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Comparison of Broadband Wireless Access Technology for HAPS Communication

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Abstract: An information system formed by HAP (High Altitude Platform) will be a new generation-system for the wireless communications and HAPS (HAP Station) communication system combines the advantages of both terrestrial and satellite communication systems and avoids, to different extents, their disadvantages. Third generation (3G) mobile technology which is specified by the third generation partnership project (3 GPP) is definitely one of the candidates. With the success of wireless network, the IEEE 802.16 standard, with its wireless metropolitan area network (MAN) air interface appears to be a strong competitor. We provide initial practical comparison of these two technologies for HAPS Communication. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: HAPS communication, Broadband wireless access, Coverage, Wireless link.

1. Introduction

Mobile communication technologies have rapidly developed in the past two decades. The fundamental problem of mobile communication lies on finding ways to enable people to communicate by all means whenever and everywhere, including mobile communication. Recently, a novel form of mobile communication has emerged, and is called the high-altitude platform station (HAPS) [1–4]. In general, a HAPS network is composed of quasi-static high-altitude platform stations at the low altitude (20–100 Km), with a certain payload, and with the residence time of 5–10 years. In the near-Earth space, HAPS adopts a stable communication platform as a microwave relay station, and forms into a communication system with ground control units, access equipment, and various wireless users. HAPS implements the integrated satellite-ground networking and supports a separate ground networking, as shown in Fig. 1. As can be seen, the communication platform is synchronized with the rotation of the earth, and it can reside in the space for a long time. HAPS utilizes sound radio transmission features and implements the communication connections between users, platforms and satellites. It also possesses the following advantages: layout flexibility, wide-ranging applications, low cost, security, reliability, and so on [5-8]. The HAPS-based information system is a new generation wireless communication system, which combines terrestrial and satellite communication systems under the principle of fostering their strengths and circumventing their weaknesses. This system is widely recognized in the fields of communication. In addition, within its coverage, the HAPS is still allowed to use cellular network communication [9-10].

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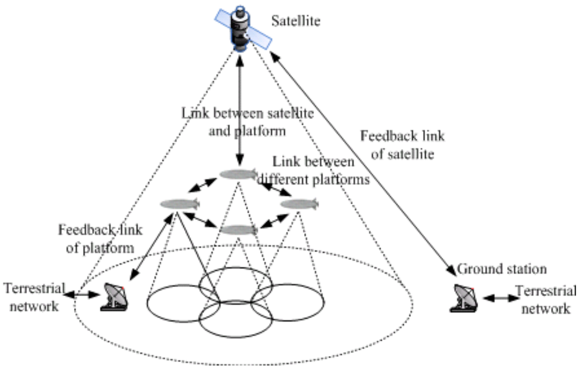
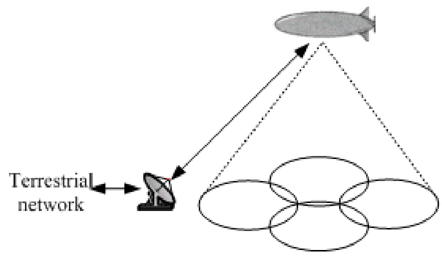
Worldwide Interoperability for Microwave Access (WiMax), 802.16e, is a wireless communication technology specified by IEEE 802.16 working group [11, 12] which aims to be a wireless replacement for a wired broadband connection. It is designed to provide network access to buildings through exterior antennas communicating with central radio base stations (BSs). Because wireless systems have the capacity to address broad geographic areas without the costly infrastructure development required in deploying cable links to individual sites.



a) Satellite-ground-HAP integrated network



b) Ground-HAP integrated network

Fig. 1. HAPS communication network architecture.

802.16 was the first standard to be published and defined a physical layer that was optimized to operate in the 10-66 GHz range. Due to operating in the high frequency band, a line of sight link (LOS) between transmitter and receiver is assumed and single carrier modulation was chosen. The 2-11 GHz amendment project that led to IEEE 802.16a was approved in March 2000. The 802.16a project primarily involves the development of new physical layer specification to cover the non line of sight (NLOS) operations, with supporting enhancements to the basic MAC. The standardization of 802.16e (WiMax) is still in progress and expected to complete in 2006. It modifies 802.16a medium access control (MAC) layer for mobility but does not change the physical layer. In this paper, we provide a comparison between WiMax technology and the TD-CDMA and address some of the engineering challenges that could be faced by WiMax designer.

2. Technology Features

OFDM is employed as the wireless access scheme for the WiMax standard. An OFDM signal is basically a bundle of narrowband carriers transmitted in parallel at different frequencies from the same source. The individual carriers in OFDM commonly called sub-carriers, are carefully spaced in frequency so that they are orthogonal and therefore do not interfere with each others. By combining the OFDM technique with error-correcting codes, adaptive equalization and reconfigurable modulation, WiMax communication is resistant against the multi-path fading channel. CDMA is also deigned to mitigate the multi-path effects in wideband environment by using equalization and advanced multi-user receiver. However, as the delay spread increases, the performance of the CDMA system degrades due to the corruption of the orthogonal relationship among codes. In addition, the complexity of the receiver may increase under this condition. On the other hand, OFDM's resistance to the multi-path interference results from the increased symbol duration for each sub-carrier and from use of a cyclic prefix, called guard period, preceding each symbol. In general, the OFDM provide performance gain comparing to the CDMA system with similar receiver complexity in a strong multi-path environment.

The air interface of WiMax is designed mainly target for low mobility application, OFDM technology is very sensitive to the received signal with frequency variation. With large Doppler frequency offset introduced by user mobility, the OFDM receiver may not able to track the frequency offset and result in performance degradation. In addition, handover between cells is not supported in the current 802.16 standard and is planed to resolve in 802.16e. On the other hand, full mobility can be supported by TD-CDMA system, the air interface is designed to handle high mobility users with up to 100 km/h for some services. Furthermore, both inter-cell and inter radio access technology (RAT) handover is realized according to the current 3GPP specification.

The UMTS TDD system is fully defined through UMTS 3GPP to cover all elements of a cellular network including both radio access network (RAN) and core network (CN). It also specified billing, security, operations & maintenance (OAM) and location management. In addition, mobility function and global roaming are fully supported. The UMTS release 4 has been launched for commercial deployment successfully for a few years. Release 5 has been completed and both TDD and FDD HSDPA features are included. The specification is reliable and stable and has been proven by commercial operations. On the other hand, 802.16 working group only covers medium access control (MAC) and physical layer (PHY) specification. Billing, security and OAM are not specified and it is still uncertain of how to integrate the 802.16 system to the existing cellular network. Furthermore, the WiMax (802.16e) specification is still in the draft state. Furthermore, the role of the current 802.20 and 802.16 has some uncertainties and doubts, consequently it may further slow down WiMax development.

AMC scheme are supported in both WiMax and HSDPA. The HSDPA can support QPSK and16QAM modulation. WiMax not only can support both modulation schemes, but also the higher modulation order 64QAM can be used optionally. It is mainly because the sub-channels in an OFDM system are orthogonal, resulting in zero or low intra cell interference. HSDPA uses the standard 3GPP turbo code as the error control coding scheme. A concatenation scheme with Reed-Solomon and convolutional coding is used in WiMax and optionally Block Turbo Coding (BTC) and Convolutional Turbo Coding (CTC) are specified. The interleaver size is smaller than the 3GPP specification; hence less memory is required with scarifying some coding gain. Low density parity check codes (LDPC) is currently being considered to include in the 802.16e standard. The complexity and performance still need to be investigated. Transmit diversity have been include in the 3GPP specification. Multiple inputs and multiple output (MIMO) technique are evaluated currently in a 3GPP standardization study item. Transmit diversity is an optional feature in the WiMax specification. Other advanced antenna techniques can definitely be included in the OFDM transmission, but the agenda to include those features in WiMax is not clear yet.

It is well known that the frequency re-use factor of one can be achieved by the CDMA, which means that all the cells can operated with a same allocated frequency band due to its processing gain from spread spectrum. However, OFDM typically needs a frequency reuse sector of more than one to maintain its maximum throughput per cell, which means the spectral efficiency of a cell must be divided by the frequency re-use factor.

3. Link Budgets

The coverage performance of both TD-CDMA and WiMax are evaluated. The link budget of both uplink and downlink are analyzed and the maximum allowable path loss is used as the performance metric.

3.1. Assumptions

In the downlink link budget calculation, a single cell with no inter-cell interference is assumed and all the transmit power is allocated to a user with maximum theoretical downlink throughput. The results indicate the maximum allowable path loss for the highest data rate service in single cell environment. On the other hand, uplink coverage is normally limited by the mobile transmission power in cellular system. The maximum range for a cell to provide service to a low data rate user is calculated in the uplink link budget. The common assumption and parameters are shown in Table 1.

Table 1. Link budget assumptions.

Assumptions	Base Station	User Terminal
Cable, connector and duplexer losses (dB)	2	0
Body losses (dB)	0	0
Receiver noise figure (dB)	3	5.5
Antenna gain (dB)	18	2
Receiver Noise density (dBm/Hz)	-171.0	-168.5
Receiver Noise Power (dBm)	-105.2	-102.7

3.2. Link Budgets for TD-CDMA

In the uplink analysis, a low data rate service of 31.4 kBps is assigned to the user, in which the spreading factor is 16, two codes and one time slot is assigned to the user. The required Eb/N0 is 4.2 dB. Table 2 shows an example link budget for TD-CDMA. It shows that the allowed propagation loss for downlink and uplink are 132.7 and 140.1 dB respectively. This indicates that if high data rate service is provided in the system, the cell range is limited by downlink rather than uplink. This observation is opposite to the normal situation of low data rate voice traffic cellular environment.

Table 2. Link budget for TD-CDMA

Parameters	Downlink Link Budget	Uplink Link Budget
Transmitter		
Maximum Tx power per code (dBm)	28	24.0
Antenna gain (dBi)	18	2.0
Tx cable loss/Body loss (dB)	2.0	0.0
EIRP (dBm)	44	26.0
Receiver		
Thermal noise density (dBm/Hz)	-174.0	-174.0
Receiver noise figure (dB)	5.5	3.0
Receiver noise density (dBm/Hz)	-168.5	-171.0
Receiver noise power (dBm)	-102.7	-105.2
Interference margin (dB)	1.9	2.5
Total noise + margin (dBm)	-100.8	-102.7
Processing gain (dB)	7.75	15.0
Require Eb/No (dB)	6.8	4.2
Receiver sensitivity (dBm)	-101.75	-113.5
Antenna Gain (dBi)	2.0	18.0
Rx cable loss/body loss	0	2.0
Maximum path loss (dB)	145.1	155.5
Log-normal fade margin (dB)	15.4	15.4
Allowed propagation loss for cell range (dB)	132.7	140.1

3.3. Link Budgets for WiMax

The link budget analysis is derived based on the assumptions that are listed in Section A and the bearer specification. Two multiple access schemes, time division multiplexing (TDM) and frequency division multiple access (FDMA), are used in WiMax system in uplink and downlink respectively. It means that for a particular time period (Time Slot), the whole spectrum is allocated for a single user in downlink and multiple users can be transmit to the base station simultaneously in uplink with part of the whole allocated spectrum. The total number of sub-channels is 32. If a user is only assigned to single sub-channel, then 1/32 of the allocated bandwidth is reserved to this FDMA uplink user. Since only a small section of bandwidth is assigned to that user in each time slot, the full transmit power can be used in one sub-channel and 15 dB sub-channelization gain is added to the uplink budget. In addition, 5 MHz spectrum is allocated for both uplink and downlink and the corresponding spectrum usage ratio is 1:4. In order to mitigate the multi-path effect, guard period is inserted in the frame to maintain the orthogonal among sub-carriers. Table 3 Similar to TDD system, the cell range is limited by the downlink with high downlink data rate. The allowable propagation loss for the cell is 128.6 and 138.2 dB for downlink and uplink respectively.

3.4. Coverage Comparison

We present the coverage comparison in Table 4. In general, it shows that the peak data rate that can be provided by WiMax is slightly higher than the service from TD-CDMA system. On the other hand, it depicts that the maximum allowed path loss of TD-CDMA system is larger than WiMax system. In addition, the maximum allowed path-loss of both systems are shown in the last column and the uplink limited cases are indicated by the grey color. It is concluded that the coverage of TDD system is better than that can be provided by WiMax.

Table 3. Link budget for WiMax.

Parameters	Downlink Link Budget	Uplink Link Budget
Transmitter		
Tx power per subcarrier (dBm)	8	-8
Antenna gain (dBi)	18	2.0
Tx cable loss/Body loss (dB)	2.0	0.0
EIRP (dBm)	24	-6
Receiver		
Thermal noise density (dBm/Hz)	-174.0	-174.0
Receiver noise figure (dB)	5.5	3.0
Receiver noise density (dBm/Hz)	-168.5	-171.0
Receiver noise power (dBm)	-134.6	-137.1
Interference margin (dB)	1.9	2.5
Sub-channelinization gain (dB)	0	15.0
Require SNR (dB)	13.5	4.7
Receiver sensitivity (dBm)	-119.2	-144.9
Antenna Gain (dBi)	2.0	18.0
1+Tg/Tb	1.25	1.25
Rx cable loss/body loss	0	2.0
Maximum path loss (dB)	144.0	154.9
Log-normal fade margin (dB)	15.4	15.4
Allowed propagation loss for cell range (dB)	128.6	138.2

Table 4. Link budget comparison.

Case	Max. Information Throughput (Mbps)		Max. allowed Outdoor path loss (DL) (dB)		Max. allowed Outdoor path loss (UL) (dB)		Max. allowed path loss (dB)	
	TDD	Wimax	TDD	Wimax	TDD	Wimax	TDD	Wimax
1	8.611	9.976	132.7	128.6	140.1	138.2	132.7	128.6
2	5.741	6.648	136.6	130.7			136.6	130.7
3	4.306	4.984	138.6	135.9			138.6	135.9
4	2.870	3.328	142.1	137.7			**140.1**	**137.7**

4. Spectrum Efficiency

We simulated the downlink spectrum efficiency of both systems. The simulation conditions are shown in Table 5. In addition, muli-cell environment with 19 cells is considered in the simulation model.

Fig. 2 shows the spectrum efficiencies of both systems in various conditions. The cell edge can be defined with criterion of providing service with less than 5 % of outage probability. The cell edge of WiMax is shown to be smaller than that of TDD in all cases.

For example, the cell edges of TDD and WiMax are about 670 m and 690 m respectively. In this section, we mainly focus on the capacity analysis; it is observed that the spectrum efficiency of WiMax is consistently lower than that of TD-CDMA due to employing high frequency reuse factor. We conclude that TD-CDMA outperforms the WiMax in these multi-cell environments.

Table 5. TD-CDMA and OFDM parameters for simulation analysis

Parameters	Value
Carrier frequency	3.4 GHz
Occupied bandwidth	5 MHz
Downlink / uplink ratio	14:1
BS maximum transmitted power	40 dBm
BS antenna gain	11 dB
User terminal antenna gain	2 dB
Antenna connector loss	2 dB
Noise figure of user terminal	5.5 dB
Pathloss formula	146.4+38.4xlog(d) 140.4+34.77xlog(d) 132.4+32.77xlog(d)
Shadow fading standard deviation	10 dB
TD-CDMA	
Chip rate	3.84 Mbps
Downlink overhead channel	1 timeslot
Burst type	2
Spreading factor	16
OFDM	
NFFT number of sub-carriers	2048
Nused number of used sub-carriers	1702
Ndata number of data sub-carriers	1536
Tg/Tb cyclic prefix to useful time ratio	1:4
CIR loss	10log10((Tg/Tb)/Tb)

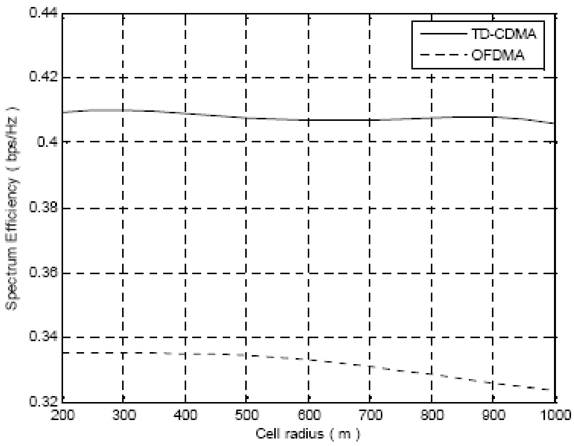


Fig. 2. Spectrum efficiency of TD-CDMA and WiMax in various conditions.

5. Conclusions

This paper investigates the performance characteristics of WiMax and TD-CDMA systems for 5 MHz bandwidth in HAPS communication network. We show that the TD-CDMA can provide better spectrum efficiency and coverage than those can be offered by WiMax. Furthermore, TD-CDMA demonstrates its superiority over WiMax in the areas of standard maturity, network management including billing and security, frequency reuse, interpolating with different vendors and communicating with the existing network.

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