CAPANINA – Communications from Aerial Platform Networks Delivering Broadband Information for All

D. Grace[1,#], M. Mohorcic[2], M. Oodo[3], M. H. Capstick[1], M. Bobbio Pallavicini[5], M. Lalovic[6]

[1] Department of Electronics, University of York, Heslington, York, YO10 5DD,United Kingdom
[#]Tel.: +44 (0)1904 432396; fax: +44 (0)1904 432335; e-mail: dg@ohm.york.ac.uk

[2] Department of Digital Communications and Networks, Jozef Stefan Institute, Jamova 39, SI-1001 Ljubljana, Slovenia

[3] National Insititute of Information and Communications Technology, Wireless Innovation Systems Group, 3-4, Hikarino-oka, Yokosuka, 239-0847, Japan

[4] Carlo Gavazzi Space SpA, Via Gallarate 150 , I-20151 Milano, Italy

[5] BTexact, Adastral Park, Martlesham, Ipswich, Suffolk, IP5 3RE, United Kingdom

Abstract— **An overview of CAPANINA, a project funded by the European Commission's 6th Framework Programme is presented. The project is developing communications technologies for use with aerial platforms with the aim of delivering communications to users in hard to reach users and those disadvantaged by geography. The paper discusses the three broad areas of the project. Specific aspects covered include: HAP broadband business models and applications selection; the associated trials along with the required wireless and free space optical equipment. Longer-term research underway into delivering broadband backhaul to high-speed trains from aerial platforms, enabling integration with on board WLAN access points is also discussed.**

I. INTRODUCTION

High Altitude Platforms (HAPs) have the potential to deliver a range of communications services and other applications cost effectively, e.g. broadband, 3G mobile, and disaster relief/event servicing. They are essentially airships or aircraft operating in the stratosphere, and due to their altitude (17-22 km) have the potential to integrate hard to reach users in a wide coverage area into terrestrial broadband network [1]. They can offer a step-change in performance and availability, and have the advantages of being able to deliver the high capacity similar to that available from terrestrial systems and wide area type coverage similar to that available from satellites [2].

HAPs are at a similar stage of development as communications satellites were in the 1960s. A number of substantive projects have commenced worldwide [3],[4], and a typical example is the recently completed project HeliNet [2], which was carried out within the 5th Framework Programme of the European Commission. The HeliNet project developed a scale-sized plane HAP and three pilot applications: broadband communications, environmental monitoring, and remote sensing.

To further develop the state-of-the-art in broadband from aerial platforms the European Commission supported a new project, CAPANINA, as part of the 6th Framework Programme. The CAPANINA project is 3-year research project that commenced on 1st November 2003. A consortium of 13 partners is involved, representing a mixture of large industry, SMEs, and academia/research organisations*.

CAPANINA is focussing on development of low-cost broadband technology from HAPs aimed at providing efficient coverage to users who may be marginalised by geography, distance from infrastructure, or those travelling inside high-speed public transport vehicles (e.g. trains travelling up to 300 km/h). The aim is to exploit this future wireless technology to deliver burst data rates to users of up to 120 Mbit/s anywhere within a 60 km coverage area. The CAPANINA scenario is illustrated in Figure 1. Both mm-wave band and free space optical communications technologies are being considered.

The project is adopting a three-strand approach:

1. Identification of appropriate applications and services and associated business models. This includes the establishing the most appropriate integrated network architectures, and will include wireless and free space optical link technologies, and multiple platform technologies and spectrum sharing.
2. The development of a system testbed that will allow nearer-term tests of broadband services/applications to fixed users, including: backhaul for terrestrial WLAN, corporate communications and video-on-demand, along with an evaluation of free space optical technology.
3. Longer-term state-of-the-art research and innovation examining advanced mobile broadband wireless access. An outline system design and critical hardware will be developed for a scenario that will deliver broadband to trains, integrating with on-board wireless LAN base stations.

The purpose of this paper is to outline work underway. Firstly, we will describe the broadband services/architectures and possible business models. We

* CAPANINA Partners are: University of York (UK)·, Jozef Stefan Institute (Slovenia), Politecnico di Torino (Italy), Universitat Politecnica de Catalunya (Spain), Carlo Gavazzi Space (Italy), Budapest University of Technology & Economics (Hungary), DLR (Germany), BTexact (UK), SkyLINC Ltd (UK), EuroConcepts Srl (Italy), CSEM (Switzerland), Contraves AG (Switzerland), and National Institute of Information & Communications Technology (Japan).

then describe the broadband trials that are being undertaken as part of the project. This is then followed by an outline description of the longer-term research intended for the high-speed train application.

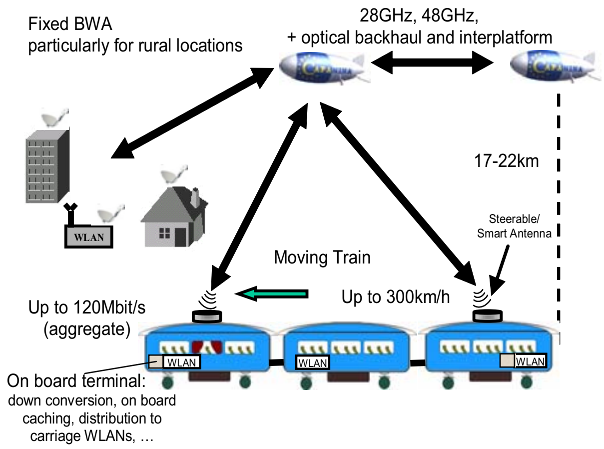

Figure 1 The CAPANINA scenario

II. Broadband Applications, Services and Infrastructure

A central aim of the project is to enable high rate communications (of up to 120 MBit/s) to be delivered directly to a user anywhere in line of sight of a HAP within a coverage area up to 60 km wide.

A. Applications and Services Selection and Associated Business Models

CAPANINA is specifically about HAPs providing two-way broadband communications to communities where it is not feasible or not possible to offer terrestrial alternatives such as xDSL. The strongest business case for broadband HAPs is probably in developing countries. HAPs can give the governments of developing countries direct control over their communications networks. HAPs can provide, at a stroke, a modern digital broadband communications network at a competitive price. Regional TV broadcasting and broadband Internet can be extended to new regions assisting economic development. UMTS mobile communications, military and surveillance payloads (outside the CAPANINA remit) can also be carried and are also of interest to developing countries. The use of HAPs on a temporary basis at disaster sites and for special events also makes a strong business case.

The most likely applications/services identified here are:

- Broadband Internet Access to residential/SOHO market
- Broadcast based Broadband (HDTV broadcast, content distribution via IP Multicast, etc.)
- Special Events and Disaster Recovery broadband connections
- WiFi on trains and bus-coaches (ISP backbone connection to mobile hotspots)
- Internet backhauling (e.g. providing connectivity for private networks, point-to-point trunk connections for ISP backbone, etc.)

The applications/services are put through the business acceptance criteria that indicate the estimated business value for each of them. Each of these scenarios has a value chain. For example, delivery of broadband service to a disaster stricken area has few but high value links, while a broadcast based service has many low value links. Therefore the integration and automation of service provision and maintenance becomes more important as the user migrates towards the access network. Figure 2 illustrates the money flow model for a typical HAPs network.

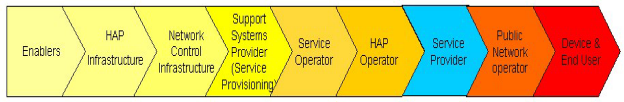

Figure 2. Money-flow model

CAPANINA has adopted the eTOM business framework from the Telemanagement Forum to define the processes required to support each of the above scenarios. This work is on-going, but initial results are that data networking (e.g. broadband in developing countries and also disaster recovery services) and subscribed information (e.g. broadcast based broadband) are the largest likely money earning services for HAPs and this will be evaluated for each of the roles and actors in the scenarios.

B. ITU Spectrum Sharing Studies

CAPANINA is also addressing an issue of the spectrum sharing between HAPs communication system and other radiocommunication services using the same/adjacent frequency bands. Currently, 47/48 GHz bands are available to HAPs on a worldwide basis, and 31/28GHz is available for up to 40 countries worldwide, following WRC-03 [5]. Europe is currently excluded from the 31/28 GHz bands allocation for the FS using HAPs since it is afraid of harmful interference from the HAPs system into terrestrial Fixed Wireless Access (FWA) system to which the same frequency bands are allocated and are considered to be deployed in Europe in the future. To make the 31/28 GHz bands available for HAPs in Europe, it is needed to show HAPs system design conditions to ensure that HAPs system can operate successfully on a non-harmful interference, non-protected basis.

CAPANINA has designed a new single HAPs system model with a 121 multi-cell and minimum user elevation angle of 30° while the current HAPs system model has about 400 multi-cell and minimum user elevation angle of 20°. The proposed HAPs model could reduce the interference from HAPs system into the FWA system as a communication link with a higher elevation angle or vertical communication link would have a smaller impact on a terrestrial FWA system with a horizontal communication link. As a result, the proposed HAPs model could reduce the required separation distance between the HAPs system and the FWA system.

Radiation patterns of HAP antenna, which could have an essential impact on the interference analysis, have been also addressed from the spectrum sharing point of view. Measurement results of prototype HAP antennas, lens antenna with a corrugated horn developed by the project, showed that the radiation patterns profiles outside the mainlobe region are meaningfully lower than the patterns [7] which have been used for the interference analysis in the ITU-R study. This implies that the interference from the actual HAPs system using the above onboard antennas into other services and vice versa could be smaller compared to the results of the current study.

It is intended that CAPANINA will contribute several documents to the ITU-R. The documents will be discussed for the revision of the ITU-R Recommendation. CAPANINA will also discuss the multiple HAPs configuration model from the spectrum sharing point of view.

C. *Optical Link Capability*

Optical links are also being investigated as part of the project. These will be used for backhaul and interplatform link infrastructure [6].

III. Broadband Trials to Fixed Users from Aerial Platforms

The project is also demonstrating the different broadband services/applications. Here we describe the System Testbed and equipment used in the trials.

A *System Testbed*

The System Testbed is intended primarily to test several possible broadband applications and services selected. Moreover, Testbed integration and operation will outline technical constraints and solutions for future aerial nodes implementation. Three different aerial platform technologies support three stages of the test campaign: low-altitude tethered balloon, stratospheric aerostatic carrier and - to be confirmed – high altitude platform (HAP).

Trial 1 took place between August-October 2004 in Pershore, UK, by means of a spherical aerostat, capable of operating at an altitude of 300m. The following aspects were successfully demonstrated (see also Figure 3):

- Broadband Fixed Wireless Access (BFWA) up to a fixed user (see Figure 4) using 28GHz band.
- Demonstration of end-to-end network connectivity, and services such as: high speed internet, video-on-demand
    - Streaming audio/video media (Windows Media Server 2004 Enterprise Edition supporting IP Multicast)
    - Content distribution (IP Multicast)
    - Internet access (simulated ISP using Web Server) including FTP downloads/uploads
    - WiFi backhauling (including WiFi access to the Internet from user's laptops).
- Optical communications - HAP ground - simplified overall system to perform tracking tests.

Subsequent tests will be undertaken by the relevant partners (outside of the project) to prove that tethered platforms can be used as a delivery vehicle in their own right.

Figure 3 Multimedia applications trial at Pershore UK

Trial 2 is scheduled for Summer 2005 near Kiruna, Sweden and will use a stratospheric balloon for a single mission of several hours, aimed to evaluating the following aspects:

- A selection of the broadband trials carried out in Trial 1 using custom built aerial and ground nodes operating in the 28/29 GHz bands.
- Optical communications, including high data rate backhaul link tests and measurement of atmospheric parameters on the channel. Results will be compared with simulation and an equivalent Japanese trial
- Integration of a multi-payload system on a dedicated stratospheric carrier, subject to specific environment, and to challenging weight and power constraints.

Trial 3 is scheduled for 2006 and the details are still being determined. It is likely to involve a HAP and be organised by NICT, as part of their parallel on-going programme [3]. They have access to HAP equipment and will be performing broadband trials in future years.

B *Equipment*

The mm-wave trial equipment is based around 28/29 GHz and 28/31 GHz frequencies. Trial 1 used a tethered aerostat with stabilised antennas with appropriate pointing acquisition and tracking (PAT) technology used on the aerial platforms. Equipment on the platforms was kept relatively simple, with RF signals at the intermediate frequency fed from a modem on the ground over a fibre radio link. The aerostat tether contains the optical fibre and power feeds to the platform. Routing and networking functions were carried out on the ground. A system level diagram of the set-up is shown in Figure 4.

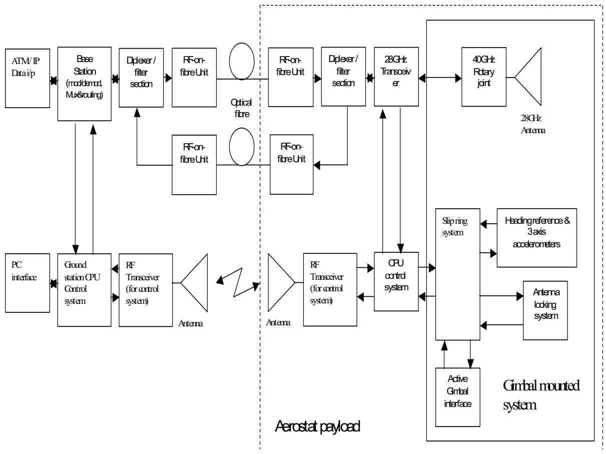

Figure 4 System level diagram for the mm-wave broadband tethered aerostat payload.

The mm-wave transceiver for the CPE was interfaced with the customer terminal equipment(s) and a commercial dish antenna and positioner. There was also the option of interfacing with other terminal equipment, for example a DBS set top box for video services or existing IEEE 802.11 or IEEE 802.16 equipment.

An Alvarion WalkAir 3000 ‘base station’ system was used to offer 36 Mbit/s net payload per customer premise equipment (CPE). The CPE antennas were two fixed small parabolic dishes (one used for user’s data and other for transmitting beacon signal used by tracking system at the payload) as illustrated in Figure 3.

Trial 2, based on the free flying stratospheric balloon will implement a simpler payload due to stringent payload mass and weight constraints. The application server will be flown on the platform and the services delivered to the CPE over a mm-wave link. The payload will implement a single beam to cover the whole of the ground footprint. The mm-wave link will use the IEEE 802.11b standard by utilising commercial wireless base unit equipment as the modem, feeding the mm-wave transceiver. On the ground the CPE will use a larger than standard dish to compensate for the reduced effective radiated power on the HAP due to the single rather than multicell architecture. This dish will be steered to point at the HAP using a pointing and tracking controller. The mm-wave radio will again interface to a commercial remote bridge and onwards to the customer equipment. The modem can switch seamlessly between data rates between 1 and 11 Mbit/s depending on received signal strength demonstrating adaptive modulation and coding on the link.

Free space optical equipment is also being developed as part of the project. This is discussed in more detail in a separate paper as part of this conference [6].

IV. Delivery of Broadband to High Speed Vehicles

Delivery of broadband services to high-speed vehicles from aerial platform network is the most future oriented part of the work in CAPANINA project. It is concentrating on a scenario of delivering broadband (backhaul) to trains equipped with an on-board WLAN access point, as shown in Figure 1. To connect this access point into backbone network via HAP we analysed a number of existing and developing broadband communication standards, in particular IEEE 802.16 family of standards, DVB family of standards and ETSI BRAN standards, in order to select the most suitable standard requiring the least adaptations considering specific CAPANINA requirements and the particular operating environment. Candidate standards were analysed against a common set of criteria addressing regulatory, technical and commercial aspects of standards. Examination has shown that none of current broadband standards are universally suitable for delivering broadband services to high-speed mobile users from HAPs, however IEEE 802.16SC represents the closest match with the predefined requirements, so it has been selected for further examination and adaptation regarding radio interface and the support for mobility management.

A detailed characterisation of the *mm*-wave band propagation environment is especially important to support design of an efficient radio interface and analysis of short-term rain outage mitigation strategies, such as time diversity and caching. In particular, the *mm*-wave bands are severely affected by rain attenuation and scattering. In addition, the Doppler effect will also be present when communicating with fast moving vehicles. Relevant satellite and terrestrial link measurements are being used, along with the outcomes of the HeliNet project, which has carried out a detailed assessment of the rain attenuation mechanisms and how they affect fixed nodes [7], in order to characterise the propagation environment and develop a propagation channel model.

The numerical channel model will be used for detailed analysis of adaptive modulation schemes and coding techniques proposed in the selected broadband communication standard, supplemented by diversity techniques to increase the link availability between high-speed moving train and a HAP. In addition, advanced signal processing algorithms are being explored that (i) minimise the processing power requirements, (ii) are computationally efficient, and (iii) cope with the high aggregate data rates and with the envisaged multipath/Doppler environment. The performance gains of these technologies achievable for aerial platform applications will be assessed through the implementation of selected algorithms on a DSP platform.

The combination of high-speed mobility and platform movement [8] present a significant challenge in maintaining adequate communication links with high-speed trains. They require rapid and frequent handover between cells on the platform, as well as between neighbouring platforms. In IP based network handovers between platforms will typically be handled on the networking layer, while handovers between cells within a single platform need to be handled by so called access-level mobility. To support faster handovers and to reduce unnecessary use of radio resources, the problem of routing to a mobile node on the networking layer is typically split into micro- and macro-mobility parts, thus dividing mobility events into those that can be handled locally and those with global impact on the route. Current investigations include the interaction of channel assignment, medium access control, inter-beam and inter-platform handoff, caching, prioritisation, and multi-level mobility support. Resource and mobility management procedures will also provide mechanisms to guarantee required QoS level on the radio interface and mapping of QoS parameters on to the higher layers [9].

Enhancements are being investigated for future HAP applications based on 'smart' antenna concepts, in order to improve efficiency, flexibility, and cost effectiveness. The ability to control beam shape, direction and other characteristics would be of considerable benefit when using a HAP, owing to its relatively loose station-keeping characteristics. Smart antenna techniques are being considered including antenna and signal processing technologies with the aim of providing complete reconfigurability. Array spacing, the element radiation pattern, directivity, gain and the resulting field of view for beam scanning are all under consideration. This will lead to recommendations for the best combination of technologies that should be applied to HAP (and train) antennas.

Advanced beamforming algorithms for the most promising array types along with the associated signal processing burden will be considered, particularly from a point of view of efficient algorithms which can be implemented in hardware. These must be computationally efficient and able to cope with high aggregate data rates, and minimise power consumption. To this end emulators for OFDM based transmitters and channels have been developed and evaluated.

The antenna technology for the high-speed train antennas is also a challenging aspect of the project. These antennas will need to sweep more rapidly and over a wider range of angles than the HAP antennas. A range of solutions that combine both electronic and mechatronic steering are being investigated where the combination may be beneficial.

V. CONCLUSIONS

This paper has described work underway as part of the CAPANINA project, a project that is investigating the viability of integrating hard to reach areas into the broadband network using different forms of aerial platform. The project is investigating possible broadband applications and services, and the most appropriate integration options for the aerial platforms, including deploying multiple platforms to serve the same coverage area, along with the most appropriate associated backhaul and network infrastructure. Mm-wave band and free-space optical communication technologies are both considered.

Three trials are planned over the lifetime of the project to demonstrate broadband services to fixed users. Aerial platform craft used for the trials include a 15m long tethered aerostat at 300m altitude and a stratospheric balloon capable of travelling to 20km altitude. The first trial using the tethered platform has successfully validated the broadband architecture, broadband services and applications, and demonstrated the viability of free space optical communications links from an aerial platform.

The project is also investigating the viability using aerial platform technology to deliver broadband backhaul to high-speed trains, using mm-wave band communications. Work covers several areas including standards selection, propagation impairments, radio resource and handoff management, through to RF and mechatronic design and adaptive beamforming techniques for the train and HAP antennas.

VI. ACKNOWLEDGEMENTS

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I. REFERENCES

[1] G.M. Djuknic, J. Freidenfelds, and Y. Okunev, *Establishing Wireless Communications Services via High-Altitude Aeronautical Platforms: A Concept Whose Time Has Come?,* IEEE Commun. Mag., pp. 128-35, September 1997

[2] D. Grace, J. Thornton, T. Konefal, C. Spillard, and T.C. Tozer, *Broadband Communications from High Altitude Platforms - The HeliNet Solution*, In Proc. Wireless Personal Multimedia Communications (WPMC) Conference 2001, Aalborg, Denmark, Vol.1, pp. 75-80, September 2001

[3] R. Miura. and M. Oodo, *Wireless Communications System Using Stratospheric Platforms*, Journal of the Communication Research Laboratory 2001, Vol. 48, No.4, pp.33-48 (http://www2.nict.go.jp/kk/e414/shuppan/kihou-journal/journal-vol48no4/toku3-2-1.pdf)

[4] J.-M. Park, B.-J. Ku, Y.-S. Kim, D.-S. Ahn, *Technology Development for Wireless Communications System Using Stratospheric Platform in Korea*, In Proc. IEEE PIMRC 2002, Sept 2002.

[5] Footnote 5.537A and 5.543A, ARTICLE 5, Chapter II, Radio Regulations, ITU and "*Potential use of the bands 27.5-28.35 GHz and 31-31.3 GHz by high altitude platform stations (HAPS) in the fixed service*," Resolution 145 (WRC-03), Radio Regulations, ITU

[6] D. Giggenbach, J. Horwath et al, *Optical Communications Aspects of CAPANINA (working title)*, IST Mobile and Wireless Summit, June 2005

[7] T. Konefal, C. Spillard, D. Grace, *Site diversity for High Altitude Platforms: A method for the prediction of joint site attenuation statistics*, IEE Proc. Ant. and Prop., April 2002

[8] J. Thornton and D. Grace, *Effect of Lateral Displacement of a High Altitude Platform on Cellular Interference and Handover*, IEEE Trans. Wireless Commun., To be published July 2005

[9] J. Bostic, U. Drcic, M. Mohorcic, G. Kandus, *Delivering IP with QoS/CoS over HeliNet*, In Proc IEEE PIMRC 2002, pp. 1591-1595, September, 2002.