Hybrid System HAP-WiFi for Incident Area Network*

G. Araniti[1], M. De Sanctis[2], S.C. Spinella[1], M. Monti[2], E. Cianca[2], A. Molinaro[1], A. Iera[1], and M. Ruggieri[2]

[1] Department D.I.M.E.T, University Mediterranea of Reggio Calabria, Via Graziella Loc. Feo di Vito, 89100 Reggio Calabria, Italy
{araniti,silverio.spinella,antonella.molinaro, antonio.iera}@unirc.it

[2] Department of Electronics Engineering, University of Rome "Tor Vergata", Via del Politecnico 1, 00133 Roma, Italy
{mauro.de.sanctis,marco.monti,ernestina.cianca, ruggieri}@uniroma2.it

Abstract. Recent large scale disasters have highlighted the importance of a robust and efficient public safety communication network able to coordinate emergency operations even when existing infrastructures are damaged. The Incident Area Network (IAN) is a self-forming temporary network infrastructures brought to the scene of an incident to support personal and local communications among different public safety end-users. In this work we are interested in investigating how the High Altitude Platform (HAP) can effectively support Multimedia Broadcast/Multicast Service (MBMS) in a scenario wherein the preexistent terrestrial network is not available. To this aim, we propose an efficient policy of Radio Resource Management (RRM) based on cooperation framework between HAP and Mobile Ad-Hoc NETwork (MANET). The proposed solution has been successfully tested through a comprehensive simulation campaign.

Keywords: Incident Area Networks, Cooperative Multicast, MBMS, HAP, MANET, WiFi.

1 Introduction

Broadband communications are particularly significant features in those areas involved in catastrophic incidents, where effective and efficient communication means, infrastructures and procedures are required to react to the accident. In this context the communication infrastructure at the incident area is often completely destroyed or only partially available. As a consequence, to ensure radio communications for an efficient organization of the relief operations, a possible solution is the deployment of ad-hoc wireless networks as an Incident Area Network (IAN). It is a self-forming temporary network infrastructure brought to the scene of an incident to support personal and local

* This work has been supported by Italian Research Program (PRIN 2007) Satellite-Assisted LocalIzation and Communication system for Emergency services (SALICE)", http://lenst.det.unifi.it/salice

K. Sithamparanathan et al. (Eds.): PSATS 2010, LNICST 43, pp. 436–450, 2010.

communications among different public safety end-users (fire brigade, police, medics, etc) and their connection with a gateway [1], [2]. In particular, considering the users involved in post-disaster operations (for instance, Emergency Vehicles - EVs, First Rescues - FRs, etc.), the IAN can replace the damaged network infrastructure. This can guarantee the continuity of standard communications (for example voice traffic with the Coordination Centre) and allows the exchange of information data related to the particular situation (hereinafter Rescue Communications), such as data on location of FRs and EVs, alert information, electronic maps, video of the monitored area to support aid forces during their motion within the disaster zone. In such a situation, broadcast and multicast communications could allow an efficient utilization of limited IAN radio resources. For example, several FR teams are likely to operate simultaneously within the critical area; each team may need to establish multicast communications for specific information delivery or co-ordination among operators. Multicast service delivery can be easily guaranteed to users by utilizing point-to-multipoint MBMS (Multimedia Broadcast/Multicast Services) architecture [3], specifically designed within the third-generation (3G) cellular systems. Notwithstanding, a terrestrial MBMS segment cannot be adequate to match the exacting requirements arising in disadvantaged operational scenarios like the above-mentioned ones. High Altitude Platforms (HAPs) are very attractive in the view of assisting incident area networks in offering broadcast and multicast services [4]. This paper aims at defining the system architecture of the IAN, as proposed by the SALICE project [5], and the cooperation framework between HAP and Mobile Ad-hoc NETworks (MANET), specifically designed to increase the effectiveness of HAP in supporting multicast transmissions in a IAN. In particular, objective of this work is evaluate the advantages introduced by a possible HAP-WiFi cooperative architecture and to define a feasible Radio Resource Management policy to manage multicast traffic delivery in presence of *multiple* MBMS sessions.

The remain part of this paper is organized as follows. Section 2 describes the systems architecture of the IAN. Section 3 illustrates the transport channels features used for MBMS services from HAPs systems and, furthermore, it introduces the cooperative HAP/MANET policy proposed for the IAN. While the results of a exhaustive simulation campaign, aiming at defining the RRM policy, are the focus of Section 4. The performance degradation of the throughput of WiFi links caused by interference is discussed in Section 5. Finally, conclusive remarks are given in Section 6.

2 System Architecture

This section aims at identifying the end-to-end architecture and topology of the IAN, including space and ground network systems. As mentioned above, the end-to-end architecture proposed could be split into two different sub-networks, based on their coverage features: *Short-Range Network*, used to carry out communications within the Incident Area Network, and *Long-Range Network*, utilized for the communications toward external zones. Long-Range Network could consist of both a space and a terrestrial segment, while the Short-Range Network takes into account only the last one. Space segment comprises satellite (GEO and LEO) and UAV systems, while the terrestrial segment consists of several mobile/wireless communication systems, such as WWAN (UMTS, TETRA), WMAN (WiMAX standard), WLAN (WiFi standard), WPAN (IEEE 802.15.3 & IEEE802.15.4 standards). These kinds of terrestrial networks are very different in terms of offered data rate, delay, security issues and communication range. This strong heterogeneity poses several problems about the definition of an efficient integration scheme which allows a smart and quick communication between the various system actors. The IAN should be conceived as the result of integration between *(i)* existing and active systems not impaired by the disaster (i.e.: satellite systems, HAP platforms and also active cellular networks) to support long distance communications, and *(ii)* terrestrial networks quickly deployed in the emergency scenario that allow users either to communicate within the same area and to access the subsystems for connections with external zones by means of an IAN Gateway. In fact, the IAN will include several Master Mobile Nodes (MMN) with gateway functionalities, equipped with different interfaces: UMTS, Satellite Networks, HAP Networks, etc. According to our proposal, a IAN should be used for both voice/video/data transmissions and wireless sensor communications in the local and/or personal area [6]. In particular, in this research work we aim at investigating how efficient HAPs can be in supporting Multimedia Broadcast/Multicast Service (MBMS) in a IAN scenario in which this multicast services cannot be provided by the terrestrial coverage. Therefore, the approach to the definition of a IAN for emergency service management is the following (see Fig. 1).

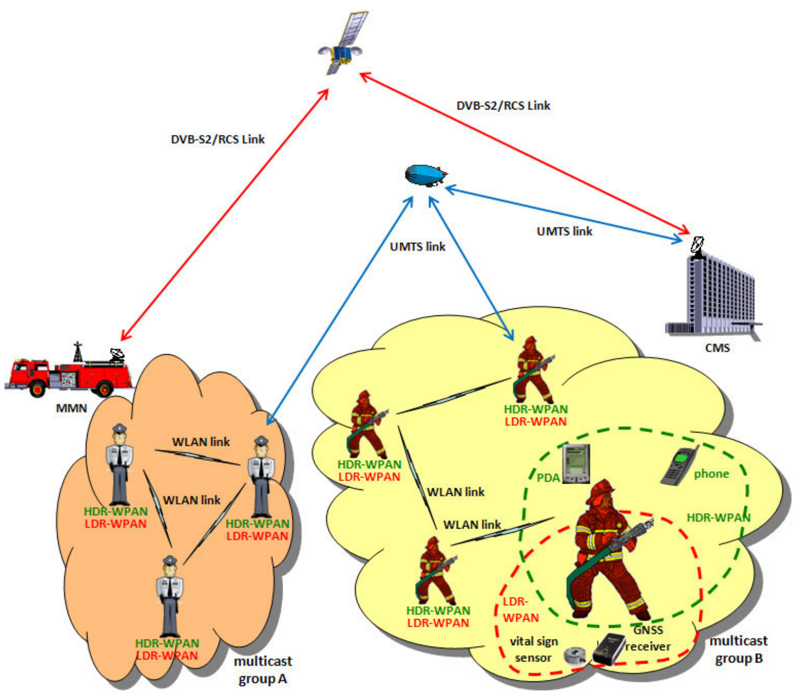

Fig. 1. System Architecture

The user (relief team member) is provided with a Relief Member Unit (RMU) which is a network node with multi-standard capabilities and bridge functionalities. The wireless standard used by the RMU are IEEE802.15.4, IEEE802.11 and possibly UMTS to allow communication with HAP system. All devices also equipped with HAP/UMTS interface could assume the role of *Anchor Node* during a multicast cooperative transmission. IEEE802.11 standard is used for communication between users in ad-hoc mode. UMTS link is used by the *Anchor Node* for relaying communications outside the IAN. Furthermore, the user is surrounded by two Wireless Personal Area Networks (WPANs) that can exchange information through the RMU:

- A LDR-WPAN composed by a set of sensors for location and context detection (e.g. vital sign sensor, temperature sensor, GNSS receiver, indoor positioning devices) with an energy-efficient Low Data Rate (LDR) WPAN air interface. The PHY transmission bit rate of the LDR interface ranges from few bps to 250 kbps [7].
- A HDR-WPAN based on IEEE802.15.3/Wimedia composed by a set of devices with a High Data Rate (HDR) WPAN air interface (e.g. Personal Digital Assistants, Phones, etc.). The PHY transmission bit rate of the HDR interface ranges from 10 Mbps to 50 Mbps [8].

This IAN should allow processing and fusion of location/context data collected by sensors of the LDR-WPAN in the RMU, and data delivery between network nodes in the HDR-WPAN and the access network. Since the above mentioned wireless systems for HDR-WPAN and LDR-WPAN exploit unlicensed frequency bands and they can be partially or totally overlapping in frequency, in this approach coexistence issues have to be carefully addressed and a solution beyond cooperation has to be identified, based on the concept of simultaneous use of different devices.

3 Cooperative Multicast

In order to optimize the coordination among different rescue teams, an efficient utilization of the limited radio resources have to be guaranteed. The employment of Multimedia Broadcast/Multicast Services provided by HAP in an incident area can enhance the overall system performance, since multicast emergency transmissions can be delivered to groups of receivers at the same time; thus avoiding data duplications both in the core network and over the air interface [9]. MBMS is the multicast technology developed by the 3rd Generation Partnership Project (3GPP). It is a downlink point-to-multipoint protocol thought for the delivery of a multicast and broadcast stream from a single source.

3.1 Transport Channels Supported by MBMS/HAP

The MBMS data can be delivered to users by utilizing any of three different transport channels: Dedicated Channel (DCH), Forward Access Channel (FACH), and High Speed Downlink Shared Channel (HS-DSCH). The selection of the appropriate radio bearer for a MBMS service should be done with respect to the other exiting MBMS sessions in the local emergency area and with respect to available power by HAP.

In this work we assumed to utilize only FACH and DCH channels, where the first one is utilized to deliver alerting information for all the population and rescue teams involved in the disaster area; while the second one is employed to deliver particularized multicast services to a given rescue team for their coordination (through Anchor Nodes, as it will be described in following). We decided not to use the shared channel, because in an emergency situation a dedicated channel (DCH) could be more reliable with respect to HS-DSCH that shares the resource with all the others users located in the same area.

Hence in this section, we briefly recall the modality to assign the transmission power to such two channels. The transmission power assigned to the DCHs can vary depending on: *(i)* the multicast users number; *(ii)* the users position with respect to the centre of the area covered by the HAP; *(iii)* the bit rate of the application.

In Eq. (1) it is shown how to define the transmission power assigned to a DCH serving the *i*-th user in a given cell (named *own cell* in the following) [10]:

$$P_{DCH,i} = (C/I)_i \frac{\sum_{j=1}^{N_{other\_cell}} P_j^{other} G_j^{other}(\theta_i, d_i) + p \sum_{k=1}^{N_{user}} P_k^{own} G_k^{own}(\theta_i, d_i) + P^{com} G_i^{own}(\theta_i, d_i) + N_d}{G_i^{own}(\theta_i, d_i)} \quad (1)$$

where the terms reported at the numerator represent: *(i)* the interference due to the transmitted power (P_j^{other}) from the *j*-th adjacent cell (the total number of interfering cells is N_{other_cell}); *(ii)* the interference due to the transmission power (P_k^{own}) from the *k*-th user belonging to the *multicast group* that receive data within the *own cell* (the total number of own cell users is N_{user}); *(iii)* the interference due to the power used for transmission over the downlink common control channels (P^{com}); *(iv)* the Additive Gaussian White Noise (AGWN) (N_0). Furthermore, p is the orthogonality factor which can be zero in case of perfect orthogonality, $G_i^{own}(\theta_i, d_i)$ is the link gain related to the *i*-th user with respect to its *own cell*, $G_j^{other}(\theta_i, d_i)$ is the link gain with respect to the *neighboring cells* while $G_k^{own}(\theta_i, d_i)$ is the one in the *own cell*; both are still related to the *i*-th user.

In general, $G(\theta$,d) and *C/I* (the Carrier-to-Interference ratio) are defined respectively by (2) and (3).

$$G(\theta, d)_{dB} = g(\theta)_{dB} - L_p(d)_{dB} \quad (2)$$

$$(C/I)_{dB} = (E_b/N_0)_{dB} - (P_g)_{dB} \quad (3)$$

θ is the angle representing the boresight direction, $g(\theta)$ is the Antenna Gain calculated in the boresight direction, $L_p(d)$ is the attenuation value caused by the Path Loss for the user at a distance equal to *d* from the centre of the HAP coverage area. E_b/N_0 is the Energy per Bit-to-Noise Power Spectral Density while P_g is the Processing Gain.

The FACH is a Point to Multipoint (PtM) channel with a power level high enough to guarantee an acceptable service in the whole coverage area [11]; it transmits at a fixed power level since fast power control is not supported in this channel. Both bit rate of the MBMS services and the cell coverage area affect the power allocated to FACHs.

High data rate MBMS services might not be deliverable by FACH, since excessive downlink transmission power would be required. High bit rates can only be offered to users located very close to the centre of the area covered by the HAP.

3.2 Hybrid Radio Resource Management Policy for IAN

Multicast transmissions have increased power requirements and consume a large portion of the available power resources of the HAP. As a consequence, the number of parallel multicast sessions that a HAP could support is limited. A promising means to overcome MBMS intrinsic limitations consists in integrating MANET technologies into HAP network. This solution foresees that RMUs cooperate in the multi-hop access to the HAP infrastructure by exploiting their short-range Wi-Fi interface. In so doing, a SALICE terminal will play the role of *Anchor Node* receiving the multicast traffic from the UMTS interface through a DCH; subsequently, it conveys the received packets, across the Wi-Fi interface, to its neighbour terminals within the MANET. This means that the users cooperate with each other to achieve the common goal of enjoying a multicast service at a given quality of service and, at the same time, cooperation between the MANET and the HAP network is established to increase the overall capacity and coverage of the IAN. The choice of the terminal to use as an *Anchor Node* is taken according to policies that may account for different parameter values.

Figure 1 shows an incident area, where a HAP serves two rescue teams (police and fire brigade) interested in downloading and streaming multicast services (i.e.: plans, video, electronic pictures and maps of the emergency site). It is worth noting that the number of users utilizing the same *Anchor Node* depends on the their mutual reachability that in turn is related to the *Wi-Fi radius coverage* (WF_{Radius}) and the *maximum number of allowed hops* (H_{Max}). For each rescue team the election of either one or more *Anchor Nodes* is foreseen.

To the purpose of reducing the adverse impact of multicast transmissions on the whole IAN traffic, an efficient Radio Resource Management (RRM) policy based on a HAP/MANET cooperative architecture is needed.

The RRM utilized for such a scenario has a threefold objective to: *(i)* define the access modality to the HAP/MBMS infrastructure from mobile terminals either directly (by means of FACH or DCH channels) or indirectly (multi-hop through the ad-hoc networks terminating to an *Anchor Node*); *(ii)* monitor continuously the conditions of network and terminals to the purpose of implementing the right policy for the election and the management of the *Anchor Nodes* at HAP level, on the basis of the signalling information sent by the cooperative terminals; *(iii)* monitor periodically rescue team priorities in order to deliver multicast information to the team with major need.

When a user terminal, for instance, a fireman's terminal, requests the access to a given multicast service, it checks in advance whether a FACH is already active for the same service. Should this be the case, then it joins the multicast group by accessing the local HAP FACH channel according to the MBMS rules. Otherwise, during a *listening* phase it searches for a reachable MANET handling a group/subgroup of users receiving the same multicast service. Following the identification of a target MANET, a *join* procedure is triggered by means of a *connect query* and the terminal keeps waiting for a reply from the Anchor Node. This latter, first checks if the acceptance of the new user in the MANET causes the trespassing of the threshold (Thr_{QoS}) on either the maximum number of users it is allowed to serve or the maximum number of hops. In this case the new user will become a member of the multicast group/subgroup; while, in case of negative reply, the user requests a DCH channel to the HAP network.

Logically, in the latter case, the new user becomes a potential new Anchor Node of a MANET that will support any future request of the same multicast service. In case a novel terminal enters/leaves a MANET, the relevant Anchor Node updates its *local database* and signals the event to the HAP, which updates its *global database*. In so doing, any time an Anchor Node leaves the system (*Old Anchor Node*), the HAP network should be able to re-elect a novel Anchor Node (*New Anchor Node*) among the multi-interface terminals previously connected to the Old Anchor Node. Moreover, if the remote CMS (Control Master Station) identified a priority assistance team with higher need for better bit rate to coordinate the emergency operations, this can request from a HAP more radio resources using a multiple DCH channels and deallocating, if it is necessary, radio resources from other teams or from FACH.

The cited procedure exploits metrics such as: *Signal to Noise Ratio* (in the following A); *Minimum distance from the Old Anchor Node* (in the following B); *Mobility level* (in the following C); *Battery level* (in the following D). Similarly to the Cluster Head (CH) election procedure in [12] with reference to a sensor network, we apply an *Analytic Hierarchy Process* (AHP) [13] to decide the relative weights of an evaluative criteria set according to the aforementioned metrics. The AHP is a theory of measurement through pair wise comparisons and relies on the judgements of experts to derive priority scales. The node with the highest weight will be chosen by the RNC to be the new AN. In our case, the following decreasing priority order is established: D, B, A, and C.

The proposed RRM policy foresees a power computation phase where, by processing the data received from the Broadcast Multicast Service Centre (BM-SC) and Radio Network Control (RNC), the required power is computed to be allocated for any MBMS session. In the Radio Bearer (R_b) selection, the P_{DCH} (power required for DCHs) and the P_{FACH} (power required for FACH) are computed and the services priority are defined. We define P_{total} as the sum of the power assigned to all the active MBMS sessions in each cell. This power will be compared to the maximum available power assigned by the network provider to MBMS sessions (P_{MBMS}).

Furthermore, we introduced two new procedures: *(i) AN Selection and (ii) AN Election/Re-election.* The former allows to evaluate if a new user can become a member of the multicast group/subgroup managed by an AN. The latter decides if a MBMS user can become a new AN to support users requiring the same multicast service. The user, obviously, starts an AN Selection procedure if a common transport channel is already active and cannot be activated for its multicast service. We define a new metric named *per-node throughput* that will be used by RNC during this procedure. This parameter is defined as the ratio of bit rate received by a multicast group member over the expected bit rate. As shown in the following, it depends either on the maximum number of users in the MANET and on the maximum number of allowed hops. Thus, it is compared with the Thr_{QoS}:

- a *per-node throughput* $\geq Thr_{QoS}$ means that the new user will join the AN;
- a *per-node throughput* $< Thr_{QoS}$ means that the new user likely will utilize a DCH channel.

For the *AN Election/Re-election procedure*, instead, the UE parameters evaluated at RNC level are the metrics in input to the aforementioned AHP, in order to choose the best AN.

If $P_{total} < P_{MBMS}$, then the suitable transport channel is assigned to the MBMS session. Differently, when $P_{total} \geq P_{MBMS}$, a session reconfiguration procedure should occur due to the fact that there are not enough radio resources available in the Node B to serve all the MBMS sessions. Possible reconfiguration events could be considered: *(i)* the reduction of the transmission rate of a MBMS session; *(ii)* the pause of alerting information for a short period of time; *(iii)* the cancellation of the service with low priority, *(iv)* the reduction of Thr_{QoS}. In so doing, as we will show in the following, a higher number of users will join the AN.

4 Simulation Results

A thorough simulation campaign has been conducted to demonstrate that the integration between HAP and MANET networks can improve the performance of system in an IAN scenario, in terms of capacity and coverage area, while providing access to multicast streaming services. In particular, the impact of the proposed architecture on *standard* MBMS is evaluated in an emergency situation, by highlighting introduced advantages and observed limitations.

Our RRM algorithm has been implemented in NS2 (Network Simulator 2) simulation environment [14]. Results described in this section are obtained with a 95% confidence interval. The main assumptions during the performed test campaigns are shown in Table I. A Poisson distributed call inter-arrival time is assumed and the values of the *multicast offered traffic* (*Erlang/cell*) depend on the specific simulation objective and vary during the tests. As reported in Table I, we conducted our simulation considering both fixed and mobile users. In particular we consider a user speed varying in the range [0:3] km/h, according to UMTS technical specifications. User mobility doesn't increase the power computation for HAP system. Nevertheless, high mobility could reduce the MANET performances in term of throughput, connectivity and as a consequence the capacity of the overall system could decrease.

We assumed (refer to Table I) several multicast groups receiving different MBMS streaming services at the same time from the same HAP. Indeed, in presence of a single multicast service per HAP, the complexity deriving from the integration between HAP and MANET is not justified.

As mentioned in previous sections, FACH will be activated to provide alerting information, while DCHs will be employed to particularized multicast services to a given rescue team through Anchor Nodes. Table II reports power values required by the FACH channel for different service bit rates and coverage areas [15]. In our simulation campaign we assumed to provide alerting services with 64 kbps in the overall incident area (P_{FACH} = 12.6 W).

However, in case of need, the alerting services will be stopped and this power will be assigned to rescue teams.

Figure 2 shows the capacity gain, defined as the ratio of the capacity of the integrated HAP/MANET with multi-hop cooperative access ($C_{HAP/MANET}$) over the capacity of the standalone HAP system (C_{HAP}):

Table 1. Simulation Assumptions

	Features	Values
HAP Features	HAP High	22 km
	Cell Radius	2,6 km
	Cell Layout	Hexagonal grid
	Number of Neighboring Cell	6
	Maximum HAP Tx Power	40 W
	Other BS Tx Power	10 W
	Common Channel Power	2 W
	Path Loss	Free Space affected by Rooftop Scattering and Mult. Screen Diffraction
	Multipath Channel	Vehicular A (3km/h)
	BLER Target	10%
	Gmax	32,2 dBi
	Thermal Noise	-100 dBm
	Orthogonality Factor	0,5
	User Speed	[0:3] km/h
MANET Features	Coverage radius	[10:100] m
	Multicast Routing Protocol	ODMRP
	Propagation Model	2-Ray Ground Reflection
	Data Rate	11 Mbps
	Number of hops	1,2,3,4
Multicast Traffic	Multicast Services (over dedicated/shared/common channels)	64 kbps
	Frame Size	400 bytes
	Frame Speed	20 frame/s
	Video Duration	300 s
	Number of Active Multicast Groups	More than 4
	User Geographical Distribution	Uniform
	Offered Traffic	400 Erlang/cell

Table 2. FACH power in function of cell coverage and service bit rate [15]

Service Bit Rate \ ***Cell Coverage***	**50%**	**95%**
64 Kbps	5.6 W	<u>**12.6 W**</u>
128 Kbps	15.2 W	31.6 W

$$Capacity\_Gain = \frac{C_{HAP/MANET}}{C_{HAP}} \tag{4}$$

This metric allows to perceive the increase in the capacity consequent to the introduction of a multi-hop cooperative access into the integrated HAP/Wi-Fi system. Capacity gain values increase with WF_{Radius} and with H_{Max}. This increasing does not require any HAP infrastructure augmentation, because the additional Wi-Fi access capability is directly provided by the RMUs. It is worth noting that choosing a given Wi-Fi coverage radius correspond to define a given level of transmission power of the

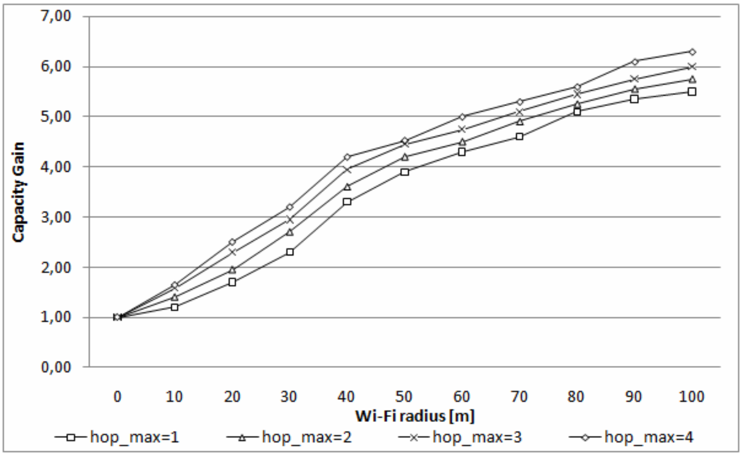

Fig. 2. Capacity Gain

802.11 terminal interface. Obviously, a higher transmission power entails both a greater Wi-Fi coverage radius and a greater number of users served by a single Anchor Node. Similar behavior is obtained increasing H_{Max}.

The price to pay is in terms of throughput reduction for multicast users, as a consequence of the increase in the maximum number of multicast multi-interface terminals that access the system through a given Anchor Node. Indeed, Figure 3 shows the per-node throughput values for a given multicast MANET receiver when varying the Wi-Fi radius and the maximum number of allowed hops.

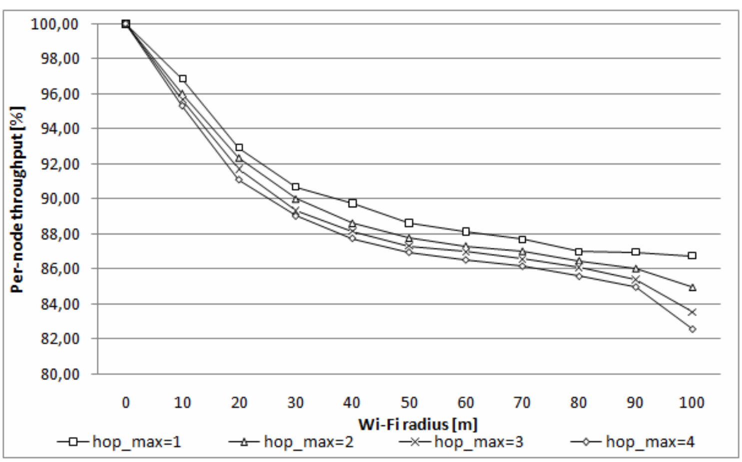

Fig. 3. Per-node throughput when varying WF_{Radius} and H_{Max}

This parameter is defined as the ratio of bit rate received by a multicast group member to the bit rate which should have been received. Per-node throughput has been calculated for each multicast MANET receiver and the mean value has been evaluated. The per-node throughput values decrease with WF_{Radius} and H_{Max}, because the number of users served by a single Anchor Node increases and, as consequence, a higher packets collision is experienced.

Other two interesting parameters to take into account are the delay and jitter that are respectively reported in Figures 4 and 5. Although both indexes increase with WF_{Radius} and H_{Max}, still the assumed values are such as not to adversely affect also the perceived quality of a potential video streaming application. In fact, the video streaming can tolerate a delay of 5 seconds and a jitter lower than 100 ms.

By summarizing, it can be stated that increasing the number of nodes allowed to connect to the same *Anchor Node* means to increase the system capacity (and the Grade of Service level); at the same time, this does not adversely affect the QoS degree perceived by any single node in terms of mean jitter and delay but it could imply a potential reduction in the throughput of the multicast service. A wise dimensioning study is thus required to enable the RNC to best choose the values of WF_{Radius} and H_{Max} (i.e. the ones which, at the same time, allow a system capacity and the multicast user throughput within their relevant acceptability ranges) for any given loading condition. The simplest RNC policy could consist in monitoring the offered load, choosing the best combination of Wi-Fi transmission power and number of allowed hops, and in communicating them to the multicast terminals. The introduction of these new features in the RNC imply some simple modifications also in the routing protocol. In particular, new Signaling and Control Packets has to be introduced with the aim to vary the maximum number of allowed hops and to manage efficiently the multicast MANET receivers connected to the Anchor Node. This dynamic parameter tuning always could maximizes the system capacity, while still maintaining system blocking probability and multicast user throughput at acceptable levels.

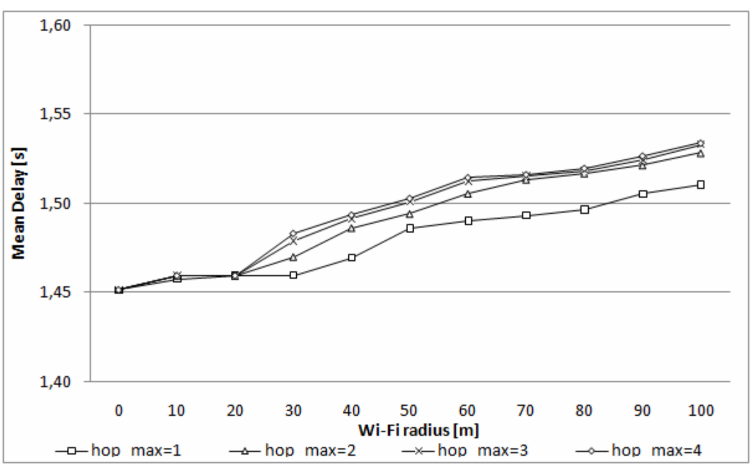

Fig. 4. Mean Delay when varying WF_{Radius} and H_{Max}

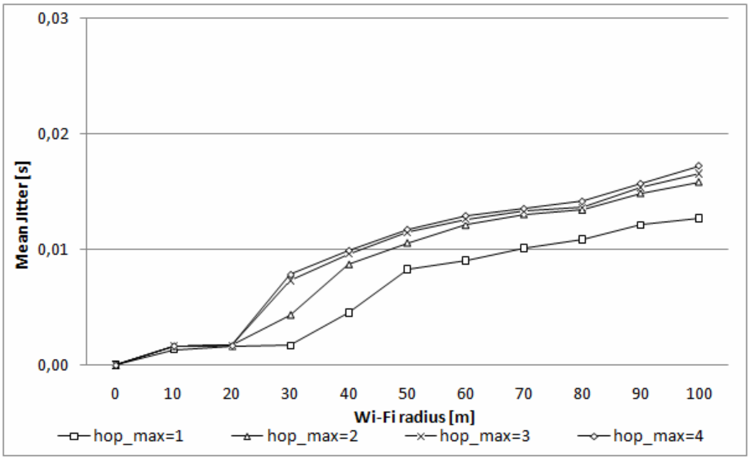

Fig. 5. Mean Jitter when varying WF_{Radius} and H_{Max}

5 Interference Issues

The architecture proposed in the SALICE project for the IAN foresees the utilization of at least two different license-exempt wireless communications standards in ISM band at 2.4 GHz, namely: IEEE 802.11/WiFi and IEEE 802.15.4/ZigBee. These standards are implemented in the RMU multi-standard node, hence resulting in co-located systems interference when two or more standards are used simultaneously. However, even if there were no interference between the air interfaces included in the RMU, the high concentration of relief team members in a small area generates interference issues between the air interfaces of RMUs of different members.

The performance of WiFi links as simulated in the previous Section and ZigBee links are highly affected by interference. In fact, the frequency band used by such wireless networks can be totally or partially overlapped, hence resulting in co-channel or adjacent-channel interference which reduce the performance. Co-channel interference occurs when the interfering signal has the same carrier frequency of the useful information signal. Co-channel interference can be reduced by using e.g. power control, directional antenna beam pointing control, interference cancellation schemes.

Adjacent Channel Interference can be categorized into in-band interference and out-of-band interference. In-band interference occurs when the centre of the interfering signal bandwidth falls within the bandwidth of the desired signal.

Out-of-band interference occurs when the centre of the interfering signal bandwidth falls outside the bandwidth of the desired signal. This kind of interference can be experienced when transmitters and receivers operate close together in terms of the two main variables that determine their degree of isolation from each other: distance and frequency separation. Out-of band interference may be caused over short to medium distances when there is insufficient isolation. This interference is not directly caused by co-channel emissions, but by having the energy of emissions at other frequencies transferred to co-channel frequencies through a number of special mechanisms. Out of band interference can be reduced with filtering. The level of interference depends on:

- the physical layer technologies;
- the relative difference between the transmission power of the intended transmitter and the interferer;
- the relative distance between the intended transmitter and the receiver and the distance between the interferer and the receiver;
- the propagation modalities and the path loss exponent; the range of frequencies that are overlapped.

In a IAN there is a high concentration of systems operating with different (uncoordinated) wireless standards, and hence, the situation of experiencing a high level of co-channel or adjacent-channel interference is very likely.

As shown in the standard IEEE 802.15.4 [16], the level of interference between WiFi and ZigBee nodes and vice versa depends on the distance between the interferer and the intended receiver and the channel frequency of the two networks. According to the level of frequency separation, the interference between WiFi and ZigBee can be in-band or out-of-band. It is shown that below the distance of 1 m, the *PER* is about 1 for any value of the channel separation, and hence almost every packet is corrupted.

The performance degradation of a WiFi or ZigBee link can be expressed in terms of goodput degradation. We propose to use the following formula for the computation of the goodput:

$$goodput = T \cdot \varepsilon \cdot (1 - PER) \tag{5}$$

Where T is the throughput of the link computed without interference as shown in the previous Section, ε is the duty cycle of the transmission and *PER* is the packet error rate. The duty cycle is also the channel utilization ratio which is equal to 1 if no coexistence mechanism based on time division alternation are used.

Assuming a distance from 10 to 20 cm between the WiFi and the ZigBee air interfaces co-located in the RMU, then the goodput of each link is zero. When the level of interference is high, i.e. the *PER* is about 1 and the goodput is zero, a coexistence mechanism is required. There are two categories of coexistence mechanisms [17]:

1) collaborative coexistence mechanisms, where the two interfering networks exchange information;
2) non-collaborative coexistence mechanisms, where the exchange of information is not allowed.

Collaborative coexistence mechanisms are more efficient but they are not always applicable. The possibility of exchanging information is quite easy when the two interfering air interfaces are co-located in the same multi-mode terminal, which is an assumption valid for the RMU. The advantages and drawbacks of well known interference management mechanisms that can be used for our purposes are reported in Table 3.

Table 3. Summary of interference management methods

Method	Description of the Method	Advantages	Drawbacks
Transmission power control	Dynamically increases and decreases the level of transmit power according to performance and interference metrics. The performance of the method depends on the channel gain and the number of devices.	Simple and well experimented implementation	Manage the interference to reduce the effects as much as possible without any minimum guaranteed quality
Dynamic frequency selection	The center carrier frequency is selected on the basis of channel occupation	Does not decrease the link capacity. Simple implementation.	The channel is not always selectable. Requires channel estimation on different bands.
Beamforming	Beam shape of the antenna is adapted with the aim to have a null towards the direction of the interferer.	Does not decrease the link capacity	Complex implementation.

6 Conclusion

This paper illustrated the analysis of a Radio Resource Management to be implemented in a multi-hop scenario in which MANETs cooperate with a HAP system to reach the common goal of enhancing the access to MBMS services. Through an exhaustive simulation campaign we demonstrated that it is possible to increase the number of multicast sessions, in a IAN scenario characterized by an intrinsic radio resource limitation. Obtained results may represent a valid support to the effective system design activity. This preliminary work provides just one of the potentials output on the cooperative behavior of HAP and MANET systems in a configuration specifically thought to provide multicast users with a multi-hop access in a IAN infrastructure. Furthermore the evaluation of the effects of interference in terms of goodput degradation is provided. Future studies will be finalized to provide a trade-off between the maximum capacity and the guarantee QoS allowed to MANET nodes different user mobility and system load conditions.

References

1. de Graaf, M., et al.: Easy Wireless: Broadband Ad-Hoc Networking For Emergency Services. In: The Sixth Annual Mediterranean Ad Hoc Networking WorkShop, Corfu, Greece, June 12-15 (2007)
2. Hoeksema, F., Heskamp, M., Schiphorst, R., Slump, K.: A node architecture for disaster relief networking. In: First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN 2005) (2005)
3. 3GPP TS 25.346 V7.0.0 (2006-03): Introduction of the Multimedia Broadcast/Multicast Service (MBMS) in the Radio Access Network (RAN), Stage 2 (Release7)

4. Araniti, G., Iera, A., Molinaro, A.: The Role of HAPs in Supporting Multimedia Broadcast and Multicast Services in Terrestrial-Satellite Integrated Systems. Wireless personal communications, Special Issue on High Altitude Platforms: Research and Application Activities 32(3-4), 195–213 (2005), ISSN: 0929-6212
5. http://lenst.det.unifi.it/salice
6. Huang, Y., He, W., Nahrstedt, K., Whay, C.: Requirements and System Architecture Design Consideration for First Responder Systems. In: IEEE Conference on Technologies for Homeland Security (2007)
7. IEEE Std. 802.15.4-2003, Standard for Telecommunications and Information Exchange Between Systems—Local Area Metropolitan Area Networks—Specific Requirements — Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks (WPAN)
8. IEEE Std. 802.15.3-2003, Standard for Telecommunications and Information Exchange Between Systems—Local Area Metropolitan Area Networks—Specific Requirements — Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for High Rate Wireless Personal Area Networks (WPAN)
9. Wittman, R., Zitterbart, M.: Multicast Communications – Protocols and Applications. Morgan Kaufmann, San Francisco (2000)
10. Taha-Ahmed, M., Calvo-Ramòn, L., de Haro-Ariet, L.: On the High Altitude Platfom (HAP) W-CDMA system capacity. Radio engineering 13(2) (2004)
11. IST-2003-507607 (B-BONE). Deliverable D2.5. Final results with combined enhancements of the air interface
12. Yin, Y., Shi, J., Li, Y., Zhang, P.: Cluster head selection using analytical hierarchy process for wireless sensor networks. In: IEEE 17th PIMRC, Helsinki, Finland, pp. 1–5 (2006)
13. Saaty, T.L.: Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process. RWS Pubs. (2000)
14. The Network Simulator–ns-2, http://www.isi.edu/nsnam/ns/
15. Raschellà, A., Araniti, G., Iera, A., Molinaro, A.: Radio resource management policy for multicast transmissions in high altitude platforms. In: ICSSC (2009)
16. IEEE Std. 802.15.4, Standard for Telecommunications and Information Exchange Between SystemsLocal Area Metropolitan Area NetworksSpecific Requirements Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks (WPAN), September 8 (2006)
17. De Sanctis, M., Monti, M., Ruggieri, M., Prasad, R.: A Collaborative Coexistence Mechanism for IEEE 802.15.3 and 802.15.4 WPANs. In: The 20th IEEE International Symposium On Personal, Indoor and Mobile Radio Communications (PIMRC 2009), Tokyo, Japan, September 13-16 (2009)