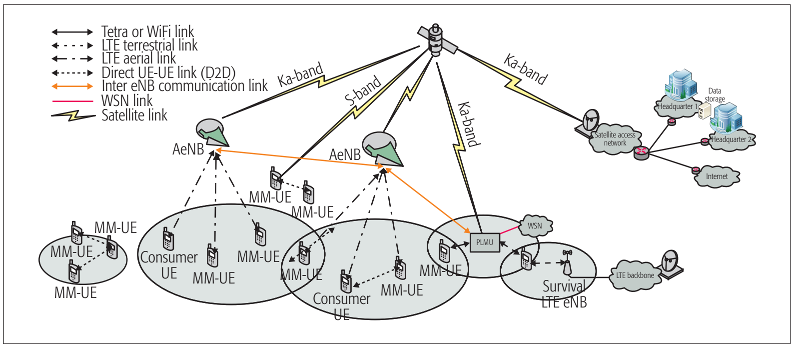

Figure 1. Overall ABSOLUTE architecture suitable for public safety scenarios. The main components of the ABSOLUTE network are aerial base stations (AeNBs), portable land mobile units (PLMUs), Ka-band satellite backhauling, S-MIM satellite messaging, and multimode user equipment (which are able to operate in direct mode).

Public Safety Scenario

Major PSDR network services encompass first responder intercommunication support, emergency medical and critical infrastructure communication facilities, surveillance and security, and so on. Such services rely on advanced devices, fully equipped to support demanding applications, notably in terms of bandwidth and delay, including the transmission of real-time video flows and high-resolution images and group conversations, and the support of remote sensing and monitoring. However, in post-disaster situations, the reliability and performance of such services may be seriously affected since regular networks can be exposed to significant impairments. For instance, terrestrial network infrastructure may be structurally damaged or subjected to power outages caused by multiple factors, including earthquakes and tsunamis.

PSDR Requirements

As a result, the nature and extent of a PSDR network is largely governed by the magnitude of the considered disaster. This leads to a series of requirements to address, including the size of the area to be covered, the number of users to support, the subsequent minimum network capacity, and the choice of adequate deployment sites for the required equipment. In addition, this network must operate robustly in potentially adverse conditions met in post-disaster situations (e.g., harsh weather, unfavorable radio propagation conditions, limited availability of electrical power, communication link disruptions, and unexpected user traffic surge). Moreover, it must be able to meet all of these constraints as autonomously as possible without compromising the expected performance. In this context, self-configuration and spectrum awareness techniques are particularly required to adapt to the existence, in the deployment area, of dynamic conditions (in terms of allowed or more appropriate frequency bands and radio frequency power bounds, power availability, varying opportunities to interconnect with surviving terrestrial infrastructure being restored, etc.) [1]. Furthermore, PSDR communication systems need to dynamically adapt to the environmental conditions of the deployment scenarios and, in particular, to the successive stages of post-disaster operations. In this regard, flexibility and modularity both represent key enablers to ensure adequate scalability of the PSDR network. Consequently, there is an increasing demand from the PSDR community for a reliable and scalable multi-purpose communication system, adapted to the provision of dynamic network coverage with low-delay and large-capacity transmissions, and able to interoperate with legacy PSDR networks.

ABSOLUTE Network Architecture

Scalable network coverage and capacity as well as a resilient, flexible, and secure infrastructure are essential features of the ABSOLUTE system. The network has been derived starting from the general user needs, and identifies the main subsystems and their interactions in terms of communication links in different scenarios [1]. The overall architecture is shown in Fig. 1.

Low-altitude platforms (LAPs), also referred to as aerial eNodeBs (AeNBs), are standalone aerial platforms that can rapidly be deployed by means of tethered balloons equipped with the LTE payload and capable of acting as base stations. LTE cell coverage can be controlled by properly setting the altitude of the helikite and transmission power.

Portable land mobile units (PLMUs) are standalone ground platforms that can be rapidly deployed in areas where terrestrial access for PSDR officers is available. The PLMU is characterized by a payload that can host several communication technologies. The PLMUs also extend the AeNB coverage and capacity by acting as eNBs, and providing terrestrial trunked radio (TETRA) and Wi-Fi connectivity.

Wireless sensor networks (WSNs) are spread over the disaster area or carried by PSDR teams. WSNs acquire different ambient information regarding temperature, humidity, or other metrics. PLMUs act as gateways for information gathered by WSNs.

Satellite backhauling functionalities for the AeNB and PLMU subsystems are achieved by means of a broadband link in the Ka-band with a geostationary satellite. This offers the system users a reliable and resilient connection to headquarters and the Internet. Notice that inter-eNB communication is also implemented by the adoption of a wireless backhaul link, using, for example, longer-range Wi-Fi technology [13].

S-MIM bidirectional messaging is implemented using the S-MIM satellite protocol. It provides PSDR officers an immediate narrowband communication with the headquarters [4].

Multimode user equipments (MM-UEs) are powerful terminals capable of supporting multiple radio links and additional services. Such devices allow PSDR officers to associate with the AeNB or PLMU to communicate with each other via LTE, Wi-Fi, or TETRA, or with their remote headquarters via the satellite link.

Device-to-device communications (D2D) links are established in an ad hoc fashion among MM-UEs, via either LTE D2D mode orvia other interfaces (Wi-Fi or TETRA). D2D communications are used out of coverage, in coverage, and in partial coverage.

ABSOLUTE System Architecture

In order to enable good connectivity over the variety of technologies available in network architecture, a coordinated mechanism such as dynamic spectrum sharing (DSS), improved handover, energy management, relay and clustering techniques, optimal base station placement, and others have been designed [4–13].

Flexible Management Entity

The LTE cells of ABSOLUTE-eNBs (AeNBs or PLMUs) are designed to work totally isolated from the physical EPC using the flexible management entity (FME) [7]. A standalone EPC is the architectural concept introduced by the FME in the ABSOLUTE architecture. The main objective of the FME is embedding the most fundamental EPC operations at the ABSOLUTE-eNB side (Fig. 2). The main difference between the FME and conventional EPC is the change of residency of core network elements, which leads to multiple advantages toward system optimization, especially scalability, and easy and fast deployment. The main advantage of placing the EPC functionalities at the ABSOLUTE-eNB side is plug-and-play capability, allowing it to operate without the necessity of third party equipment, which is highly beneficial in disaster system deployments. Thus, the virtual-EPC (vEPC in Fig. 2) supports specific EPC functionalities that give the AeNB the freedom to operate autonomously providing connectivity and other services to users. It is composed of the following parts:

- The gateway agent (GW-A) manages all the mechanisms implemented for supporting serving gateway and packet data network gateway functionalities.
- The mobility management entity agent (MME-A) supports the mechanisms implemented for supporting the MME stack and non-access stratum (NAS) functionalities.
- The home subscriber server (HSS) is a database that contains public safety user and subscription-related information.
- The device-to-device agent (D2D-A) is responsible for managing D2D communications.

To support the networking requirements of operating an EPC, the FME implements additional units and agents:

- A routing management unit (RMU) is responsible for the routing mechanism in the network.
- A topology management unit (TMU) is responsible for topology optimization and load balancing techniques.
- A link management unit (LMU) manages the backhauling connectivity.
- A cognitive dynamic spectrum access agent (CDSA-A) implements cognitive dynamic spectrum access techniques.
- A disruption management agent (DMA) implements techniques for disruption-tolerant operations.

These units and agents perform tasks based on information collected at the cell or network level. These allow distributed radio and network resources management among the multiple access technologies and subsystems.

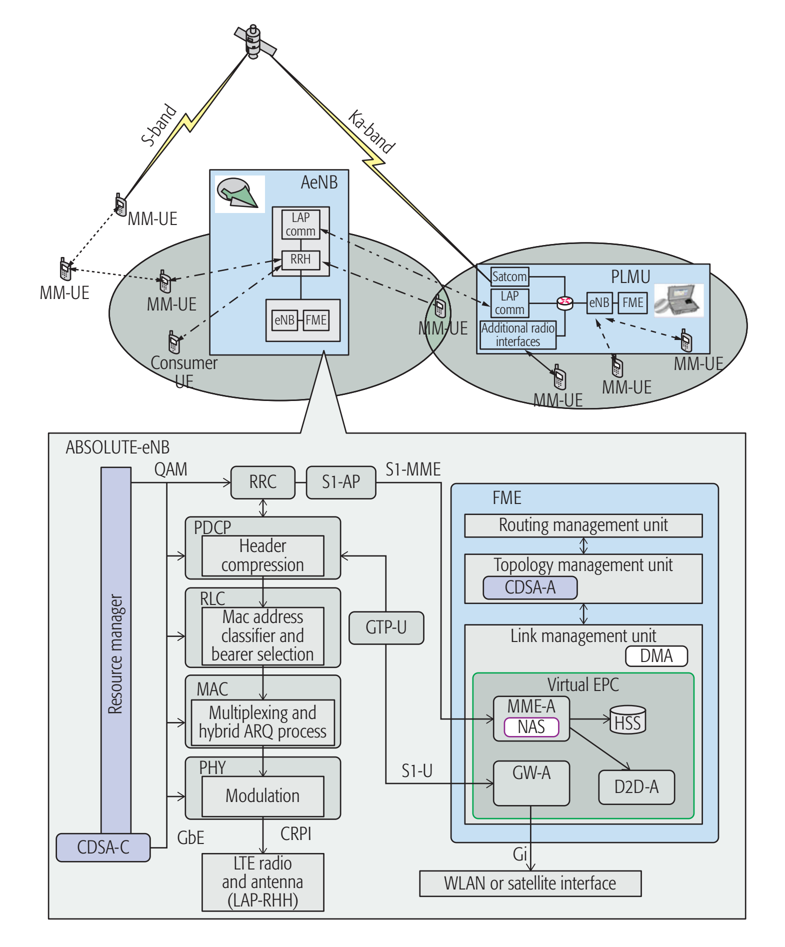

Figure 2. High-level view of the units and agents of the flexible management entity (FME), which is part of the system-level protocol of ABSOLUTE-eNB.

Mobility and Topology Management

Since the ABSOLUTE network is characterized by flexible and dynamic deployment of subsystems in order to provide coverage and sufficient capacity, the network is rolled out and rolled back in multiple phases. Therefore, several algorithms and techniques have been proposed in the ABSOLUTE project in order to optimize capacity in the dynamic network architecture using topology management protocols. Mobility management techniques that allow efficient mobility management of connected users across the subsystems have also been studied, including handover techniques and mobility robustness optimization schemes. The proposed techniques include:

- Geographical placement and re-placement of ABSOLUTE-eNBs such that coverage and capacity of the network are maximized and interference is minimized
- Clustering of MM-UEs mapped onto a limited number of ABSOLUTE-eNBs to improve energy efficiency
- Activation and deactivation of ABSOLUTE-eNBs and MM-UEs distribution to trade off traffic load, capacity, energy consumption, and so on
- Handover parameters optimization for reducing radio link failures

Figure 3. Aerial-eNodeB implementation: aerial segment (RRH and antenna) and terrestrial segment (EPC, LTE baseband Ka-band equipment) during validation phase.

- Detection and minimization occurrences of too-early and too-late handovers, wrong handovers, and unnecessary handovers (to avoid the ping-pong effect)

Dynamic Spectrum Sharing Mechanisms

The ABSOLUTE project focused on investigating, proposing, and implementing techniques for sharing portions of spectrum with primary users, since it is likely that dedicated spectrum will not be available in all cases for PSDR. Sharing needs to be achieved on a dynamic basis and is implemented in a distributed way at each eNB, using a CDSA-A. Dynamic spectrum sharing (DSS) is enabled using spectrum awareness to dynamically determine which resources are available for use, on either whole LTE channels or resource block groups within an LTE channel.

Spectrum awareness comprises a radio environment map (REM), which is an intelligent database that stores, processes, and delivers information about the status of the radio environment needed to support DSS. The REM is initially based on knowledge retrieved from mobile operators and telecommunications regulatory agencies about the locations of existing base stations and their basic parameters. This is supplemented by spectrum sensing, which is based on spectrum sensing information supplied by the ABSOLUTE-eNBs and MM-UEs. This allows the list of radio channels available for transmission, the maximum transmit power for a specified location, and configuration of each base station to be determined in real time in a distributed fashion. The REM, via a web interface, can also be used to calculate the coverage achieved with radio signals [13], exclusion zones, different LTE parameters, and expected throughput in the region.

This list of available resources is then used by the cognitive dynamic spectrum access to prioritize the resources to be used. This is an extended version of LTE-A, which creates the flexibility to achieve DSS within the PSDR context. Several cognitive techniques have been developed to prioritize the resources. These exploit different forms of machine learning, allowing historical information to be used to improve performance. These include [8–10]:

- An adaptive call admission control scheme for distributed reinforcement learning based dynamic spectrum access
- Heuristically accelerated Q-learning, which significantly speeds up the learning process
- Case-based reasoning reinforcement learning to cope with asymmetric traffic loads
- Transfer learning for dynamic spectrum and topology management in flexible architectures to assist with the rollout and rollback of the ABSOLUTE infrastructure in PSDR scenarios

D2D Communications

The advantage offered by the D2D feature is to enable proximity services and quick data exchange among MM-UEs without resorting to the intervention of the AeNB or PLMU. D2D communications over LTE require a number of challenges to be solved that include the definition of a D2D protocol for communication, potential D2D pair discovery, and security. In order to solve these challenges, a suitable protocol was proposed within the project [8], in which a selected MM-UE becomes the enabler, coordinator, and manager of the D2D network. Thus, when MM-UEs lose connectivity with the ABSOLUTE-eNBs, or the LTE coverage does not exist for at least a specific amount of time, the selected MM-UE is responsible for establishing and managing the D2D network. The proposed protocol includes the mechanisms for network discovery, D2D communication session setup, and association/disassociation in the different scenarios of radio coverage. In addition, a security mechanism for D2D that is based on exchanging shared encryption keys was also proposed [12]. The key strength of such a mechanism consists of its simplicity, and a number of security parameters have been studied in order to adapt to the peculiarities of D2D communications. It is worth emphasizing that devices involved in D2D communications are battery operated and therefore sensitive to energy waste. Furthermore, the length of the security keys must be limited to avoid having too high a requirement on the computational power and memory storage at the MM-UE side.

Demonstrator

The project consortium successfully demonstrated the use of several implemented subsystems of the ABSOLUTE system to the European Commission reviewers and end users (the event took place in France in September 2015).

AeNB Implementation

The AeNB is composed of aerial and terrestrial segments. The aerial segment consists of a Helikite platform with its radio remote head (RRH) (plus antenna and battery power payload) operating at varying altitudes on the air, while the terrestrial segment consists of an eNB baseband (plus EPC and satellite equipment) operating stationary on the ground.

Aerial Segment: An important component of the aerial segment is the Helikite, which is a helium inflatable kite that relies on lighter-than-air principles to achieve buoyancy, with increased lift and stability thanks to its kite profile and the use of a tether (which is moored to the terrestrial segment). Helikite aerostats are reliable in high winds, heavy rainfall, or very dusty conditions. The ABSOLUTE system uses moderate sized helikites of 34 m^3, which are highly mobile, simple/fast to set up, and only require a few days of training for operators. This helikite is 6.5 m long and 5 m wide, and has a net helium lift in no wind, in dry conditions, of 14 kg. Note that rainfall, snow, sleet, and so on will reduce the lift by 3 kg or so. Therefore, this leaves about 10 kg for maximum payload, including RRH, fiber optic, batteries, waterproof cases, and so on.

Since the helikite payload is limited, significant effort has been made in designing and choosing efficient but very lightweight and cost-efficient RRH, waterproof suitcase, batteries, and antennas that integrate easily into the AeNB environment. To achieve this, metalized foam has been used to realize the antenna. The total weight of the helix antenna including radoma, cable, and *N* connector is 240 grams. The helikite also provides a system suitable to fix the RRH in the kite and the antenna shapes onto the balloon, which consists of two vertical bars fixed at the back of the balloon, as shown in the aerial segment of Fig. 3.

Another key component of the aerial segment is the RRH, which supports a wide frequency range from 70 MHz up to 6 GHz. The RRH design allows a power reduction to 1 A, without power amplifiers (PAs), while with external PAs, the power consumption totals 1.7–1.8 A. Flexible software defined radio (SDR) runs on the RRH. SDR consists of a stacked digital interface card and a radio frequency front-end fiber optical baseband interface. The most relevant SDR-RRH characteristics are:
- 2 radio frequency transceivers with 2-antenna duplex operation with up to 56 MHz analog bandwidth
- 70 MHz–6 GHz carrier frequency range and different reference clocks
- Duplex components (filters, diplexers and/or TDD switches) on extra plug-on modules

Device	Functionality
Energino	Measures the voltage, current, and power consumption
4G eNodeB	Provides an LTE network
WLAN router	Provides a Wi-Fi network
3G+ femtocell	Provides an HSPA network
Wireless sensor gateway	Provides environmental measurements and connectivity to the sensor nodes
Single-board computer	Constitutes the main processing platform
Relay blocks module	Allows switching on/off of the communication technologies for saving battery and increasing PLMU autonomy
Tablet	Offers an interface to the main user

Table 1. List of components integrated within the PLMU.

- Cognitive extension with key sensing functionalities for obtaining occupancy thresholds of spectrum and collecting data measurement (e.g., signal strength indicators)

Finally, an industry-standard common public radio interface (CPRI) is used for the optical link that connects the aerial (RRH) and terrestrial segment (eNB baseband). Notice that the fiber optic is moored with the helikite tender.

Terrestrial Segment: In the terrestrial segment, the eNB baseband boards are integrated in a 19 in AMC rack fitted in a deployable cabinet (hereafter called "baseband cabinet" and shown in Fig. 3) so that they can easily be used in outdoor conditions. In complement to the eNB baseband boards, the baseband cabinet comprises all the necessary functions of the AeNB subsystem. To this purpose, it is equipped with following elements:
- A MicroTCA rack aimed at receiving the eNB baseband boards for the PHY and MAC layers
- A server where the EPC software and SIP server software run
- A foldable keyboard and screen to have easy access to the server (e.g., to perform registration of new MM-UEs)
- A rack dedicated to routing, cabling, and powering functions of the terrestrial segment

The baseband cabinet is linked by Ethernet to the deployable Ka-band satellite terminal on one hand and to the RRH via optical fiber on the other.

PLMU Implementation

The PLMU corresponds to the terrestrial communication segment of the ABSOLUTE architecture. This unit is deployed on the ground and therefore offers smaller coverage compared to that reached with the AeNB. However, it provides additional wireless communication technologies and is also highly modular for answering different users' needs. The PLMU has been implemented as a complete communication system embedded in a rugged suitcase, as shown in Fig. 4. It is composed of several components,

Figure 4. Portable land mobile unit equipment (PLMU, on the right) and its battery (on the left) during the validation phase.

Communication	Technology	Cell radius (m)	Data rates (Mb/s)	
			Uplink	Downlink
SatCom	DVB-like	NA	8.4	18.5
Wi-Fi	IEEE 802.11n	450	29.8	31.9
3G	HSPA	600	3.9	17.9
4G	LTE Rel. 8	650	19.5	61.6

Table 2. Performance measurements of the PLMU.

listed in Table 1. The entire system can be powered by either a regular power outlet or a battery pack providing up to several days of autonomy, depending on the battery capacity and the components in use. The PLMU is modular and easily adaptable to the requirements of each specific emergency situation by using only the required communication technologies, which are switched on/off using the relay blocks module. External devices can be plugged to the PLMU for extending its capabilities (e.g., a satellite system for enabling satellite backhauling).

The components and applications integrated in the PLMU provide the following services and functionalities:

- *System management*: PSDR officers can remotely control the PLMU subsystems and see their power consumption.
- *Voice calls and SMS*: PSDR officers can call and send SMS to any other first responder, using either the same communication technology or any other one (interoperability), and to any public switched telephone network (PSTN) subscriber.
- *Internet access*: PSDR officers can access the Internet using any of the available communications technologies.
- *Messages and location*: Victims can send geo-located distress messages to the PSDR network using the ABSOLUTE application. PSDR officers can grade distress messages, see their location on a map, and exchange other PSDR messages.
- *Area monitoring*: PSDR officers can see environmental measurements (temperature, pressure, light intensity, humidity, etc.) provided by the deployed WSN and geo-located on a map.

Note that voice calls and messages services are supported and managed by a standalone Session Initiation Protocol (SIP) server running in the PLMU. Therefore, those services are available without an external Internet connection. SMS are enabled by the standalone EPC; additionally, the SIP server allows interoperability between the different communication technologies. Apart from local services, access to the PLMN and PSTN is also possible thanks to the SIP server communicating with an external SIP provider.

Performance Evaluation: The performance of the PLMU has been evaluated in both the laboratory and the field during the demonstration of the project. Different metrics have been measured, ranging from the services and application performance to the efficiency of the wireless communication networks. The results shown in Table 2 are obtained without any optimization of the radio frequency frontend (i.e., no dedicated power amplifiers and specific antennas).

Ka-Band Backhauling Implementation

Satellite is a critical component of ABSOLUTE system where infrastructure may be damaged or not fully functional. It allows for connectivity in almost any weather condition and any location. The Ka-band antenna subsystem is the element that connects the ABSOLUTE-eNB with the satellite segment, and thus enables the backhauling functionalities. The Ka-band antenna subsystem is auto-pointing and easy to deploy and set up with a minimal amount of training, as shown in Fig. 5. The Ka-band subsystem is composed of the following:

- *The antenna* is a portable and motorized satellite dish with auto-pointing functionalities. Less than 10 min is required for deployment and connection setup.
- *The suitcase unit* is a ruggedized 19 inches flight case hosting a modem, a router, and an antenna control unit. The modem is based on the ViaSat SurfBeam2 technology, granting high speed and performance.

The Ka-band backhauling makes use of the Tooway system of Eutelsat, which provides satellite broadband services all over Europe via the 82 spots of the high-throughput geostationary satellite KA-SAT, positioned at 9° East. The ground segment is composed of eight terrestrial gateways, plus two for backup, deployed in different regions and interconnected in a fiber ring for maximum reliability. This backhauling solution provides a tried and tested, stable, and reliable platform able to perform any IP communication, from voice to data, from any location in Europe as long as there is line of sight (LOS) from the terminal to the satellite.

S-MIM Messaging Implementation

Third party applications for messaging, including WhatsApp, Hangouts, Skype, and similar, installed on MM-UE can be used with the

S-band terminal. The S-band terminal acts as an IP satellite gateway for PSDR users connected to the S-band terminal via its embedded Wi-Fi access point. The transmission of data packets over the satellite link takes place according to the S-MIM standard.

The S-band terminal prototype, shown in Fig. 5, is integrated inside a polycarbonate ruggedized suitcase with a weight of 24 kg, and an embedded battery pack granting an autonomy of 3 h (it also works with 230 V AC). The S-band terminal uses two satellite antennas: one for transmission and one for reception. Although two omnidirectional antennas are embedded in the suitcase, it is recommended that two external directive antennas are used that ensure a higher gain. Communication in S-band was provided through the geostationary satellite Eutelsat 10A (E10A), positioned at 10°, East and the antennas have to be positioned in LOS with the satellite. The S-band terminal implements the S-MIM protocol with a spread spectrum on a channel of 5 MHz and operates at 2005 GHz in transmission and 2193 GHz in reception. It is optimized for bursts of messages, with a maximum transmitted power of 5 W. It provides a maximum data rate in transmission (terminal to satellite) of 80 kb/s and a maximum data rate in reception (satellite to terminal) of 2.1 Mb/s [4].

MM-UE Implementation

Nowadays smartphones and tablets are a real breakthrough compared to previous generations of terminals. Indeed, they can run many applications downloaded from app stores on the Internet and embed many interfaces and communication standards: 2G/3G, 4G (LTE-A), Wi-Fi, Bluetooth, and GPS. Adding some dedicated ABSOLUTE applications on a smartphone is a smart and cheap solution for the MM-UE. However, while having some appealing functions, the smartphone cannot answer all PSDR officers' needs as such, especially in disaster scenarios.

The MM-UE needs to be fully secure and reliable in adverse situations, with huge autonomy and extended radio range. Besides, for PSDR officers performing specific operations in harsh environments (high temperature, shocks, possible water immersion, etc.) with extended autonomy expectations and extended radio coverage, dedicated rugged devices are an imposition. To this end, two rugged MM-UE designs are defined:

- An autonomous small MM-UE for personal use
- A rugged Ethernet UE in aluminum casing

MM-UEs also include multi-band operations comprising PSDR bands, as well as commercially operated bands to allow users to roam from PSDR networks to public networks when needed.

Figure 5. Ka-band Backhauling (Antenna and Suitcase Unit) and S-band Messaging (Modem, Wi-Fi and Antennas) Satellite Equipment.

Regulatory Aspects

As a radio system, the used frequencies in the ABSOLUTE system must be coordinated with those of other nearby networks in order to minimize interference. In the temporary event scenario, the deployment of LAPs is coordinated by a PLMN operator (PLMNO), which uses the ABSOLUTE network to strengthen its ground network. It is therefore the responsibility of the PLMNO to obtain the appropriate licenses for the deployment of the ABSOLUTE network. On the other hand, in the disaster relief scenario, the system is deployed by the PSDR agencies, which must hold the appropriate frequency license in order not to disturb surviving network infrastructure. The European Union and NATO have agreed on allocating frequencies in the 300 MHz band for PSDR usage. In addition, countries in South America and the Asia-Pacific region will also use the 800 MHz band.

The radio spectrum for broadband PSDR (BB-PSDR) in Europe is still under study by Conference of European Posts and Telecommunications (CEPT)-ECC in Working Group FM49 [15]. This group provides a BB-PSDR regulatory framework, with 3GPP LTE Release 12 as the reference technology. The main directions followed in this regard are to consider the provision of broadband PSDR services within the paired frequency arrangement (703–733

The ABSOLUTE project designed and demonstrated the high capacity and coverage capabilities of technical solutions adapted to the field of broadband emergency communications in which LTE technology is predominantly adopted.

MHz and 758–788 MHz), provided that the implementation is in line with the assumptions made by the mobile telcos. Furthermore, there is consideration of a harmonized solution for ad hoc PSDR network usage above 1 GHz, and other solutions outside the 700 MHz band (e.g., 400 MHz) and/or the possible use of guard band and duplex gap of 700 MHz with a conventional duplex: for example, the following options are under consideration: 2 x 5 MHz (698–703/753–758 MHz) and 2 × 3 MHz (733–736/788–791 MHz). Nevertheless, the United States and Australia have already regulated the 700 MHz and 800 MHz bands, respectively, for LTE BB-PSDR usage.

Conclusions

The ABSOLUTE project designed and demonstrated the high capacity and coverage capabilities of technical solutions adapted to the field of broadband emergency communications in which LTE technology is predominantly adopted. In PSDR scenarios the key solution is to adopt flexible base stations embedded onboard aerial platforms and terrestrial land mobile stations. The ABSOLUTE project also provides a reference implementation for an interoperable and backward-compatible network solution, including relevant regulatory and standardization efforts, which enable quick adoption of 4G communication technologies to remarkably improve disaster recovery and crisis management preparedness. This is based on the ability to operate with existing LTE spectrum by exploiting energy-efficient cognitive mechanisms, which provide agile reconfiguration. Since technical and business cases for ABSOLUTE system exploitation are also been studied for industrial partners, it is expected that the ABSOLUTE system can rapidly be produced and marketed.

Acknowledgment

The research leading to these results received partial funding from the EC Seventh Framework Programme (FP7-2011-8) under Grant Agreement FP7-ICT-318632.

References

[1] M. Kobayashi, "Experience of Infrastructure Damage Caused by the Great East Japan Earthquake and Countermeasures against Future Disasters," *IEEE Commun. Mag.*, vol. 52, no. 3, Mar. 2014, pp. 23–29.

[2] A. Valcarce *et al.*, "Airborne Base Stations for Emergency and Temporary Events," *Proc. PSATS*, Toulouse, France, June 2013.

[3] I. Bucaille *et al.*, "Rapidly Deployable Network for Tactical Applications: Aerial Base Station with Opportunistic Links for Unattended and Temporary Events ABSOLUTE Example." *Proc. IEEE MILCOM.*, Nov. 2013, pp. 1116–20.

[4] A. Recchia, F. Collard, and N. Antip, "Performance Analysis of the S-MIM Messaging Protocol over Satellite," *Proc. Advanced Satellite Multimedia Sys. Conf. and Signal Processing for Space Commun. Wksp.*, Sept. 2012, pp. 7–12.

[5] A. Hourani. S. Kandeepan and S. Lardner, "Optimal LAP Altitude for Maximum Coverage," *IEEE Wireless Commun.*, vol.3, no.6, Dec. 2014, pp. 569–72.

[6] S.Chandrasekharan *et al.*, "Clustering Approach for Aerial Base-Station Access with Terrestrial Cooperation," *Proc. Wi-UAV Wksp.*, *IEEE GLOBECOM*, Atlanta, GA, Dec. 2013, pp. 1397–1402.

[7] K. Gomez *et al.*, "Enabling Disaster-Resilient 4G Mobile Communication Networks," *IEEE Commun. Mag.*, vol. 52, no. 12, Dec. 2014, pp. 66–73.

[8] Q. Zhao, D. Grace, and T. Clarke, "Transfer Learning and Cooperation Management: Balancing the Quality of Service and Information Exchange Overhead in Cognitive Radio Networks," *Trans. Emerging Telecommun. Technologies*, vol. 26, no 2, Feb. 2015, pp. 290–301.

[9] N. Morozs, T. Clarke, and D. Grace, "Distributed Heuristically Accelerated Q-Learning for Robust Cognitive Spectrum Management in LTE Cellular Systems," *IEEE Trans. Mobile Computing*, published online 17 June 2015.

[10] N. Morozs, T. Clarke, and D. Grace, "Heuristically Accelerated Reinforcement Learning for Dynamic Secondary Spectrum Sharing," *IEEE Access,* Dec. 2015.

[11] L. Goratti *et al.*, "A Novel Device-to-Device Communication Protocol for Public Safety Applications," *Proc. D2D Wksp.*, *IEEE GLOBECOM*, Atlanta, GA, Dec. 2013, pp. 629–34.

[12] L. Goratti *et al.*, "Connectivity and Security in a D2D Communication Protocol for Public Safety Applications," *Proc. IEEE Wireless Commun. Sys.*, 26–29 Aug. 2014, pp. 548–52.

[13] D. Sekuljica *et al.*, "Mobile Networks Optimization Using Open-Source GRASS-RaPlaT Tool and Evolutionary Algorithm," *Proc. Euro. Conf. Antennas and Propagation*, Apr. 2015, pp. 1–5.

[14] T. R. Rasheed *et al.*, "On the Feasibility of Handover over WiFi Backhaul in LTE-based Aerial-Terrestrial Networks," *Proc. IEEE Wireless Commun. and Networking Conf.*, Apr. 2014, pp. 2196–2201.

[15] R. Ferrus *et al.*, "Public Safety Mobile Broadband: A Techno-Economic Perspective," *IEEE Vehic. Tech. Mag.*, vol. 8, no. 2, June 2013, pp. 28–36.

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