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Research Article

A WiMAX Payload for High Altitude Platform Experimental Trials

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The Swiss-based "StratXX" project during 2006-2007 has been developing a stratospheric lighter-than-air platform for deployment of telecommunications and environmental monitoring services. In support of a first round of experimental trials, a WiMAX communications subsystem, including platform payload and ground stations, has been developed. The communications system design and results of terrestrial pretrials are reported.

1. INTRODUCTION

Wireless local and metropolitan area networks (WLANs/WMANs) continue to gain acceptance and commercial rollout, enabled typically through the IEEE 802.11 and .16 family of standards. While these are generally terrestrially-based networks and now technologically quite mature, a contrasting approach is that of the high altitude platform (HAP) where very high system spectral efficiency could be obtained by use of cellular networks and spot beam antennas on a platform payload located at an altitude of around 21 km in the stratosphere [1–3].

A number of programmes are promoting and now testing HAP communications, and a concept gathering momentum is the deployment of the 802.16 family, also called *Wireless Interoperability for Microwave Access* (WiMAX) to enable HAP-terrestrial links. WiMAX is increasingly seen as the future basis for broadband wireless Internet services, and is well suited to delivery from HAPs, which would effectively represent very tall radio masts. WiMAX thus represents a logical choice for development from this type of platform, and has been selected by the StratXX programme as offering near-term commercial benefit in this context.

To date, only very limited practical trials of the communications capabilities of HAPs have been reported. Some stratospheric communications trials were conducted in 2002 by CRL (now NICT) of Japan [4] with an Aerovironment "Pathfinder Plus" craft: this demonstrated high definition TV in UHF and a video connection using an off-the-shelf W-CDMA cell phone from a payload limited to 50 kg. Most other activity has been only with low altitude craft or has been supportive work such as direction-of-arrival measurements. A later NICT trial with an airship in 2004 again demonstrated HDTV and also autonomous flight, albeit at an altitude of 4 km. NICT have also developed a range of steerable antenna solutions for 28 GHz, 31 GHZ and 48 GHz, but these have only been trailed at low altitude. The European 5th Framework Helinet programme [5] conducted mainly theoretical studies, while the 6th Framework CAPANINA project [6–8] succeeded in demonstrating broadband communications at up to 11 Mbps using a "one-shot" stratospheric balloon to 24 km altitude and 40 km ground distance using an 802.11 basestation with frequency conversion to the 28 GHz carrier frequency and a high gain, tracking reflector antenna at the ground station (see "Trial 2" in [9]).

The StratXX programme involves a number of trials, phased towards a full sized stratospheric airship demonstration representative of commercial service provision. Following their experience of developing and executing the CAPANINA payload and wireless trials, a team at the University of York has been tasked with developing the WiMAX payload and communications subsystem for the first full trial of the StratXX platform. This paper reports briefly on

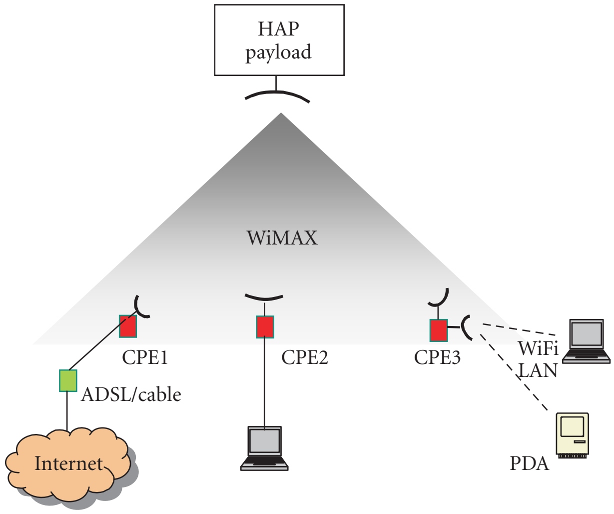

Figure 1: Typical WiMAX-from-HAP trials scenario.

Table 1: Alvarion's *BreezeMAX* radio specifications.

Radio frequency (MHz)	3450–3500, Uplink (UL)	3550–3600, Downlink (DL)
Channel bandwidth	3.5 MHz/1.75 MHz	
Output power	BS+28 dBm CPE+20 dBm	
Modulation	OFDM, 256 FFT points	
Forward error correction	Convolutional coding: rates 1/2, 2/3, 3/4	

Table 2: Alvarion's *BreezeMAX* adaptive modulation levels.

Modulation and coding	"rate"	Net bit rate (Mbps)	Sensitivity (−dBm)
BPSK 1/2	1	1.41	100
BPSK 3/4	2	2.12	98
QPSK 1/2	3	2.82	97
QPSK 3/4	4	4.23	94
16QAM 1/2	5	5.64	91
16QAM 3/4	6	8.47	88
64QAM 2/3	7	11.29	83
64QAM 3/4	8	12.71	82

the requirements, constraints, system design, link budgets, choice of equipment, and so forth, and then presents some early results of communications link performance from terrestrial and airborne pretrials.

2. SCENARIOS AND SYSTEM REQUIREMENTS

Our end goal was the demonstration of broadband wireless services over a link length in excess of 20 km between an HAP and at least one ground station or customer premises equipment (CPE). The link should also support data streaming from an onboard optical sub-payload. A typical scenario is illustrated in Figure 1.

The essential features of Figure 1 include

(1) one CPE acting as the gateway to the wired internet;

(2) at least one CPE is "remote" and is linked to the wider internet via the HAP payload;

(3) further users might utilise a WiFi access point whose backhaul is provided via the WiMAX CPE.

Numerous variants are of course possible. However, from the typical scenario of Figure 1, certain inferences can already be highlighted. Since WiMAX is intended as a point-to-multipoint WMAN, the base station must be placed on the HAP so as to have in view all the CPEs. Furthermore, one of the CPEs must then be used, in effect, as the backhaul station (CPE1 in Figure 1), which would tend to act as a bottleneck when the system is heavily loaded. This architecture is therefore suitable as a minimal approach to a first demonstration of WIMAX to the stratosphere, and would benefit from a dedicated backhaul (possibly in another radio band, e.g., 28/31 GHz) should the system be scaled-up with additional users.

3. PAYLOAD HIGH LEVEL SYSTEM DESIGN

Any HAP communications payload is liable to constraints in terms of mass, volume, and available power, some of which may be severe. An important factor is whether the payload should or not be pressurised and it was decided early in the design process that pressurisation should be used so that off-the-shelf equipment could be used with minimal risk of it failing due to pressure loss. Various system options were considered such as whether to modularise the payload subsystems into separate pressurised containers, whether to use steered or nonsteered WiMAX antennas, whether to use additional WiMAX channels for a dedicated backhaul and also whether this might use a dedicated millimetre-wave link. Several of these options had to be abandoned due to mass, cost, and also time constraints, and the current design is summarised in Figure 2. Here, various details have been omitted for clarity, such as the temperature and pressure probes which feedback local environmental data to the failsafe controller - this important bespoke item is in overall control of the payload and would selectively shut down subsystems to control the thermal and power budgets as necessary. The other items in the payload can be summarised as

(1) PC servers—one to provide local web services and some house-keeping functions and one to manage the gimballed camera/video sub-system;

(2) power conditioning unit (bespoke);

(3) WiMAX sub-system (adapted);

(4) telecommand and control.

The need otherwise for a gimballed (steerable) payload spot beam antenna was considered at some length before adopting a compromise configuration which allows switching between relatively wide and narrow beams.

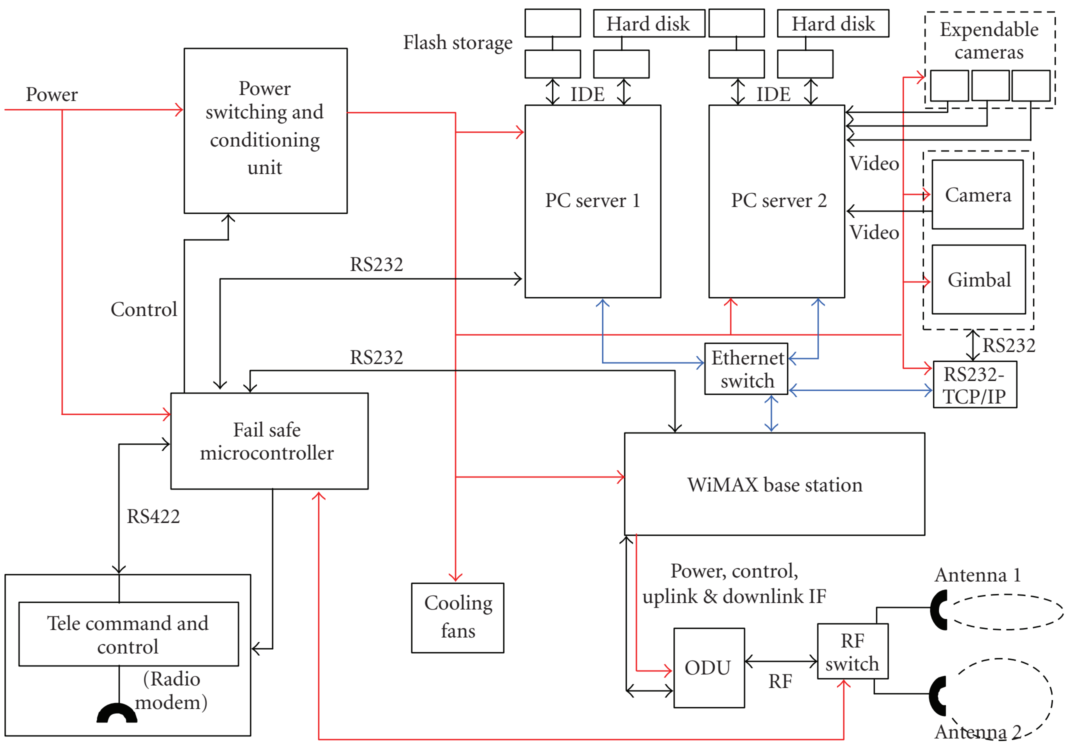

Figure 2: High-level payload system diagram.

4. WiMAX SUBSYSTEM

Early in the design life cycle we carried out a survey of available WiMAX equipment and of suitable spectrum. The remit was for use of bands close to 3.5 GHz for short-term trials in Switzerland. Following a short evaluation phase, we chose Alvarion's *BreezeMAX* micro-base station and associated CPE equipment. The radio specifications for these are summarised in Table 1.

Further specifications associated with the eight adaptive modulation levels (also called "rates") are shown in Table 2. These are specific to a 3.5 MHz bandwidth radio channel and quoted for a typical packet error rate of 1%. We should add that the BS can operate in frequency division duplexing (FDD) and time division duplexing (TDD) when working with more than one CPE, while each CPE can operate in TDD only.

In hardware terms, the minimum *BreezeMAX* working configuration comprises one BS, one BS outdoor unit (ODU, see Figure 2), BS antenna, one CPE outdoor (RF) unit, and CPE antenna. Ethernet ports at the CPE ODU and at the BS provide network connectivity. At the CPE, a separate indoor power supply provides −48 V DC to the ODU via power over ethernet cables.

4.1. Terrestrial WiMAX evaluation

Hardware was procured for the above *BreezeMAX* configuration, along with operating system (OS) and computer servers. These were configured with applications software and made ready for terrestrial field trials for purposes of evaluating the WiMAX equipment prior to full HAP payload build. The antennas used at this stage were standard Alvarion items, namely, a 14 dBi sector antenna and an 18 dBi CPE antenna, these being linear polarised and thus unsuitable for the final HAP trial due to the polarisation misalignment that is likely to occur with changes in platform yaw angle.

A temporary nonoperational radio license was obtained from *Ofcom* in the UK for operating the uplink at 3.485 GHz and downlink at 3.585 GHz. For this, the license application detailed a number of sites in North Yorkshire, UK, from which a line-of-sight (LOS) to the University of York was available (since the eventual HAP trial was for LOS, our interest lays in investigating the limit of performance for long range LOS links rather than non-LOS, high multipath conditions). A series of such trials was performed during the period March to August 2007. A typical mobile test arrangement is shown in Figure 3 where the WiMAX subpayload was driven to the remote site in a van. The CPE was retained at the University of York. This arrangement allowed internet browsing at rates up to about 8 Mbps from remote sites at distances of 30 km and beyond.

During the trials the WiMAX system was driven by applications software so as to stimulate either the uplink or the downlink to run at maximum possible data rates, for example, by demanding large file transfers of up to 70 MBytes. In parallel, various outputs from the operating system were recorded, chief among these are received signal strength (RSS), signal-to-noise-ratio (SNR), and "code rate" (at level 1 to 8, being, resp., the lowest and highest order

(a) Antennas on mast, Vale of York beyond

(b) Payload with BS in vehicle

Figure 3: A remote, portable WiMAX test rig.

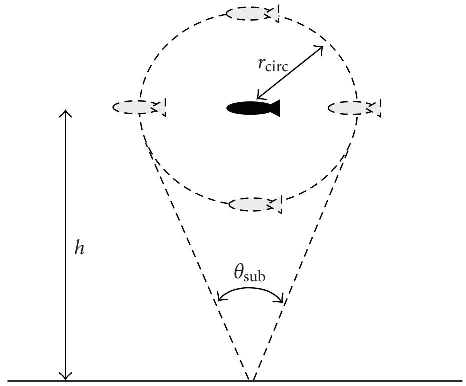

Figure 4: StratXX platform position keeping sphere.

modulation levels shown in Table 2) for both UL and DL. An extract from many hundreds of lines of logged data is shown in Table 3 where the link distance is 20 km and the combined antenna gain specifications are 32 dBi. Also a 20-dB attenuator has been inserted in one of the RF antenna interconnects so as to force the system to operate at rates below maximum, which to some extent emulates the effect of a ten-fold increase in path length.

In Table 3, we would emphasise that the data is generated by the WiMAX hardware and operating system, and we have no direct way of measuring independently each parameter. The absolute accuracy of this data should therefore be regarded with a little scepticism: the nature of the logged data is intended for network administration purposes and should be interpreted with care if used in the context of a more rigorous scientific analysis. Nevertheless it is worth pointing out some of the properties of the logged data. For example, although the link is nominally static (the terminals are not moving), the logged SNR and RSS are not quite static (nor are they logged to equal precision for UL and DL). Where the UL and DL throughputs show zero, this is most likely due to their not being stimulated, that is, no traffic is being demanded; demand first occurs in the second line at time 14:57 where the DL is stimulated until time 15:00. During this time, the UL indicates relatively little throughput, and much of this traffic will be due to protocols and acknowledgements. From 15:07 this scenario is reversed and the UL is driven by demand. It is also evident that the time sampling bins are quite coarse, being about 30 seconds (hence the coarse times logged under the first column) and the logged data will be an average over each period. UL&DL data rates within Table 3 are in effect TCP/IP throughputs measured within the base-station network processor unit whilst those described in Table 2 are "raw," that is, before the protocol overheads are removed. For example, a single CPE with a DL of rate 8 which has a theoretical net bit rate of 12.71 Mbps would achieve a measured TCP/IP throughput of 9–9.5 Mbps.

In parallel with preparation for these trials, a link budget calculator was written for purposes of establishing a theoretical link prediction tool against which measured data could be compared (see Table 4). Here, several approaches are suitable, including a fully theoretical treatment based on required energy-per-bit-to-noise density; a simpler treatment using the equipment's sensitivity specification for each modulation level; and a further empirical method based on observed behaviour where we correlate logged "rate" against SNR and received power. Following some refinement, these approaches generally agree to within 2 dB or so. A typical such link budget is shown as a spreadsheet in Table 4 .

5. WiMAX ANTENNAS SUBSYSTEM

Antennas are a particularly important component in any wireless network and especially so when this is deployed by an HAP. The platform displacement, pitch, roll, and yaw, along with carrier frequency have a profound influence on the choice of antenna technology and its cost. Where a multicell layout is used to maximise spectrum reuse, the problem can be complex although tractable [10]. For present purposes, a single cell and hence beam only was needed, with a ground footprint of around 12 km diameter. To mitigate against platform movement, a steered antenna was in many ways preferred, although time and cost implications of either developing a bespoke gimbal or modifying a commercial item were such that this approach was not pursued for the initial trial. The station-keeping targets for the HAP are also fairly stringent, these being a 5 km radius (r_{circ}) position sphere and maximum ± 5° pitch or roll, and from these it

Table 3: Extract from logged WiMAX link data.

Time	SNR UL (dB)	SNR DL (dB)	RSS, UL (dBm)	RSS, DL (dBm)	Rate UL	Rate DL	Throughput UL (Mbps)	Throughput DL (Mbps)
14:56	10.7	17	−94.6	−87	4	6	0	0
14:57	10.1	16	−94.3	−88	4	6	0.121	5.416
14:58	10.4	16	−94	−88	4	6	0.11	4.918
14:58	10.9	16	−94.1	−88	4	6	0.119	5.406
14:59	11	16	−94	−88	4	6	0.109	4.934
15:00	10.5	16	−94	−88	4	6	0.129	5.91
15:00	10.3	17	−94.4	−88	4	6	0.128	5.915
15:01	10.7	17	−94.4	−87	4	6	0	0
15:01	10.3	16	−94.4	−87	4	6	0	0
15:02	10.4	16	−94.2	−88	4	6	0.129	5.952
15:03	9.9	17	−94.4	−88	4	6	0.13	5.908
15:03	10	16	−94.4	−88	3	6	0.07	3.279
15:04	10.7	17	−94.1	−88	4	6	0	0
15:05	10.5	16	−94.2	−88	4	6	0	0
15:05	10.3	16	−94.3	−88	4	6	0	0
15:06	10.7	16	−94.1	−88	4	6	0	0
15:07	10	16	−94.3	−88	2	6	0	0
15:07	10.2	17	−94.5	−88	4	6	2.657	0.054
15:08	10.2	16	−94.1	−88	4	6	2.699	0.056
15:08	10.2	16	−94.1	−88	4	6	2.647	0.061
15:09	10	16	−94.1	−88	4	6	2.652	0.06
15:10	11.1	16	−94.2	−88	4	6	2.698	0.057
15:10	9.9	16	−94.4	−88	4	6	2.38	0.054
15:11	10.2	16	−94.2	−88	4	6	2.696	0.06
15:12	10.6	16	−94.2	−88	4	6	2.646	0.061
15:12	10.3	16	−94.2	−88	4	6	2.447	0.055
15:13	10.5	16	−94.2	−88	4	6	2.698	0.056
15:13	10.6	16	−94.2	−88	4	6	2.653	0.061
15:14	10.4	16	−94.4	−88	3	6	2.655	0.063

is straightforward to derive optimum antenna beamwidth as follows.

The HAP is intended to be on station at height h directly over one of the ground terminals. Figure 4 shows the geometry, where angle θ_{sub} is subtended by the position sphere. To this we add the range of pitch and roll change $2\theta_p$ to derive the effective total change in angle θ_t which must be accommodated by the HAP antenna:

$$\theta_t = \theta_{\text{sub}} + 2\theta_p = \arcsin\frac{r_{\text{circ}}}{h} + 2\theta_p. \quad (1)$$

From which we derive $\theta_t = 39^\circ$. While a simple approach might be to set the antenna half power beam width (HPBW) to this figure, we prefer to choose a slightly smaller beamwidth and one which maximises the gain at the angle of maximum displacement, that is, at $\theta = (1/2)\theta_t$. This may be expressed as the value of HPBW which satisfies

$$\frac{\partial}{\partial\theta_{\text{HPBW}}}\left(D(\theta)_{\theta=(1/2)\theta_t}\right) = 0, \quad (2)$$

that is, we solve for the maximum directivity $D(\theta)$ as a function of θ_{HPBW} at $\theta = (1/2)\theta_t$. (The approach is analogous to that of optimising cell-edge directivity in [10].) From this simple recipe we choose $\theta_{\text{HPBW}} = 32.6^\circ$ ($D = 15.8$ dBi). This represents the optimum HAP payload antenna HPBW given the above input data on station keeping. A narrower beam will improve the link budget so long as the HAP is on station, but will degrade the link budget should the antenna pointing error meet the above limits. A similar treatment for the ground antenna, assumed fixed and so not subject to pitch and roll error, yields an optimum beamwidth of 24° ($D = 18.5$ dBi). For the purpose of procuring antennas, which tend to be specified in terms of gain, we have assumed an efficiency of 50% (this being quite reasonable for printed circuit array types which are commercially available), that is, $G(\text{dBi}) = D(\text{dBi}) - 3$ dBi. As a mitigation strategy against the HAP station keeping error being excessive, a second antenna of lower directivity was added to the payload, a gain of 7 dBi being here chosen. Circular polarisation

Table 4: Form of typical link budget calculator.

Transmitter (CPE)	
Power per carrier (dBm)	20.0
Antenna gain (dBi)	15.0
Antenna feed loss (dB)	1.0
EIRP (dBm)	34.0
Receiver (HAP)	
The Boltzmann Constant (dBJ/K)	−228.6
Noise Temperature (K)	300.0
Thermal noise density (dBm/Hz)	−173.8
Receiver noise figure (dB)	3.0
Receiver noise density (dBm/Hz)	−170.8
Antenna gain (dBi)	13.0
Cable loss at ground station	1.0

Modulation Scheme	64QAM	64QAM	16QAM	16QAM	QPSK	QPSK	BPSK	BPSK
Required Eb/No	16.5	16	12	11	9	7.8	8.2	8
Bit/symbol	6	6	4	4	2	2	1	1
Bandwidth (MHz)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Code Rate	0.75	0.67	0.75	0.50	0.75	0.50	0.75	0.50
Data Rate (Mbit/s) (25% rolloff)	12.6	11.2	8.4	5.6	4.2	2.8	2.1	1.4
Data Rate (dBbit/s)	71.0	70.5	69.2	67.5	66.2	64.5	63.2	61.5
Required C/(Io+No) (dBHz)	87.5	86.5	81.2	78.5	75.2	72.3	71.4	69.5

input noise dBm = −108.39

P_received (dBm)	−84.57	SNR	20.82

Link Parameters	
Frequency (GHz)	3.485
Wavelength (m)	0.086
Ground Distance (km)	5.0
Platform Height (km)	20.00
LOS Distance (km)	20.62
FSPL (dB)	129.6
Misc Atmospheric Losses (dB)	0.0
Edge of cell and antenna beam losses	1.0
Clear air losses (dB)	130.6

Alvarion sensitivity (dBm)	−82	−83.0	−88.0	−91	−94	−97	−98.0	−100.0
margin derived from sensitivity	−2.6	−1.6	3.4	6.4	9.4	12.4	13.4	15.4

Alvarion "code rate"	8	7	6	5	4	3	2	1
min SNR	21	19	16	12	9	7	5	3
margin derived from SNR vs rate	−0.18	1.82	4.82	8.82	11.82	13.82	15.82	17.82

was specified. The two payload antennas are just visible in Figure 3(a) and also in Figure 9. The RF switch used is of a coaxial electromechanical type and its measured loss does not exceed 0.1 dB. The switching operation is controlled via the telecommand system.

For the two payload antennas (13 dBi and 7 dBi) we then compute power rolloff due to pointing loss, using a simple curve-fit approximation [10], as a function of platform displacement. This loss can then be used in the link budget calculator to derive expected modulation level (or "rate") as a function of lateral displacement. This is shown in Figure 5 for $h = 20$ km and where we assume the ground station antenna can be pointed (either manually or under electro-mechanical control) to mitigate against occurrence of a further loss term here.

In Figure 5, the effect of the wider payload antenna beam is evident in allowing a link should the HAP drift beyond intended limits such as might occur during a launch phase. In dimensioning the WiMAX link budget we have concentrated on the UL, since the CPE has available 8 dB less output power

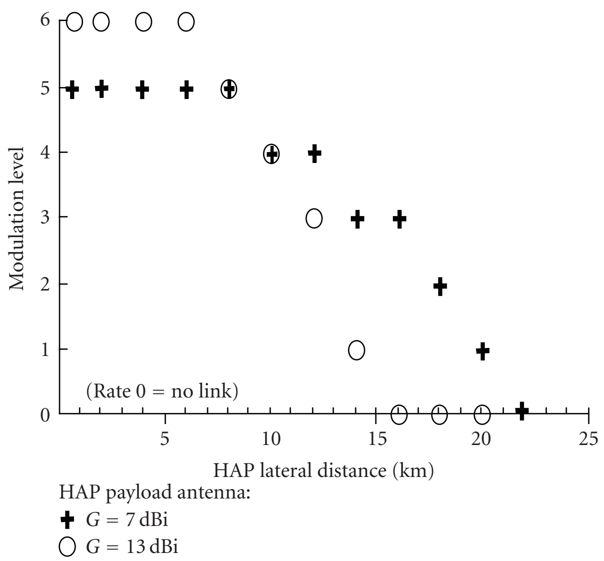

FIGURE 5: Derived UL modulation level ("rate") versus HAP displacement for $G = 15$ dBi ground antenna.

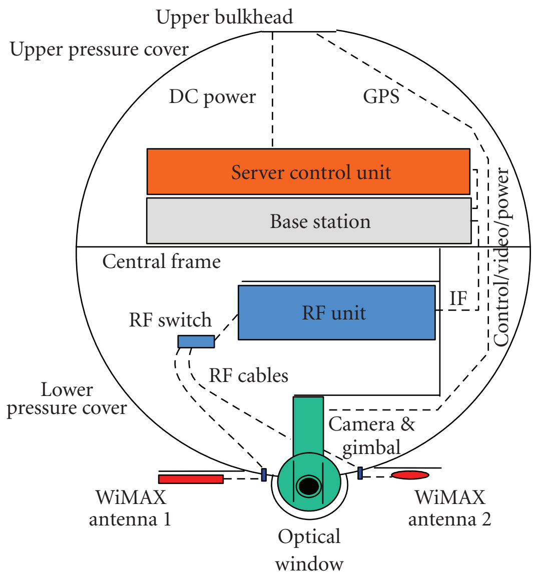

FIGURE 6: Schematic of payload physical layout.

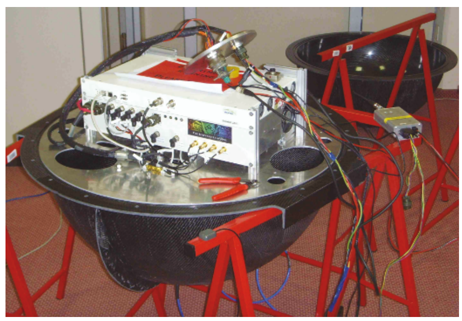

FIGURE 7: Payload interior components.

than the downlink (BS output power). Should the UL fail, then the system becomes inoperative. Since one CPE acts as the backhaul, it is particularly important to maintain a reasonable data rate on that link, since this acts effectively as a bottleneck on the whole WiMAX HAP network. For present purposes with only two or three CPEs, this is not a major problem, but for a future or commercial deployment a different architecture, with dedicated backhaul spectrum, would be preferable.

6. PAYLOAD

The combined WiMAX and optical payloads are to be housed in a spherical pressure chamber for deployment in the stratosphere. The sphere diameter is 750 mm. This layout dictates much of the mechanical design, which is illustrated in Figure 6, where the important payload components are mounted above and below a central circular aluminium frame which comprises numerous access holes to facilitate assembly. The optical subpayload comprises a gimbal mounted camera which has integral stabilisation and control system. This is a "TASE" [11] unit procured from Cloud Cap Technology Inc., Hood River, USA who has developed the unit for unmanned aerial vehicles (UAVs). It features a 112 mm diameter gimbal turret, 0.05° pointing resolution in a package weighing 0.9 kg. The bespoke server control unit houses the failsafe microcontroller, power management and conditioning, environment monitoring, network infrastructure and two pc servers. PC server 1 running a Linux OS provides locally hosted web, email, and ftp services, which allows the demonstration of these without the requirement for a high speed backhaul connection to the internet. Server 1 also hosts web proxy services to demonstrate their ability to reduce user download times and to reduce the backhaul traffic. PC server 2, running embedded Microsoft *XP* OS, hosts video acquisition software to service the gimballed camera and up to a further three fixed (and expendable) external video cameras mounted outside the pressure chamber. After compression the video is streamed over the WiMAX network to ground based clients. The optical subpayload is housed low in the payload vessel and behind an optical window. The remaining payload skin is optically opaque. The WiMAX antennas are mounted externally to the vessel and connected via hermetically sealed microwave bulkhead connectors. The equipment is cooled by recirculating the air in the chamber at atmospheric pressure, thus emulating a pressure and temperature environment very similar to that at ground level.

The components of the "upper" payload are shown in Figure 7 where the base station and server control units are visible above the circular aluminium frame, below which are the WiMAX RF unit and the optical subpayload. The darker hemispheres of the pressure vessel are also discernible.

A view of the lower side of the payload is shown in Figure 8 where the optical window is apparent, although the exterior WiMAX antennas are not yet attached. The payload maximum power consumption is 180 W, including the DC power converters.

Figure 8: Exterior of lower payload.

Figure 9: Helicopter-mounted payload.

7. FIRST AIRBORNE TRIALS

The payload components were prepared for installation on a helicopter (see Figure 9) for a first airborne trial in Switzerland during July 2007. Being a nonstratospheric trial, the pressure vessel was not used at this stage. The two WiMAX antennas were mounted so as to provide a downward beam and a rear facing beam since the helicopter would fly to a 40 km ground distance but not exceed an altitude of about 2 km: these are visible, respectively, as the black circular and square antennas in Figure 10, and below the former, on the left-hand side, the very compact "TASE" camera turret is clearly seen.

The helicopter flew two missions whose flight plans are illustrated in Figure 11. The WiMAX link was kept operational using the wider beamwidth, downward facing antenna during each takeoff and climb phase, and the narrower beamwidth rear facing antenna during the outward flights. The link was thus unavailable during the return flights.

The performance of the uplink during these missions is summarised in Figure 12 by plotting the logged modulation level. This frequently peaked at rate 8 at distances up to 28 km. The "bursty" nature of the logged uplink rate is typical and also seen in Table 3. The sudden fluctuations in rate seen during the flights, as shown in Figure 12, are due to the combined effects of the bursty UL demand and link outages during helicopter manoeuvring; the latter effect being a consequence of the relatively narrow antenna beams.

Figure 10: Payload components for first airborne trial.

8. GROUND-BASED USER TRIAL

Following the successful airborne trials the WiMAX and optical payloads were fully integrated into the spherical pressure chamber and, complete with ancillary equipment such as power supplies and UHF radio modem, prepared for a further, longer duration trial. During August 2007 the payload package was transported and temporarily installed within a north-east facing hotel room at the Pilatus Mountain complex, Switzerland [12]. From this vantage point at 2132 m (7000 ft) altitude the two small circularly polarised antennas mounted vertically on the outside of the building window had a clear line of sight path to the ground station located in Hünenberg, 24.4 km distant. The ground station consisted of two CPEs, one acting as the gateway to the wired internet and one as the "remote terminal" as in Figure 1. The trial consisted of over 30 hours of continuous use with the remote CPE providing "real" users with access to the internet via wired and WiFi connectivity. Users had access to live video streams provided via the onboard cameras as well as a host of locally (to the payload) stored media. During the trial the payload was remotely managed by staff via the UHF telecommand and control link demonstrating the ability to enter very low power states and to reactivate the payload systems.

9. CONCLUSIONS

The development of a WiMAX payload for a stratospheric HAP trial has been reported, where commercially available equipment has been used as far as possible and integrated with bespoke equipment. We used Alvarion's *Breezemax* base station and associated customer equipment operating in bands close to 3.5 GHz. The uplink and downlink data rates are asymmetric due to an 8 dB difference in RF unit output power (resp., 20 dBm and 28 dBm). In terrestrial evaluation and using standard linear polarised antennas of aggregate gain 32 dBi, we obtained data throughputs of 8 Mbps and 9 Mbps, respectively, for UL and DL at a distance of 20 km: these are in fact the highest rates we have observed from the equipment. HAP displacement and pitch/roll considerations lead to an optimum HAP payload antenna directivity of 16 dBi and ground antenna directivity of 18 dBi. Assuming 50% antenna efficiency, this gives an aggregate antenna gain of 28 dBi: a link budget calculation predicts that the UL

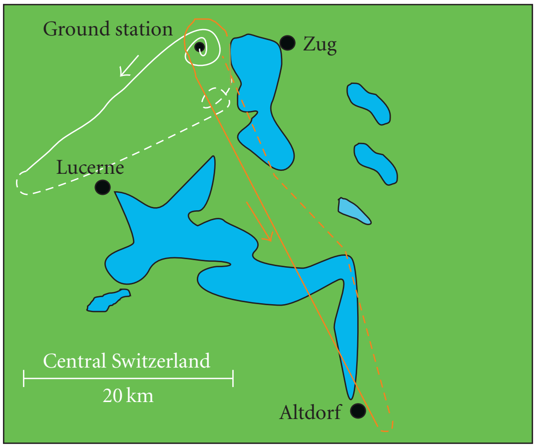

FIGURE 11: Helicopter flight plan.

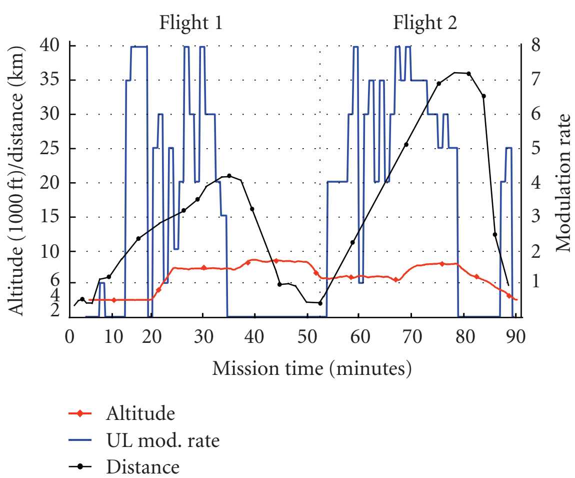

FIGURE 12: Helicopter flights: uplink rate, altitude and link distance versus time.

should run at 16QAM modulation and 3/4 code rate offering 8 Mbps net in each 3.5 MHz bandwidth channel for an HAP at height 20 km within a 5-km position sphere.

A payload comprising WiMAX base station, microcontroller, PC servers and application software, camera, and gimbal subpayload, RF unit, RF switch and antennas, was constructed at the University of York for integration into a spherical pressure chamber for stratospheric trials to be carried out later in 2007 or in 2008. The payload was evaluated in an airborne trial in Switzerland in July 2007 where UL and DL WiMAX links performed as expected at distances up to 36 km during helicopter flights. A longer duration terrestrial trial of the integrated payload followed in August 2007 demonstrating successful link operation and remote payload control during a 30-hour period over a 24.4-km distance.

These trials have demonstrated the potential for WiMAX services from aerial platforms, and validated design aspects of the HAP communications payload. Subsequent phases of the trials are planned with the StratXX airship operating at around 2-km altitude.

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REFERENCES

[1] N. J. Colella, J. N. Martin, and I. F. Akyildiz, "The HALO network^{TM}," *IEEE Communications Magazine*, vol. 38, no. 6, pp. 142–148, 2000.

[2] T. C. Tozer and D. Grace, "High-altitude platforms for wireless communications," *Electronics and Communication Engineering Journal*, vol. 13, no. 3, pp. 127–137, 2001.

[3] J. Thornton, D. Grace, C. Spillard, T. Konefal, and T. C. Tozer, "Broadband communications from a high-altitude platform: the European HeliNet programme," *Electronics and Communication Engineering Journal*, vol. 13, no. 3, pp. 138–144, 2001.

[4] R. Miura and M. Suzuki, "Preliminary flight test program on telecom and broadcasting using high altitude platform stations," *Wireless Personal Communications*, vol. 24, no. 2, pp. 341–361, 2003.

[5] www.elec.york.ac.uk/comms/projects/helinet/index.html.

[6] http://www.capanina.org.

[7] M. Mohorcic, D. Grace, G. Kandus, and T. C. Tozer, "Broadband communications from aerial platform networks—an overview of CAPANINA," in *Proceedings of the 13th IST Mobile and Wireless Communications Summit*, pp. 257–261, Lyon, France, June 2004.

[8] D. Grace, M. H. Capstick, M. Mohorcic, J. Horwath, M. B. Pallavicini, and M. Fitch, "Integrating users into the wider broadband network via high altitude platforms," *IEEE Wireless Communications*, vol. 12, no. 5, pp. 98–105, 2005.

[9] M. Bobbio Pallavicini, J. Horwath, M. Capstick, et al., "Test Results Summary Report, FP6 CAPANINA Project," Doc Ref: CAP-22a-WP44-CGS-PUB-01, September 2006, http://www.capanina.org/documents/CAP-D22a-WP44-CGS-PUB-01.pdf.

[10] J. Thornton, D. Grace, M. H. Capstick, and T. C. Tozer, "Optimizing an array of antennas for cellular coverage from a high altitude platform," *IEEE Transactions on Wireless Communications*, vol. 2, no. 3, pp. 484–492, 2003.

[11] http://www.cloudcaptech.com/gimbal_tase.shtm.

[12] http://www.pilatus.ch.