Capacity Evaluation of Aerial LTE Base-Stations for Public Safety Communications

Karina Gomez†, Akram Hourani‡, Leonardo Goratti†, Roberto Riggio†,
Sithamparanathan Kandeepan‡ and Isabelle Bucaille§
†CREATE-NET, via alla Cascata 56D, 38123 Trento, Italy
‡School of Electrical and Computer Engineering, RMIT University, Melbourne, Australia
§Thales Communications & Security, Paris, France
Email: {name.surname}@create-net.org; {name.surname}@rmit.edu.au; {name.surname}@thalesgroup.com;

***Abstract*—Aerial-Terrestrial communication networks able to provide rapidly-deployable and resilient communications capable of offering broadband connectivity are emerging as a suitable solution for public safety scenarios. During natural disasters or unexpected events, terrestrial infrastructure can be seriously damaged or disrupted due to physical destruction of network components, disruption in subsystem interconnections and/or network congestion. In this context, Aerial-Terrestrial communication networks are intended to provide temporal large coverage with the provision of broadband services at the disaster area. This paper studies the performance of Aerial UMTS Long Term Evolution (LTE) base stations in terms of coverage and capacity. Network model relies on appropriate channel model, LTE 3GPP specifications and well known schedulers are used. The results show the effect of the temperature, bandwidth, and scheduling discipline on the system capacity while at the same time coverage is investigated in different public safety scenarios.**

***Index Terms*—Aerial network infrastructure; emergency communications; low altitude platforms; Long Term Evolution (LTE);**

I. Introduction

During critical situations, communications among first responders of different public safety agencies are hampered by interoperability problems. In Europe, incompatibility is mainly due to the lack of a harmonized approach to frequency planning and standards for public safety communications. Thus the possibility to reuse commercial radio technologies for public safety communications is emerging as a suitable solution to solve interoperability issues. Furthermore, first responders need a better blend of reliability and multimedia capability, which can be provided by 4G-LTE cellular technology and its advanced version LTE-A.

Massive destruction of communication infrastructures caused by natural disasters or unexpected events might also hamper the communication of the public safety agencies over a disaster area. To fulfill the requirement of deploying flexible and rapidly deployable resilient communication infrastructures for public safety, the main goal of the FP7 ABSOLUTE project [1] is to design and validate an innovative holistic network architecture ensuring dependable communication services based on the following main features: rapid deployment, flexibility, scalability, resilience and provision of inter-operable broadband services.

In this paper, we studied a holistic and rapidly deployable mobile network architecture based on the hybrid aerial-terrestrial combination designed within ABSOLUTE project. The proposed architecture opportunistically combines terrestrial, aerial and satellite communication segments. Focusing on the aerial segment, we investigate the performance of Aerial LTE base stations (AeNB) deployed on airborne platforms in terms of achievable cell coverage and channel capacity for a 4G-LTE system in Frequency-Division Duplex (FDD) mode. In this context, we analyze the impact of several parameters such as temperature, bandwidth, scheduling disciplines and propagation environment on the aforementioned AeNBs coverage and capacity in scenarios modeled whereby appropriate channel model for air-to-ground propagation. Moreover we resort to well-known schedulers available in the literature.

The remainder of the paper is organized as follows. In Section 2 we summarize the related work, and in Section 3 we describe an Aerial-Terrestrial network architecture. In Section 4 the system model is discussed and Section 5 details the performance evaluation. Finally, we provide concluding remarks of the paper in Section 6.

II. Related Work

Few papers investigate the use of Low Altitude Platforms (LAP) for provisioning radio connectivity that specify the communication technologies and their performance. Authors in [2] investigate the feasibility of deploying High Altitude Platforms (HAP) carrying WiFi equipment for supporting multimedia broadcast/multicast services. In [3], the HAP–based emergency communications network for delivering emergency calls and multimedia broadcast services are investigated. The proposed network architecture consists of a two–hop relay system based on WiMAX stations. While, the use of balloons combining IEEE 802.11 technology for building an ad hoc communication is investigated in [4]. The main objective of the proposed network is to support emergency medical services inside incident areas. In our previous work [5], we investigated the performance of 4G LTE base stations embedded on aerial platforms in a Time-Division Duplex (TDD) configuration mode. We studied the effect of platform altitude and mobility on cell coverage and channel capacity.

978-1-4673-7359-3/15/$31.00 ©2015 IEEE

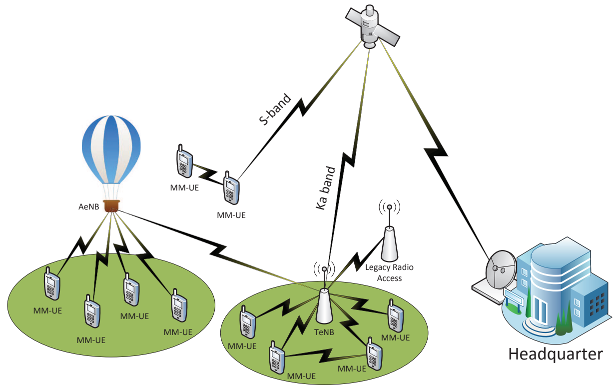


Fig. 1: Hybrid Aerial–Terrestrial Network Architecture proposed by ABSOLUTE project.

III. System Architecture

In the aftermath of a disaster, the coordination and effectiveness of support actions can be dramatically improved by the availability of a communication system capable to offer in a quick and reliable manner broadband links to interconnect different devices, as well as connect to remote command centers. Such objectives call for the challenging task to design a network that can be rapidly deployed and reconfigured. ABSOLUTE project has the aim to design and analyze a realistic Aerial-Terrestrial system architecture based on the 4G-LTE and satellite connectivity [1]. In order to implement a system capable to achieve the objectives mentioned above, the ABSOLUTE system has been designed following a holistic approach that opportunistically combines terrestrial, aerial and satellite communication capabilities. The overall network architecture proposed by ABSOLUTE project is illustrated in Figure 1. The proposed architecture adopts the features of the 3GPP LTE technology to efficiently support the low latency and high capacity requirements of future public safety networks and mass event requirements (e.g. soccer world cup). The ABSOLUTE architecture is based on:

- Aerial LTE Base Stations (AeNB): The AeNB subsystem will be deployed by means of tethered Helikites platform [6] equipped with the LTE payload (Remote Radio Head (RRH), batteries and antennas). An optical fiber using CPRI interface is connecting the RF part (RRH on the aerial platform) and the Base Band eNB (BB-eNB) being on the ground. The complete system (RF part and BB-eNB) is capable of acting as base station [7] and it is connected to a Flexible Management Entity (FME) [8], which is a virtual EPC [8]. Then the FME is connected to a Ka- band satellite modem in order to provide Internet access for the served devices. Notice that FME brings the CORE network close the end users, in this way the delay introduced by the satellite link is avoided in the intracell communications. The use of AeNBs allows envisioning efficient broadband mobile network planning, advanced mobility patterns, dynamic spectrum access and management as well as the provision of rapidly deployable multi-purpose services.

- Portable Land Mobile Unit (PLMU): The PLMU is a standalone and self-sufficient communication platform that integrate a WLAN access point, an IP router, a 3G femtocell, a Wireless Sensor Network gateway, a TETRA base station, a Ka-band satellite modem and a 4G eNB. Additionally, the PLMU also includes subsystems that support its main role as a communications platform such as batteries, power supply and a PC that controls all of the PLMU functions.

- Multi-Mode User Equipment (MM–UE): The MM–UE purposes is to integrate several technologies in order to provide at any time the necessary communication means for first responders. The MM-UE is able to communicate with AeNB, PLMU and also performs device-to-device communications.

The simulation parameters used in this paper are based in the settings that will be used in the final project demonstration of the ABSOLUTE communication system and they include frequency, coverage area, transmission power and bandwidth.

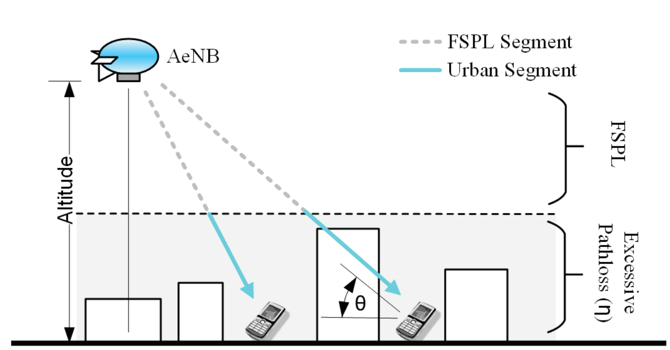


Fig. 2: ATG propagation model between an AeNB and UEs.

IV. System Model

A. Air-to-Ground Channel Model

Radio propagation in an Air-to-Ground (ATG) radio channel largely differs from legacy terrestrial propagation models since radio signals emitted by an AeNB propagate in free space until reaching the urban environment where they incur in shadowing and scattering caused by man-made structures (as depicted in Figure 2). In terrestrial communications, where the transmitted RF signals traverse the urban environment, the mean path-loss is usually modeled whereby a log-distance relation [9], with the radio signal's amplitude decaying as a function of the traveled distance. On the other hand, in an ATG channel, the path-loss is heavily dependent on the elevation angle which is the angle at which the AeNB is seen from the ground.

ATG path-loss is modeled with two components [10], [11]. The first component consists of the free space path-loss, whilst the second part includes the additional losses caused by the urban environment, called also as the *excessive path-loss* η. The ATG path-loss can be expressed as follows [10]:

$$\mathrm{PL}_{\xi} = \mathrm{FSPL} + \eta_{\xi} \ , \tag{1}$$

where FSPL represents the free space path-loss between the AeNB and a UE and ξ refers to the propagation group. The excessive path-loss of each propagation group is characterized with different statistical parameters, or in other words with is different mean and standard deviation, while the distribution is modeled as Gaussian. On the other hand the probability of group occurrence is by itself dependent on the elevation angle. Thus, the power received (in dBm) at the UEs is calculated as follow:

$$P_{\mathrm{rx}} = P_{\mathrm{tx}} - \mathrm{PL}_{\xi} \ , \tag{2}$$

where P_{tx} is the transmission power in dBm. The Signal-to-Noise-Ratio (SNR) is used to compare the level of a desired signal to the level of the receiver's noise. The received SNR is written as follows:

$$SNR = \frac{P_{\mathrm{rx}}}{k_{\mathrm{B}} \cdot T \cdot W \cdot N} \ , \tag{3}$$

where k_{B} is the Boltzmann constant in J/K ($k_B = 1.38 \cdot 10^{-23}$), T is the temperature in Kelvin, W is the bandwidth in Hz, N is noise figure of the UE, and P_{tx} in Watts. The SNR is crucial for obtaining a mapping with the LTE-defined Channel Quality Indicators (CQIs), which is explained below, as specified by 3GPP [12] technical specifications. Notice that the SNR is used because licensed spectrum dedicated to public safety communications in this case is allocated to LTE systems. However, in the case of unlicensed spectrum the Signal-to-Interference-plus-Noise Ratio (SINR) should be considered.

B. System Capacity Considerations

We consider an LTE-based cellular network where one AeNB is serving a set of m UEs with UEs indexed with i ($i = 1, 2, ..., m$). LTE transmissions are organized in radio frames (each radio frame consists of 10 sub-frames of 1 ms each) and resource blocks (RBs) over frequency. Thus, the downlink bandwidth is divided into a set of maximum n RBs, each RB is indexed by j ($j = 1, 2, ..., n$) [1]. In LTE systems each RB (physical channel) has a corresponding quality indicator, denoted here by α, expressing channel conditions. In practice, in the downlink case this information is provided by the UEs through the feedback of the Channel Quality Indicators (CQIs). Consequently, the a set of values α_{ij}, which denotes the CQI corresponding to UE i and RB j, is available at the AeNB. Notice that each α_{ij} can be represented by 16 standard values as shown in Table I [12]. Each value of α corresponds to a specific modulation and coding scheme (MCS), determining in this way the maximum capacity of a RB.

In terms of scheduled resources, a UE can be assigned with a minimum of one RB in frequency and one Transmission Time Interval (TTI) over time. A TTI is simple denoted by t hereinafter. Thus the role of the scheduling discipline is to distribute the available resources across the served UEs following specific rules. Therefore, the CQI values and the scheduling schemes are crucial elements in LTE and have significant impact on the system capacity.

1) Jains Fairness Index: In order to compare the different scheduler schemes the Jains fairness index is used [13]. This index, denoted by $\mathcal{J}$, quantifies the fairness among the users.

[1]It is worth reminding that each RB consists of 12 sub-carriers with 15 kHz of band each.

TABLE I: Channel Quality Indicator.

CQI (α)	**Modulation**	**Approximate Code Rate**	**Information bits per symbol**
0	no transmission	–	–
1	QPSK	0.076	0.1523
2	QPSK	0.120	0.2344
3	QPSK	0.190	0.3770
4	QPSK	0.300	0.6016
5	QPSK	0.440	0.8770
6	QPSK	0.590	1.1758
7	16-QAM	0.370	1.4766
8	16-QAM	0.480	1.9141
9	16-QAM	0.600	2.4063
10	64-QAM	0.450	2.7305
11	64-QAM	0.550	3.3223
12	64-QAM	0.650	3.9023
13	64-QAM	0.750	4.5234
14	64-QAM	0.850	5.1152
15	64-QAM	0.930	5.5547

The index $\mathcal{J}$ is calculated as shown below

$$\mathcal{J}(C_1, C_2, \ldots, C_m) = \frac{(\sum_{i=1}^{m} C_i)^2}{m \cdot \sum_{i=1}^{m} {C_i}^2} \ , \tag{4}$$

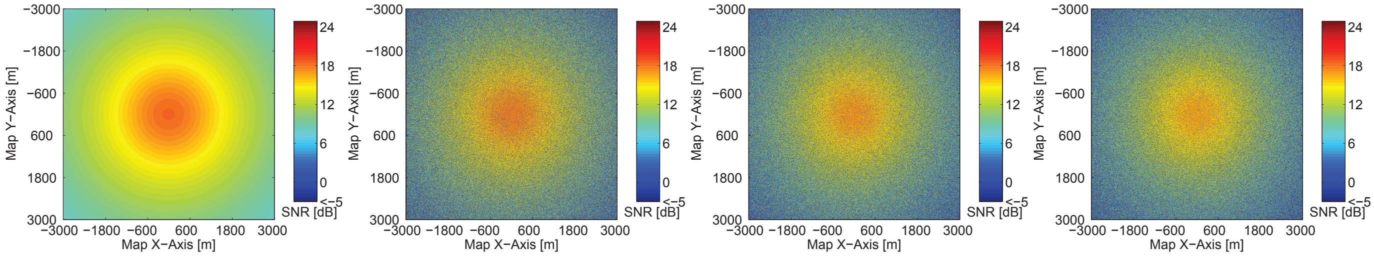
where C_i is the throughput of the ith UE from a total of m UEs. The index $\mathcal{J}$ equal to 1 reflects the case where all UEs receive equal number of resources (fair case). While decreasing index $\mathcal{J}$ reflects the case where UEs receive a different amount of resources depending on the scheduling discipline.

2) Scheduling Schemes: The majority of the LTE-based scheduling disciplines proposed in literature are based on maximizing fairness ($\mathcal{J}$) and throughput (C) [14]. The most well-known and used schedulers are:

- **Best CQI (Best–CQI):** It is an unfair scheduling scheme, where only UEs with the best channel conditions are scheduled across the available RBs (only the RBs with the best α are used while fairness is ignored).
- **Round Robin (RR):** To enhance fairness among UEs the RR scheduler can be used. UEs are scheduled with the same amount of RBs without taking the CQI into account (the α values are ignored but fairness is considered).
- **Proportionally Fair (PF):** In PF scheduler, each UE is scheduled using a utility function that takes into account the CQI and the amount of RBs assigned (the α values and fairness are both considered).

V. Performance Evaluation

A Matlab-based LTE simulator is used [15] in order to evaluate the capacity of the AeNB. Table II shows the simulation parameters used in the LTE simulator based on the 3GPP specifications [12] and setups of the ABSOLUTE project final demonstration. The simulation setup consists of a single LTE-cell, where one AeNB with an omni-directional antenna (SISO configuration) is located in the center at 1000 meters of altitude. It is assumed that the served area is a square of 6000x6000 meters. The cellular network is configured in FDD mode and the transmission power of the AeNB is



(a) Free Space, $T=-25°C$, (b) ATG, $T=-25°C$, (c) ATG, $T=20°C$, (d) ATG, $T=50°C$,

Fig. 3: SNR distribution over the AeNB coverage area (P_{tx}=23 dBm, W=10 MHz, Dense–urban Scenario, f=2.6 GHz).

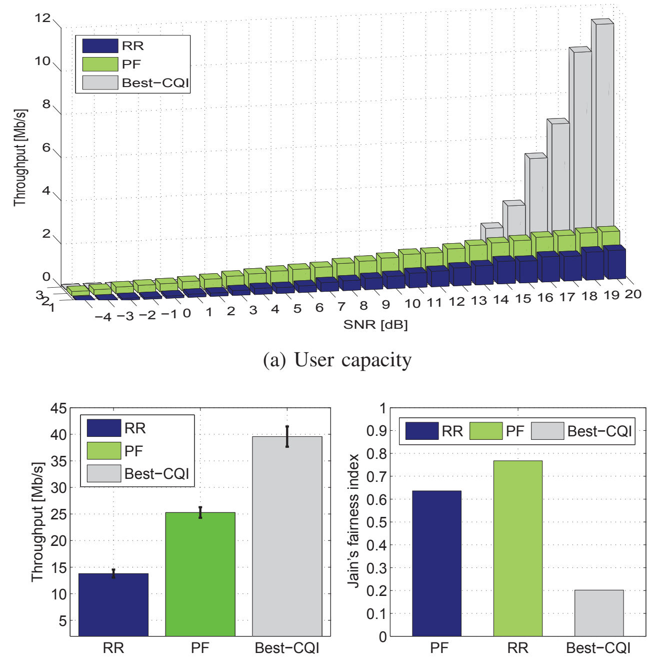
TABLE II: Simulation parameters [12].

Parameter	Value
AeNB Altitude	1000 m
Duplex Mode	Frequency-Division
System bandwidths (W)	[1.4, 3, 5, 10, 15 20] MHz
Number of RBs	[6, 15, 25, 50, 75, 100]
Carrier frequency (f)	2.6 GHz
RB bandwidth	180 kHz
TTI	1 ms
Modulation	QPSK, 16–QAM, 64–QAM
Transmission Power (P_{tx})	23 [dBm] (including antenna Gain)
Temperature (T)	[-25, 20, 50]°C
Channel Model	ATG Channel
Environment Properties	Sub–urban, Urban, Dense–urban, and High–rise urban
Antenna configuration	1 transmit, 1 receive (1x1)
Receiver sensitivity	-107.5 [dBm] (20°C, 50 RB)
Noise figure of the UE (N)	-7 [dB]
UE distribution	Uniform
Served UEs	[1, 25]
Traffic model	Infinitely backlogged
Schedulers	Best–CQI, PF, RR

set to 23 dBm including the antenna gain[2]. The licensed carrier frequency is fixed to 2.6 GHz, which is the choice of ABSOLUTE project for public safety communications. Bandwidth values used are 1.4, 3, 5, 10, 15 and 20 MHz in downlink, equivalent to 6, 15, 25, 50, 75, and 100 RBs respectively. Uplink traffic is not considered in this work.

As explained in the previous section, a statistical propagation model for predicting the ATG path loss between the AeNB and terrestrial terminals is used [10]. The results are based on the sub–urban, urban, dense–urban and high–rise urban environment characteristics, and on the elevation angle between the UEs and the AeNB. In order to reproduce public safety scenarios variable values of ambient temperature levels are considering (-25°C, 20°C and 50°C). To map the channel conditions of the UEs, CQI values are generated as specified in [15]. In the simulation a variable number of UEs is assumed, [1,25], which are uniformly distributed inside the cell. The UEs receiver sensitivity is set to -107.5 dBm (for 20°C and 50 RB). Traffic is modeled with a infinite backlog of packets or equivalently UEs are in saturation conditions. In order to serve

[2]23 dBm is the maximum output power achieved at the AeNB due to the weight payload limitations at the helikite, which limits the weight of the battery and consequently its power capacity.



(a) User capacity

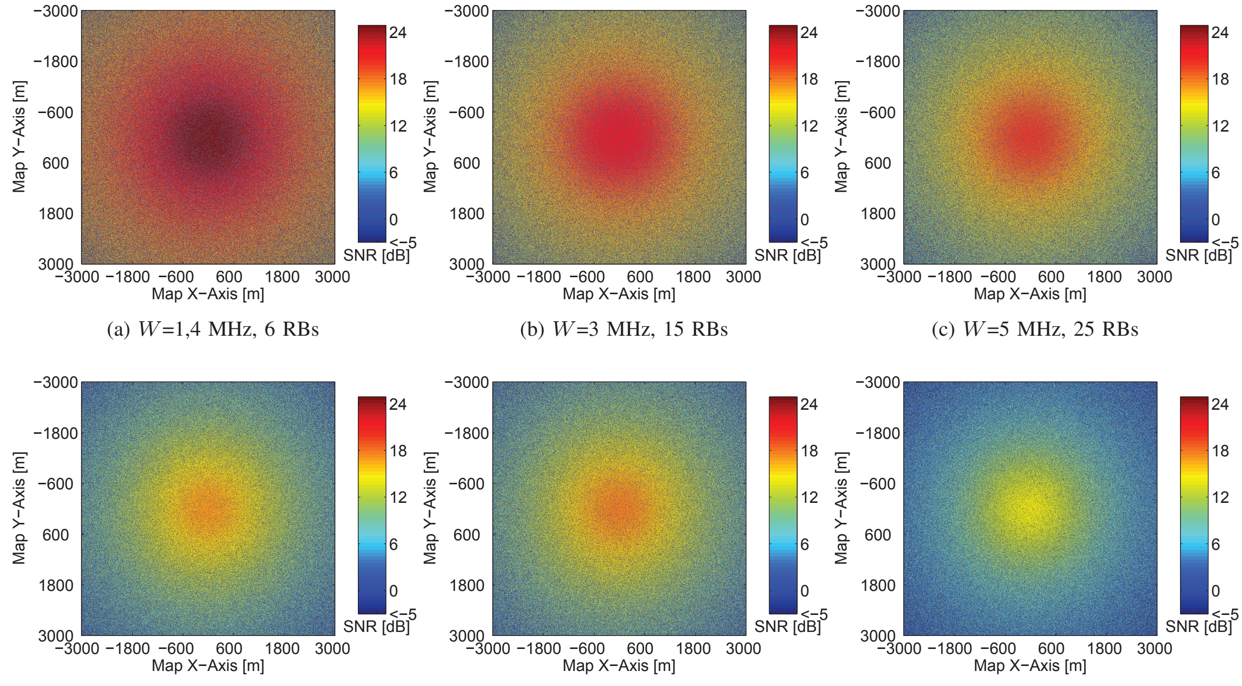
(b) AeNB capacity (c) Fairness

Fig. 4: AeNB capacity performance (P_{tx}=23 dBm, W=10 MHz, Dense–urban scenario, T=20°C, f=2.6 GHz, ATG model, UEs=25).

the UEs the RBs are distributed using RR, PF and Best–CQI schedulers [14]. Based on the receiver sensitivity, it is assumed that the communication between UEs and AeNBs is possible only with SNR values higher than -5 dB. The simulation results have been averaged over 1000 different simulations and reported with the 95% confidence interval.

Figure 3 shows the SNR distribution across the coverage area of the AeNB. The SNR was calculated using free space and ATG channel model using different ambient temperature levels (-25°C, 20°C and 50°C). The ambient temperature was selected considering the real requirements of the lower and higher temperatures achieved by first responder in disaster scenarios (more information on this are available in the Deliverable 2.1 of ABSOLUTE project [1]). As it can be noticed from the results showed in Figures 3.b-c, the temperature has little influence on the AeNB cell coverage.

Based on the results of Figure 3.c, Figure 4 shows through-



(a) W=1,4 MHz, 6 RBs (b) W=3 MHz, 15 RBs (c) W=5 MHz, 25 RBs

(d) W=10 MHz, 50 RBs (e) W=15 MHz, 75 RBs (f) W=20 MHz, 100 RBs

Fig. 5: SNR distribution over the AeNB coverage (P_{tx}=23 dBm, Dense–urban scenario, T=20°C, f=2.6 GHz, ATG model).

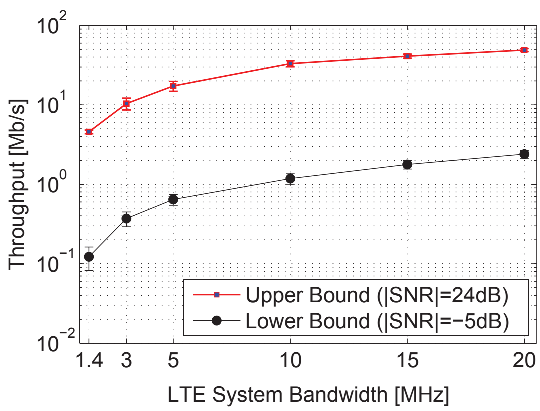
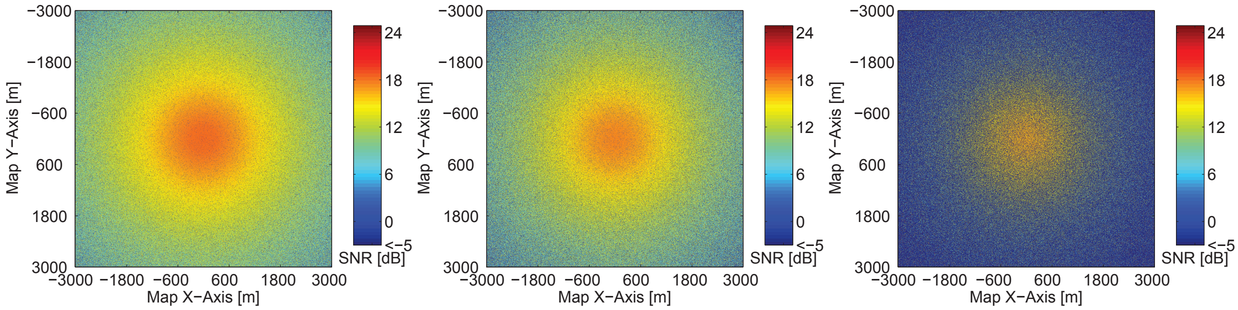


Fig. 6: Lower and upper bounds of the AeNB capacity versus LTE system bandwidth (P_{tx}=23 dBm, Dense–urban scenario, T=20°C, f=2.6 GHz, ATG channel model, UE=1).

put and fairness of different schedulers. The cell is serving 25 UEs (the UEs experience an average SNRs distributed from -4 dB up to 20 dB in steps of 1 dB). Figures are provided for RR, PF and Best–CQI schedulers for the bandwidths equal to 10 MHz and dense–urban scenario. The main objective of Figure 4.a is to show the effect of the SNR (and consequently CQI) on the achievable capacity of each UE. In terms of performance, Figure 4.b shows that the highest cell–level throughput is achieved using the Best–CQI scheduler since it serves only UEs with good channel conditions (see also Figure 4.a). The lowest cell-level throughput is instead achieved using the RR scheduler since it allocates the resources without taking into account channel conditions of the UEs. A compromise is achieved using PF scheduler since the channel conditions of the UEs are taken into account for allocating the resources. Looking at the fairness results showed in Figure 4.c, the lowest fairness is achieved with the Best–CQI scheduler as expected. The RR scheduler performs better than Best–CQI but worse than PF. The best fairness is achieved with the PF scheduler, thus complementing the good throughput performance achieved. Our results show that the scheduler discipline should be carefully selected for the AeNB because it has a strong impact on the capacity achieved by UEs and AeNB.

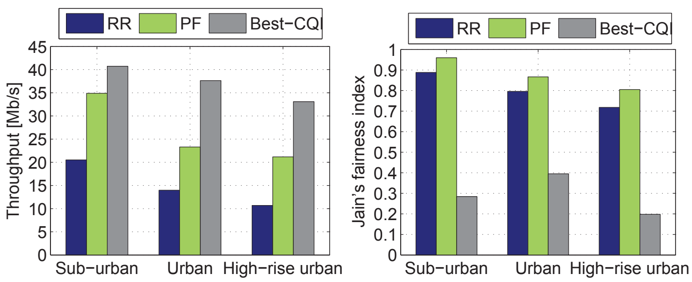
In order to understand the effect of the system bandwidth on the AeNB cell coverage and capacity, Figure 5 shows the SNR distribution across the coverage area of the AeNB using different LTE system bandwidth values in high–rise scenario. As it can be seen in Figures 5.a-f, the system bandwidth has considerable effect on the AeNB coverage area. Based on the results of Figure 5, Figure 6 shows the lower and upper bound of the cell-level capacity versus the LTE bandwidth. The cell is serving 1 UE with an average SNR equal to i) -5 dB for the lower bound, and ii) 24 dB for the upper bound. As expected the AeNB capacity depends on the amount of RBs in each LTE bandwidth value.

Finally, we analyze the effect of the propagation environment on the AeNB cell coverage and capacity, Figure 7 shows the SNR distribution across the AeNB coverage area using sub–urban, urban and high–rise urban propagation environments. As it can be seen from Figures 7.a-c, the different scenarios have considerable effect on the AeNB cell cover-



(a) Sub–urban (b) Urban (c) High–rise urban

Fig. 7: SNR distribution over the AeNB coverage area (P_{tx}=23 dBm, W=10 MHz, T=20°C, f=2.6 GHz, ATG model, UEs=25).



(a) Cell Capacity (b) Fairness

Fig. 8: AeNB capacity versus the characteristics of the propagation environment (P_{tx}=23 dBm, W=10 MHz, T=20°C, f=2.6 GHz, ATG model, UE=25).

age. Based on the results of Figure 7, Figure 8 shows the performance of RR, PF and Best–CQI schedulers in terms of fairness and capacity. The cell is serving 25 UEs uniformly distributing over the AeNB coverage area for the scenarios in Figure 7. We observe that the additional attenuation caused by the presence of buildings has an effect on the achievable capacity.

VI. Conclusions and Future Work

To bring broadband connectivity to public safety organizations in a resilient and reliable manner, the FP7 ABSOLUTE project has designed an Aerial–Terrestrial network architecture suitable for public safety communications. This paper has showed an evaluation of the achievable AeNB cell capacity and coverage in downlink for different perturbations caused by different factors. We selected the simulation parameters based on i) real requirements of the first responders during disaster scenarios, and ii) the setup of the ABSOLUTE final project demonstration. The simulations also considered an appropriate channel model for modeling air-to-ground propagation properties of the sub–urban, urban, dense–urban and high–rise urban environment. Our results show that temperature has little effect on the AeNB coverage area and capacity. On the other hand, bandwidth, scheduling discipline and environment properties significantly affect the AeNB coverage and capacity. More in general, we demonstrated that the adoption of AeNB is a suitable solution for provisioning coverage and broadband communications during emergency scenarios.

Acknowledgments

The research leading to these results has received partial funding from the European Commissions FP7 (FP7-2011-8) under the Grant Agreement FP7-ICT-318632.

References

[1] "ABSOLUTE EU FP7 Integrated Project," Available at http://www.absolute-project.eu/.

[2] G. Araniti, M. De Sanctis, S. Spinella, M. Monti, E. Cianca, A. Molinaro, A. Iera, and M. Ruggieri, "Hybrid system hap-wifi for incident area network," in *Personal Satellite Services*. Springer, 2010, vol. 43.

[3] L. ping Zhu, X. Yan, and Y.-S. Zhu, "High altitude platform-based two-hop relaying emergency communications schemes," in *Wireless Communications, Networking and Mobile Computing*, Sept 2009.

[4] A. Qiantori, A. Sutiono, H. Hariyanto, H. Suwa, and T. Ohta, "An emergency medical communications system by low altitude platform at the early stages of a natural disaster in indonesia," *Journal of Medical Systems*, vol. 36, no. 1, 2012.

[5] K. Gomez, T. Rasheed, L. Reynaud, and S. Kandeepan, "On the performance of aerial LTE base-stations for public safety and emergency recovery," in *IEEE Globecom Workshops)*, Dec 2013, pp. 1391–1396.

[6] "Allsopp Helikites Limited," Available at http://www.helikites.com.

[7] K. Gomez, T. Rasheed, L. Reynaud, and I. Bucaille, "Realistic deployments of LTE-based Hybrid Aerial-Terrestrial Networks for public safety," in *IEEE Workshop on CAMAD*, Sept 2013, pp. 233–237.

[8] K. Gomez, T. Rasheed, L. Reynaud, and L. Goratti, "FME: a flexible management entity for virtualizing LTE evolved packet core," in *IEEE Network Operations and Management Symposium (NOMS)*, May 2014.

[9] A. Al-Hourani, S. Chandrasekharan, and S. Kandeepan, "Path loss study for millimeter wave device-to-device communications in urban environment," in *IEEE Communications Workshops (ICC)*, June 2014.

[10] A. Al-Hourani, S. Kandeepan, and A. Jamalipour, "Modeling air-to-ground path loss for low altitude platforms in urban environments," in *IEEE GLOBECOM*, Dec 2014, pp. 2898–2904.

[11] A. Al-Hourani, S. Kandeepan, and S. Lardner, "Optimal LAP altitude for maximum coverage," *Wireless Communications Letters, IEEE*, vol. 3, no. 6, pp. 569–572, Dec 2014.

[12] "Technical Specification Group Radio Access Networks; Deployment aspects (Release 8)," Available at: http://www.3gpp.org/ftp/Specs/html-info/25943.htm.

[13] R. Jain, D.-M. W. Chiu, and W. R. Hawe, "A Quantitative Measure Of Fairness And Discrimination For Resource Allocation In Shared Computer Systems," Digital Equipment Corp., Tech. Rep., Sep. 1984.

[14] S. Schwarz, C. Mehlfuhrer, and M. Rupp, "Low complexity approximate maximum throughput scheduling for LTE," in *IEEE ASILOMAR*, 2010.

[15] J. C. Ikuno, M. Wrulich, and M. Rupp, "System level simulation of LTE networks," in *IEEE VTC*, Taipei, Taiwan, May 2010.