Interoperability between WiMAX and Broadband Mobile Space Networks

Romeo Giuliano, Michele Luglio, and Franco Mazzenga,

ABSTRACT

In several countries manufacturers, operators, and public authorities look at WiMAX system as a viable technology to fill the "digital divide," providing broadband services mainly in suburban and rural areas, but also in densely populated areas. Nevertheless, as a standalone system it will never offer global services, and to complement its capabilities, the utilization of broadband space-based access shared among users represents a scalable and cost-effective solution to offer wider area coverage, improved performance in terms of QoS, service continuity in case of terrestrial network failure, and long-range user mobility. Integration between WiMAX and a space-based infrastructure, composed of a combination of satellites and high altitude platforms, can be pursued in several ways. The simplest solution is based on connecting a WiMAX network by means of a terrestrial network terminating at a hub station connected to the space infrastructure. A more flexible solution should allow the WiMAX subscriber station or base station to directly access the space infrastructure. This article addresses the identification of suitable scenarios and a feasibility analysis presenting link budget results related to a subset of the identified solutions.

INTRODUCTION

In recent years broadband access to communication networks has become a requirement for a large percentage of the population. Wireless digital subscriber line (WDSL) based on the Worldwide Interoperability for Microwave Access (WiMAX) standard [1, 2] can play a significant role in providing fast Internet access, voice, and video distribution services even for non-line-of-sight (NLOS) environments to fixed, nomadic, and mobile users. In point-to-multipoint configurations WiMAX provides up to 70 Mb/s per station for cells with radii of several kilometers. These target characteristics make WiMAX very attractive for different market segments (residential and business users) and geographical areas (developing countries, rural areas, densely populated areas).

To provide the best performance and ensure business continuity, an infrastructure that is composed of a terrestrial segment and a space segment, including satellites and/or high altitude platforms (HAPs) [3], can be implemented.

In particular, the space infrastructure can:
- Interconnect a set of subscriber stations (SSs) or base stations (BSs) where no or poor terrestrial infrastructures are deployed, to provide coverage contiguity and service continuity for long-range mobility or ensure backup in case of either temporary failure or overflow of terrestrial networks
- Guarantee service continuity and connectivity with remote networks or remote locations to a terrestrial network in case of emergency (earthquake, storms, terrorist attack) when the terrestrial infrastructures can be seriously damaged or temporary wireless access is set up for operation

Furthermore, the two systems can reciprocally fill each other's service gaps: WiMAX as an in building and under shadowing gap filler of satellite/HAP, and satellite/HAP as a gap filler of WiMAX in not covered areas. Finally, the integration of the two systems can represent a valuable element to guarantee security and safety services for monitoring and surveillance.

Integration between the two system can be achieved in several ways. The simplest solution can be based on interconnecting them by means of a terrestrial network. A more flexible solution allows the WiMAX SS and/or the BS to directly access the space segment. The HAP can be considered as an intermediate (relay) node useful to relax both user terminal and satellite payload requirements, thus greatly improving feasibility.

The article is structured as follows. Interoperability and integration of a WiMAX terrestrial system and a space system are addressed, identifying suitable architectures. A system feasibility study is presented along with link budget analysis. Then results are reported. Finally, conclusions are drawn.

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Scenarios and System Architectures for WiMAX-Satellite Interoperability and Integration

International Telecommunication Union — Radio Communication Standardization Sector (ITU-R) Recommendation M.1182-1 [4] defines the following five levels of integration between satellite and terrestrial systems:

1. **Geographical** — Satellite provides service only in areas not covered by terrestrial networks; services and technologies can be different.
2. **Services** — Implies geographical integration and compatibility among services provided by the two networks; performance can be different.
3. **Network** — The same procedures and protocols allow the same number to be dialed independently on the terminal; different carrier frequencies eventually utilized by the two segments must be taken into account.
4. **Equipment** — Compatibility in terms of access, protocols, data rate; at least some circuits could be shared.
5. **System** — Maximum level; users are not aware of what kind of connection has been established.

Interoperability between a WiMAX system and a space system can be related to levels 1, 2, and partially 3 and 4. Three significant service scenarios have been identified [5]:

A **Satellite link as backbone among WiMAX cells** — main application: transport security

B **Satellite extending WiMAX coverage** — services for private residential and small-medium enterprise

C **Satellite link as coverage gap filler** — main application: mobile telephony, messaging, and Internet

System Architectures Supporting Interoperability and Integration

Service scenarios A–C can be supported by different system architectures. For the space segment two architectures have been envisaged:

- *Geostationary platforms*. They represent the best choice in terms of coverage extension, provided capacity, and technology/capacity availability from commercial systems.
- *Geostationary satellite integrated with HAPs as an intermediate device*. A HAP, flying at relatively low altitude (typically from a few up to 20 km), is helpful to mitigate several of the problems, such as propagation delay and physical layer adaptation, raised when direct connection between WiMAX SS or BS and the space segment is considered. HAP allows to enlarge coverage (although less than satellites) keeping similar requirements both for SSs and BSs at the expense of increased complexity and costs.

Twelve different connectivity architectures have been identified. They will be introduced briefly and compared to show the correlation between the previous service scenarios A–C and the connectivity architectures that can support one (or more than one) of them, showing the level of integration that can be pursued according to [4]. To easily guarantee compliance with the WiMAX standard, satellites and HAPs transparent payload architectures are envisaged.

Connectivity Architectures Supporting WiMAX-Satellite Scenarios Based on Geostationary Satellite

To realize the connectivity of WiMAX with standalone geostationary satellites, seven architectures have been identified. The availability of low-cost ground segment equipment and capacity on commercial platforms enhances feasibility assessment [6].

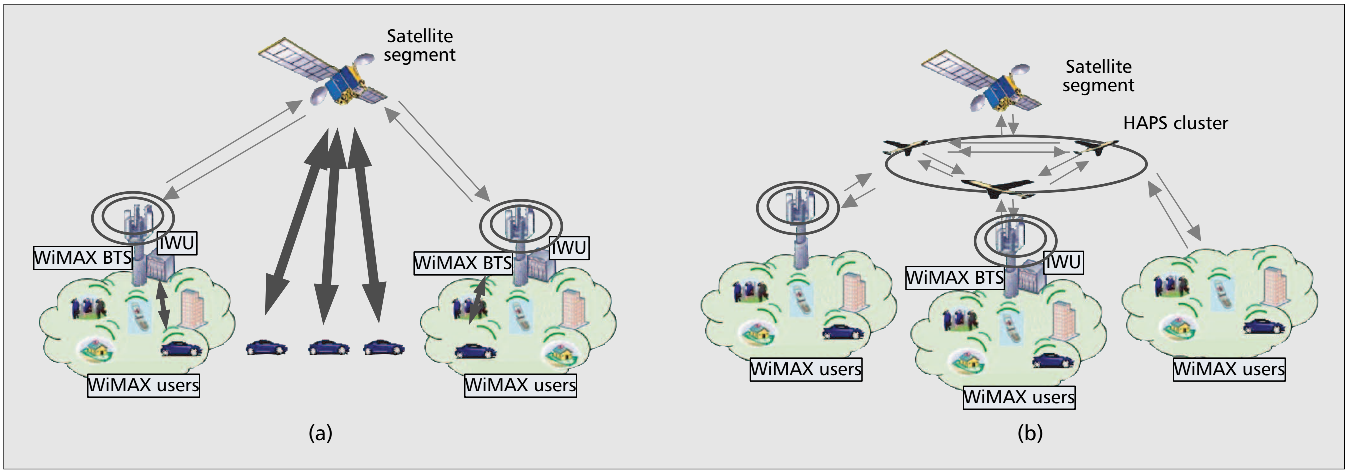
To realize the connectivity of WiMAX with stand alone geostationary satellites, seven architectures have been identified. The availability of low cost ground segment equipment and capacity on commercial platforms, enhances feasibility assessment.

Architecture A: Wideband Satellite — WiMAX BSs provide connectivity to users located inside their coverage area and are connected to a core network that interconnects the WiMAX BSs and is linked to a terrestrial transport network. WiMAX-satellite connectivity is provided by the terrestrial network, and suitable network protocols must be adopted. The satellite link can be either symmetric or asymmetric. In the former, very small aperture terminal (VSAT)-like architecture with full mesh connectivity topology can be implemented. In the latter, star network topology provides high capacity in the forward link and limited capacity in the return link. Utilizing the digital video broadcast (DVB) radio communications satellite (RCS) (or similar) standard, up to 45 Mb/s can be provided on the forward link and up to 2 Mb/s on the return link. Interconnection between the WiMAX core network or with the BS and satellite is obtained through an interworking unit (IWU).

Architecture B: Core Network — Satellite — CNSat is similar to the wideband satellite (WSAT) architecture, but the WiMAX core network is directly connected to the satellite by means of an IWU. No interface for terrestrial networks is needed.

Architecture C: Single WiMAX Satellite — The WiMAX BS is directly connected to the satellite in S-WiSat. Users inside the BS cell can communicate only with the BS. The adaptation of the WiMAX air interface to directly communicate over the satellite link is needed. The design should account for the propagation conditions typical of the satellite link (delay, free space losses, supplementary attenuation).

Architecture D: Double WiMAX Satellite — D-WiSat is shown in Fig. 1a. SSs can be connected to a remote WiMAX BS by means of the satellite link. SSs directly access the satellite, which acts as a transparent repeater toward the BS. The system in Fig. 1a allows the coverage area of the single BS to be enlarged to reach users in remote locations. On the other side, the BS supports satellite connection as in architecture C. Adaptation of the WiMAX air interface to the characteristics of the satellite link is needed.



■ **Figure 1.** *System architecture: a) based on satellite including gap filling functionality; b) using integrated HAP/satellite configuration.*

Architecture D1: Mesh WiMAX Satellite — M-WiSat allows the WiMAX network to exploit full mesh architecture. The satellite is a mesh (relay) node providing interconnection among terminals that can be remotely located. WiMAX users can directly access the satellite link, and the satellite can work either in transparent or regenerative mode. Adaptation of the WiMAX air interface to the characteristics of the satellite link is needed.

Architecture E: Backbone WiMAX Satellite — In B-WiSat the satellite link is used to interconnect two or several remote WiMAX BSs, thus providing either backbone or backup capability. Therefore, each BS is directly connected to the satellite, while SSs are connected to BSs through a terrestrial wireless link. Adaptation of the WiMAX air interface to the characteristics of the satellite link is needed.

Architecture F: Gap Filler WiMAX Satellite — In GF-WiSat, in normal conditions SSs access the network through the terrestrial wireless link. When WiMAX supports mobility, connectivity outside the BS coverage can be provided using the satellite as a gap filler (Fig. 1a).

When the SSs get out of the WiMAX network area, an intersegment handover [7] is implemented to switch the connection to a remote WiMAX BS through the satellite link, or the satellite repeater itself can act as the BS. When the mobile user reaches another WiMAX network, a reverse intersegment handover occurs to switch back to the terrestrial link. SS-to-satellite connection can be achieved using a satellite terminal embedded in the WiMAX device or a WiMAX terminal extended to support satellite communications. In the latter case adaptation of the WiMAX air interface to the characteristics of the satellite link is needed.

HAP-Based Architectures

To simplify the interoperable SS terminal architecture as well as protocol procedures, it would be desirable to keep the WiMAX interface (practically) unchanged. Interconnecting the WiMAX equipment with the satellite through HAPs, typically located at heights ranging from a few hundred meters up to about 20 km, is a way to improve feasibility. In fact, these distances are on the same order of the typical BS coverage radius; thus, no modifications would be required to the WiMAX radio interface. In addition, at the frequency band allocated to WiMAX (around 3.5 GHz) rain attenuation is not as critical as for some bands allocated to broadband satellite services (Ku band and beyond).

Architecture CH: Single WiMAX Satellite HAP — In S-WiSatH the WiMAX BS is connected to the HAP, while SSs communicate only through a terrestrial link. Satellite connectivity will be guaranteed by either a single HAP or a cluster of HAPs interconnected with the satellite through dedicated links (Fig. 1b).

Architecture DH: Double WiMAX Satellite HAP — In D-WiSatH, depicted in Fig. 1b, HAPs are used to provide last mile connectivity to WiMAX SSs that can reach the BS using a four-link connection.

Architecture D1H: Mesh WiMAX Satellite HAP — In M-WiSatH the HAP is used as a mesh (relay) node. Thus, SSs can be directly interconnected among them.

Architecture EH: Backbone Double WiMAX Satellite HAP — BD-WiSatH is based on one HAP interconnecting two or more WiMAX BSs. A more complex architecture utilizes a cluster of interconnected HAPs, each serving one or more WiMAX BSs. In both cases the HAP(s) will ensure the connectivity with the satellite and other terrestrial networks through its (their) gateways.

Architecture FH: Gap Filler Double WiMAX Satellite HAP — In GFD-WiSatH one or more HAPs can be used as a gap filler between two closest WiMAX cells, thus playing the same role of the satellite in architecture F. Connectivity with the satellite is under the charge of the HAP, so the mobile SSs will reach remote locations and be connected to other terrestrial networks, including other BSs. In fact, the satellite will be interconnected with a number of BSs,

Scenario	Architecture	I — Satellite link as backbone among WiMAX cells	II — Satellite link as transport means	III — Satellite link as gap filler
A	Wideband satellite (WSAT)	1, 2	1, 2, 3	
B	Core network satellite (CNSAT)	1, 2	1, 2, 3	
C	Single WiMAX satellite (S-WiSat)		1, 2, 3	
D	Double WiMAX satellite (D-WiSat)		1, 2, 3, 4	1, 2, 3, 4
D1	Mesh WiMAX satellite (M-WiSat)		1, 2, 3, 4	1, 2, 3, 4
E	Backbone WiMAX satellite (B-WiSat)	1, 2, 3, 4	1, 2, 3	
F	Gap filler WiMAX satellite (GF-WiSat)		1, 2, 3, 4	1, 2, 3, 4
CH	Single WiMAX satellite HAP (S-WiSatH)		1, 2, 3	
DH	Double WiMAX satellite HAP (D-WiSatH)		1, 2, 3, 4	1, 2, 3, 4
D1H	Mesh WiMAX satellite HAP (M-WiSatH)		1, 2, 3, 4	1, 2, 3, 4
EH	Backbone double WiMAX satellite HAP (BD-WiSatH)	1, 2, 3, 4	1, 2, 3	
FH	Gap filler double WiMAX satellite HAP (GFD-WiSatH)		1, 2, 3, 4	1, 2, 3, 4

Table 1. *Correlation architectures scenarios.*

and the HAP will play the role of a moving BS. This connectivity architecture can be helpful in case of disaster recovery operations.

SYNOPTIC VIEW

Table 1 summarizes how the proposed architectures can support scenarios A–C. The envisaged level of integration, referred to as ITU-R Recommendation M.1182-1 [4], is also indicated.

FEASIBILITY ANALYSIS

The IEEE802.16 standard [2] defines four air interfaces, two of which are based on the orthogonal frequency-division multiplexing (OFDM) modulation. For feasibility assessment only OFDM with 256 subcarriers (OFDM-256) is considered. The methodology can easily be extended to the case of OFD multiple access (OFDMA) radio access. It is also assumed that the WiMAX SS or BS owns all the necessary equipment to up/down translate the signal in the satellite operating bands (when necessary). The following analysis is based on ideal multihop link budget calculation that can be corrected to account for intermodulation due to nonlinear effects on the OFDM-256 signal.

MODELS AND ASSUMPTIONS

OFDM-256 Signal Characteristics — The main characteristics of the OFDM-256 signal in [2] are now summarized. The number of OFDM subcarriers (N_{FFT}) is 256, and the number of used subcarriers, N_{used}, is 200. Up to eight pilot subcarriers can be inserted in the signal. Guard band carriers are numbered from –128 to –101 and from 101 to 127. The guard time interval is $T_g \cong 3$ μs corresponding to 1/16 of $T_b = 44$ μs, which is the useful OFDM symbol time. For link budget purposes we consider an OFDM signal bandwidth of 5 MHz corresponding to a subcarrier spacing of 22.5 kHz and an equivalent noise bandwidth of 4.5 MHz.

Disturbs and Interference Issues — When no automatic gain control is considered on the satellite or HAP, and frequency conversion and filtering operations are ideal, the main factor influencing performance is the nonlinearity due to the high power amplifier (HPA) on the signal to be retransmitted. The nonlinear effects are particularly evident in multicarrier input signals such as OFDM. Nonlinearities lead to:

- Interference between the in-phase and quadrature (I/Q) components due to AM/AM and AM/PM conversion (when present)
- Intermodulation among OFDM subcarriers

As a final result, the bandwidth of the output signal is greater than the bandwidth of the input signal. Thus, to avoid (significant) adjacent channel interference (ACI) among different OFDM transmissions, guard bandwidths are inserted. In the OFDM-256 signal adopted in WiMAX only $N_{used} = 200$ over $N_{FFT} = 256$ subcarriers are used, and the guard bandwidth is obtained by nulling the transmissions on the first 28 and last 28 OFDM subcarriers. To control intermodulation, the (average) input power to the HPA is set by the ground stations to a fixed level in order to guarantee a desired output power level and a corresponding power of the disturbance due to intermodulation.

In a satellite or HAP characterized by multi-

When two HAPs are used to interconnect WiMAX terminal with the satellite, communication between earth stations and the HAP is in the 3.5 GHz band. In this case no frequency conversion sub-systems should be embedded in the WiMAX terminal.

Parameter	WiMAX		HAP		Satellite
	WiMAX-SAT	WiMAX-HAP	HAP-WiMAX	HAP-SAT	
Transmitter side					
Uplink frequency (GHz)	30	3.5	3.0	30	30
Downlink frequency(GHz)	20	3.0	3.5	20	20
Equivalent noise bandwidth (MHz)	4.5		4.5		4.5
Transmitter loss (dB)	1		1	1	1
Antenna efficiency	0.6		0.6		0.6
Tx antenna diameter (m)	0.1		5	8	8
Pointing error loss (dB)	1	0	0	1	0
Receiver side					
Receiver loss (dB)	1		1		1
Noise system temperature (K)	200	200	200	300	400
Rx antenna diameter (m)	0.1		5	8	8

Table 2. *Selected system parameters for link budget.*

ple beam antennas, transmission/reception interference can be caused by antennas serving "cells" on the same channels and arise from overlapping main lobes or sidelobes [8]. In general, we can distinguish among:

- Interference to the satellite originating from WiMAX BSs (or SSs) directly accessing the satellite
- Interference to the HAP originating from WiMAX BSs (or SSs) accessing the HAP or satellite
- Interference to the satellite due to HAPs served by the same satellite with different beams

The interference powers in the above cases are different and can be evaluated once the distribution of the WiMAX devices (BSs or SSs) and/or HAP in the area have been specified.

Satellite and HAP Characteristics — Satellite and HAP payloads are assumed to be transparent. The Ka frequency band is used on satellite links. The received signal is first filtered and then sent to a low noise amplifier (LNA). The signal at the output of the LNA is (optionally) frequency converted to another band before downlink transmission. The signal is then amplified by a HAP before retransmission. It is assumed that HAPs communicate with the terrestrial segment and satellite using two different frequency pairs. When two HAPs are used to interconnect a WiMAX terminal with the satellite (Fig. 1b), communication between earth stations and the HAP is in the 3.5 GHz band. In this case no frequency conversion subsystems should be embedded in the WiMAX terminal, and all necessary frequency conversion operations for communications with the satellite are implemented inside the HAP. The Ka band is considered for satellite-to-HAP and/or earth-stations-to-satellite communications.

Link Budget Analysis

To assess feasibility, we performed multiple-hop link budget analysis (LBA) in the following three configurations:

- *Two links* in which two WiMAX devices are connected through a satellite
- *Three links* in which one WiMAX device is directly connected to the satellite and the other is connected to the satellite through a HAP acting as a relay node
- *Four links* in which both WiMAX devices are connected to the satellite through a HAP

The main goal of LBA is to calculate the power at the output of each relay device (satellite or HAP) so that the carrier-to-noise ratio at the input of the nth receiver is equal to

$$\left(\frac{C}{N}\right) = N_l \left(\frac{C}{N}\right)_t M \text{ (balanced hops case)} \qquad (1)$$

where N_l is the number of links, $(C/N)_t$ is the reference carrier-to-noise ratio (including coding) required to obtain the specified bit error rate, and M is the margin. The values of the target $(C/N)_t$ are ([2, 5]):

- +6.4 dB — Binary phase shift keying (BPSK) modulation with code rate 1/2
- +9.4 dB — Quaternary PSK (QPSK) modulation with code rate 1/2
- +16.4 dB — 16-quadrature amplitude modulation (QAM) with code rate 1/2
- +22.7 dB — 64-QAM with code rate 1/2

Furthermore, the ratio between the power at the output of the single relay system with the corresponding input power provides the overall required gain in the receiver-transmitter chain of the (transparent) relaying subsystem.

Multihop analysis is carried out under the following simplifying assumptions:

- Intermodulation effects are neglected for the moment.
- Line of sight propagation is assumed.
- Rain margin and additional losses due to atmospheric effects are included in the calculations.
- Interference and shadowing are not considered.
- The earth-station-to-HAP link is at 3.5 GHz; the HAP-to-earth-station link is at 3.0 GHz; WiMAX or HAP transmissions to the satellite take place in the Ka band (30 GHz uplink; 20 GHz downlink).

In the asymmetric link case we assume that the diameters of the earth station and HAP transmitting and receiving antennas can change. As an example, the satellite repeater can use an antenna with diameter D_1 when it transmits (receives) to (from) the WiMAX terminal and an antenna with diameter D_2 when it transmits (receives) to (from) the HAP.

Starting from previous assumptions, the overall signal-to-noise-plus-interference (intermodulation only) ratio at the end of the multihop transmitter receiver chain is

$$\left(\frac{C}{N+I}\right) = \frac{1}{\sum_{n=1}^{N_l} (SNR)_n^{-1} + \sum_{n=1}^{N_l-1} (SIR)_n^{-1}} \quad (2)$$

where N_l is the number of links and $\mathbf{SNR}_n$ is the useful signal-to-noise ratio at the input of the nth receiver; that is,

$$SNR_n = \frac{L_{(n-1)n} P_T^{(n-1)}}{N^{(n)}} \quad (3)$$

where $P^{(n-1)}{}_T$ is the (maximum) useful transmitted power at the output of the $(n-1)$th transmitter, $L_{(n-1)n}$ is the overall attenuation (including path loss and transmitter and receiver antenna gains) from the $(n-1)$th transmitter to the nth receiver, and $N^{(n)}$ is the noise power at the nth receiver. The SIR_n is the useful signal-to-intermodulation ratio measured at the output of the nth transmitter in the chain.

Link Budget Parameters

The link budget parameters used for calculations at the Ka band are shown in Table 2.

The link characteristics are:

- Distance, earth station–satellite = 40,000 km
- Distance, earth station–HAP = 20 km
- Vapor loss = 3 dB
- Additional loss due to rain at 30 GHz = 15 dB
- Additional loss due to rain at 20 GHz = 8 dB

As indicated in Table 2, two different sets of parameters are considered for the HAP. The first accounts for the HAP–earth station link and the second for the HAP–satellite link. In both cases, to calculate link budgets we assume a parabolic antenna with a given diameter. To assess feasibility, the main goal of the link budget is to determine the ratio G between the required useful output power and the useful input power at each repeater stage. This ratio provides the gain of the Tx-Rx chain to be achieved in each repeater (i.e., the satellite or HAP) in order to respect the target SNR performance.

Architecture	G (dB)		
	HAP	Satellite	HAP
WiMAX-SAT-WiMAX	—	132.0	—
WiMAX-HAP-SAT-WiMAX	91.5	130.0	—
WiMAX-SAT-HAP-WiMAX	—	86.7	62.3
WiMAX-HAP-SAT-HAP-WiMAX	91.5	90.2	62.3

Table 3. *Required repeater subsystem gain for the different architectures.*

Architecture		Transmitted Power (dBW)			
		WiMAX	HAP	Satellite	HAP
WiMAX-SAT-WiMAX	QPSK	14.6	—	8.4	—
	64-QAM	27.9	—	21.7	—
WiMAX-HAP-SAT-WiMAX	QPSK	–44.7	–33.4	8.2	—
	64-QAM	–31.4	–20.1	21.5	—
WiMAX-SAT-HAP-WiMAX	QPSK	16.6	—	–35.2	–60.0
	64-QAM	29.9	—	–21.9	–47.3
WiMAX-HAP-SAT-HAP-WiMAX	QPSK	–43.4	–32.0	–30.3	–59.2
	64-QAM	–30.1	–18.7	–17.0	–46.2

Table 4. *Required transmitted power for each subsystem, QPSK and 64-QAM modulation formats.*

Results

In Table 3 we show the Tx-Rx gain G required in each repeater for different system architectures. Since we assume that the required SNR at each stage is the same, G is independent of the reference SNR.

In Table 4 we indicate the useful power to be transmitted at the output of each subsystem to satisfy the quality of service (QoS) requirements.

As shown in Table 3, for the WiMAX-HAP-Sat-WiMAX architecture, we separately examine the two communication directions (i.e., WiMAX-HAP-Sat-WiMAX and WiMAX-Sat-HAP-WiMAX). The critical path is the satellite-to-WiMAX link. This is due to the limited characteristics of the WiMAX

It was observed that to realize direct connection of WiMAX devices with the satellite, large gain in the satellite transceiver is necessary. New generations of satellites will meet these requirements.

Modulation format	TWT				SSP			
Reference probability of bit error = 10^{-3}	Predistorter OFF		Predistorter ON		Predistorter OFF		Predistorter ON	
	OBO	SIR	OBO	SIR	OBO	SIR	OBO	SIR
QPSK	5.0	12	3.8	14	3.3	15	2.0	19
16-QAM	7.0	18	6.0	23	5.4	18	4.2	27
64-QAM	9.5	22	8.8	33	8.0	23	7.0	32

Table 5. *OBO and SIR corresponding to minimum TD.*

transmitter/receiver and the presence of the additional rain margin on this link only. In the second case the WiMAX transmitter is constrained to provide higher power to reach the satellite (more than 40 W for QPSK).

The third architecture seems to be the most promising for wideband WiMAX communications through satellite. In fact, since HAPs are located at an altitude of 20 km from the Earth and operate around 3 GHz, in the link with WiMAX no rain margins must be considered with a remarkable improvement in terms of feasibility as shown in Tables 3 and 4. The availability of two HAPs acting as repeaters to/from the satellite allows the WiMAX transmitter-receiver requirements to be relaxed in terms of transmitter power and antenna size.

To obtain data in Tables 3 and 4 we assumed a small WiMAX antenna. Several requirements could be relaxed by increasing antenna dimensions, especially for WiMAX BSs. One more improvement can be obtained by considering subchannel transmissions, which are allowed in OFDM and OFDMA as proposed for WiMAX. As an example, when only one subchannel is considered for transmissions, the equivalent noise bandwidth in Table 2 should be reduced by a factor proportional to the number of subchannels.

Nonlinear Effects on the 256-OFDM Signal

The operating point of the amplifier is commonly identified by the *backoff*. For link budget purposes we only need the output backoff (OBO) defined as the ratio between the mean power of the useful transmitted signal and the maximum useful output power. Nonlinear impairments can be reduced working with high backoff, which corresponds to moving the operating point of the amplifier to the linear region, thus leading to loss in HPA efficiency.

A useful performance measure is the total degradation (TD) which is a function of the OBO; that is, $TD = OBO + SNR_{dB} - SNR'_{dB}$, where SNR_{dB} is the required signal-to-noise ratio in dB at the input of the threshold detector to obtain a fixed probability of bit error; SNR'_{dB} is the required SNR to obtain the same probability of bit error in the absence of nonlinear effects. For each OBO we can calculate the corresponding SIR to be inserted in Eq. 2. The optimum OBO corresponding to the minimum TD has been obtained from further simulations. The results are based on the amplifiers models considered in [9] concerning both traveling wave tube (TWT) and solid state power (SSP) amplifiers. TWT and SSP amplifiers with and without (analytical) predistortion have been considered [9, 10]. Results are reported in Table 5 for a bit error probability of 10^{-3}.

Due to the absence of AM/PM effects, SSP performances are always superior to TWT. As expected, higher-efficiency modulation formats require a higher OBO to obtain the same QoS specification.

Conclusions

We present feasibility analysis for three architectures proposed to enhance WiMAX capabilities through the use of a space-based architecture. It is observed that to realize direct connection of WiMAX devices with the satellite, a large gain in the satellite transceiver is necessary. New generations of satellites will meet these requirements. To improve on this, the adoption of HAP located at 20 km altitude can be helpful to relax both the WiMAX transmitter requirements and the satellite gain requirements. This allows very high link budget margins to be achieved on the WiMAX-HAP and HAP-SAT links. However, in the asymmetric cases the WiMAX-SAT link turns out to be critical, so the same considerations as for the WiMAX direct connection architecture apply. Thus, the solution including a HAP as a repeater for the WiMAX signal to the satellite allows the above mentioned problems to be solved, and looks very attractive and promising.

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Biographies

ROMEO GIULIANO (romeo.giuliano@uniroma2.it) received a telecommunication engineering degree cum laude in1999, an M.B.A. in 2001, and a Ph.D. degree in telecommunications and microelectronic engineering in 2004 from the University of Rome Tor Vergata, Italy. In 2001 he joined RadioLabs, a research consortium specialized in wireless communications. At present he is working on capacity analysis and coexistence for a UWB system. Other research interests are the wireless access of UMTS, Bluetooth, ultra-wideband, and WiMAX systems.

MICHELE LUGLIO (luglio@uniroma2.it) received a Laurea degree in electronic engineering in 1990 and a Ph.D. in telecommunications in 1994. In 1992 he worked at Comsat Labs. From 1995 to 2004 he was researcher at the University of Rome Tor Vergata, where he is now an associate professor. He works on designing satellite systems for multimedia services. In 2001 and 2002 he was a visiting professor at the University of California at Los Angeles. He teaches satellite telecommunications, and signals and transmission.

FRANCO MAZZENGA (mazzenga@ing.uniroma2.it) received a Dr. Ing. degree in electronics engineering cum laude from the University of Rome Tor Vergata in 1993. Currently he is an associate professor of communications in the Electronic Engineering Department of the same university. He is the author of more than 70 scientific publications in journals and international conferences. His main research areas are statistical signal processing and local/personal wireless transmission technologies.