Broadband For All by WiMAX Technology.

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ABSTRACT

The demand for broadband connectivity is growing rapidly, but cannot be met effectively by existing wire line technology. The vision of a fully mobile broadband service which addresses the needs of the consumer has captured the attention of most of the major providers and vendors in the world. A host of technologies are competing to deliver commercial mobile broadband services. WiMAX (Worldwide Interoperability for Microwave Access) is the IEEE 802.16 standards-based wireless technology for making broadband for all a reality everywhere. The low-cost, all-IP network architecture and backwards compatibility with existing 2G and 3G cellular network deployments makes WiMAX easier and more cost-effective to deploy and operate than current mobile wireless data solutions. This paper provides an overview of WiMAX including its history, features, technology evolution, and network architecture. This paper also analyzes the future prospects of WiMAX and its contribution to the wireless and mobile communication technology field.

(Keywords: WiMax, worldwide interoperability for microwave access, IEE 802.16, MIMO, OFDMA, mobile broadband)

INTRODUCTION

The explosive growth of the Internet over the last decade has lead to an increasing demand for high-speed, ubiquitous Internet access. Broadband wireless access (BWA) has created demand for new wireless technologies to reduce the cost of operation and by pass monopoly of service providers in wire-line access. A host of technologies are competing to deliver commercial mobile broadband services. Worldwide Interoperability for Microwave Access (WiMAX) is among the leading technologies to meet the demand for broadband connectivity in a wide range of devices from smartphones to notebook computers.

Mobile WiMAX meets the requirements of these devices today and offers plenty of versatility for supporting the evolving needs of the mobile broadband business for many years to come. With the ability to provide efficient broadband connectivity for multiple services — such as data, voice over internet protocol (VoIP), and video streaming with carrier-class quality of service (QoS) to every user — Mobile WiMAX is a leading choice for fourth-generation (4G) cellular technology [4].

According to the WiMAX Forum, more than 150 WiMAX networks have been turned on over the past year to reach a total of 472 networks across 139 countries in April 2009 [1]. Also, WiMAX Forum projects over 800 million people to have access to next-generation WiMAX networks by 2010 [3].

According to Pyramid Research, fixed and mobile broadband service revenue will nearly double and amount to $629bn by 2014, 38% of total telecommunications service revenue, up from $338bn in 2008 (see figure 1) [1].

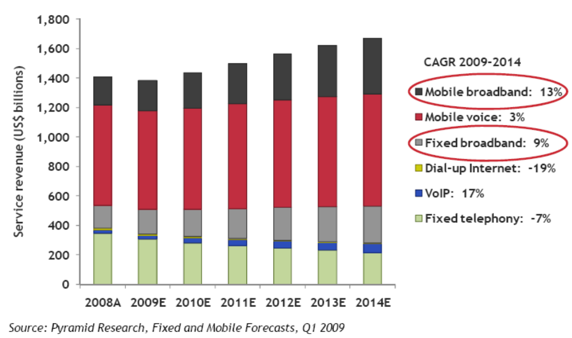

Figure 1: Global Telecommunications Service Revenue, 2008-2014 [1].

A compelling reason for deploying WiMAX is the structured and extensive ecosystem that is being created to support the technology. Device vendors, infrastructure manufacturers, chipset makers, system integrators, operators, applications developers and other players are all focused on making WiMAX a success. The IEEE (Institute of Electrical and Electronics Engineers) has been developing and will continue to evolve the radio interface standards that support WiMAX [5].

TECHNOLOGY EVOLUTION OF WiMAX

The Local Multipoint Distribution Systems (LMDS) is the first notable BWA that showed a short-lived rapid success as a wireless alternative to fiber and coaxial cables in the late 1990s. LMDS has utilized 28 and 31 GHz, offers up to several hundreds of megabits per second, and requires roof-top antennas to achieve line-of-sight (LOS) connection. Also, Multichannel Multipoint Distribution Services (MMDS or Wireless Cable) technology emerged at 2.5 GHz and became popular in sparsely populated rural areas. LMDS and MMDS have adapted the modified version of Data Over Cable Service Interface Specification (DOCSIS) for wireless broadband also known as DOCSIS+. MMDS provided greater range than LMDS but still required LOS link to operate [8].

In 1998, IEEE addressed the LOS challenge of broadband wireless with OFDM modulation and standardization activities under the 802.16 Working Group. This group targeted to standardize the technology for Wireless Metropolitan Area Network (Wireless MAN), also adopted by ETSI HiPERMAN (High Performance Radio Metropolitan Area Network). In 2001, the first standard was approved as Wireless MAN-SC which specified a single-carrier technology for operation in the 10–66 GHz band like LMDS. Non-LOS (NLOS) which has been addressed in the 2–11 GHz band for licensed and unlicensed frequencies as amendments to existing 802.16 standards. The IEEE 802.16a, completed in 2003 introduced three access schemes: single-carrier, OFDM and OFDMA for fixed NLOS access. It also specifies a common MAC layer for all three access schemes where concepts were mainly adapted for wireless from DOCSIS. The IEEE 802.16-2004 standard ratified in 2004 replaced the IEEE 802.16, 802.16a, and 802.16c standards with a single standard and formed the basis for fixed WiMAX solution. In 2005, IEEE 802.16e-2005 amendment, which forms the basis for mobile WiMAX, was ratified to introduce enhancements for high-speed mobility. The IEEE 802.16 framework specifies the physical and media access control layers but does not deal with the end-to-end systems' requirements and interoperability criteria of systems built on these requirements. The industry-led WiMAX Forum was organized to fill this void to address fixed WiMAX and mobile WiMAX network architectures and protocols including interoperability and certification [8].

The current Mobile WiMAX technology is mainly based on the IEEE 802.16e amendment, approved by the IEEE in December 2005, which specifies the Orthogonal Frequency Division Multiple Access (OFDMA) air interface and provides support for mobility [7].

The selection of features to be implemented in WiMAX systems and devices is presented in the mobile WiMAX System Profile Release 1.0 which was developed in early 2006 and is currently maintained by the WiMAX Forum. It is this very technology defined in WiMAX Forum that was adopted by International Telecommunications Union (ITU) as the 6th air interface of IMT-2000 family. The flexible bandwidth allocation and multiple built-in types of Quality-of-Service (QoS) support in the WiMAX network allow the provision of high-speed Internet access, Voice over IP (VoIP) and video calls, multimedia chats and mobile entertainment. In addition, the WiMAX connection can be used to deliver content to multimedia gadgets such as the iPod [7].

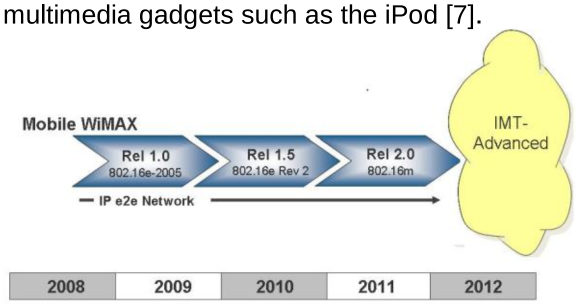

Figure 2: Mobile WiMAX Timeline [6].
Source: WiMAX Forum

Since the completion of the Release 1.0 Mobile System Profile, the WiMAX Forum has been working on a certification program which is a critical step for the proliferation of any modern communication technology throughout the world. As the result, the first WiMAX Forum Certified Seal of Approval for the 2.3 GHz spectrum was awarded to four base stations and four mobile stations in April 2008. In June 2008, another four base stations and six mobile stations were awarded the WiMAX Forum Certified Seal of Approval for the 2.5 GHz spectrum with advanced features such as Multiple Input Multiple Output (MIMO) in time for commercial deployments around the world [7].

The WiMAX Forum is currently working on the short-term migration of the profile called Release 1.5. Generally it is focused on optimization introducing optimized FDD/HFDD operations and features that can be added to Release 1.0 WiMAX devices through a software upgrade. This generation includes additional selection of 802.16 elements available through the ongoing IEEE 802.16 REV2 standard to address the Efficient FDD/HFDD Operations, New Band Classes, Enhanced MIMO/BF Operations, Enhanced MAC Performance, Bluetooth Coexistence in the Same Mobile and Extended Networking Features [7].

Mobile WiMAX based on 802.16e (also called WiMAX-e) would not qualify as a 4G IMT-Advanced standard since data rates even under ideal conditions are much lower but IEEE 802.16m, which is considered as the next Mobile WiMAX technology (we call WiMAX-m) and expected to be ratified in 2009, satisfies 4G requirements by achieving 1 Gbps data rate. Similar to current 802.16e Mobile WiMAX, the 802.16m standard would use multiple-input, multiple-output (MIMO) antenna technology, while maintaining backward compatibility with the existing standards [8].

The long-term migration from Release 1.0 is known as Release 2.0 and the corresponding specification is being developed in the IEEE 802.16m project. Unlike Release 1.5, which focused on FDD/HFDD and software-based additions to Release 1.0, the goal of Release 2.0 is to meet International Mobile Telecommunications (IMT)-Advanced requirements for next-generation mobile networks (Figure 2)[7].

WiMAX TECHNOLOGIES

The key critical technologies of WiMAX are:

Scalable OFDMA

OFDMA is the multiple access technique for mobile WiMAX. OFDMA is the Orthogonal Frequency Division Multiplexing (OFDM) based multiple access schemes and has become the *de facto* single choice for modern broadband wireless technologies adopted in other competing technologies such as 3GPP's Long Term Evolution (LTE) and 3GPP2's Ultra Mobile Broadband (UMB). OFDMA demonstrates superior performance in non-line-of-sight (N-LOS) multi-path channels with its relatively simple transceiver structures and allows efficient use of the available spectrum resources by time and frequency subchannelization [7].

In OFDMA systems, the multiple user signals are separated in the time and/or frequency domains. Typically, a burst in an OFDMA system will consists of several OFDM symbols. The subcarriers and the OFDM symbol period are the finest allocation units in the frequency and time domain, respectively. Hence, multiple users are allocated different slots in the time and frequency domain (i.e., different groups of subcarriers and/or OFDM symbols are used for transmitting the signals to/from multiple users). For instance, Figure 3 illustrates an example where the subcarriers in an OFDM symbol are represented by arrows and the lines shown at different times represent the different OFDM symbols. It shows how the resources can be allocated by using the different subcarriers and OFDM symbols among 5 users [11].

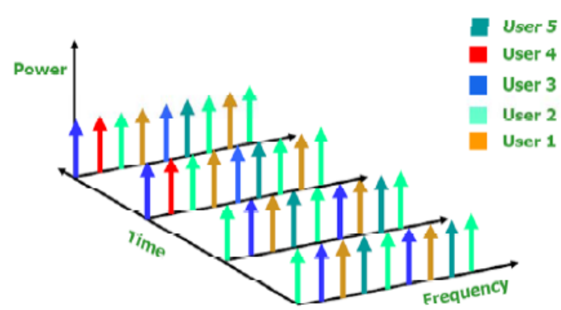

Figure 3: Allocation of Resources to Users in OFDMA [11]

In practice, the allocation in the frequency domain is not addressed at the level of subcarriers. Typically, sub-channels which are the smallest granular units in the allocation are created by grouping subcarriers in an OFDM symbol in various ways. The formation of these sub-channels from carriers is an important concept in

OFDMA systems. The formation can be classified into 2 types; one is the mapping of a contiguous group of subcarriers into a sub-channel called *Adjacent Subcarrier Method (ASM)* and the other is the diversity/permutation based grouping called *Diversity Subcarrier Method (DSM)* [11].

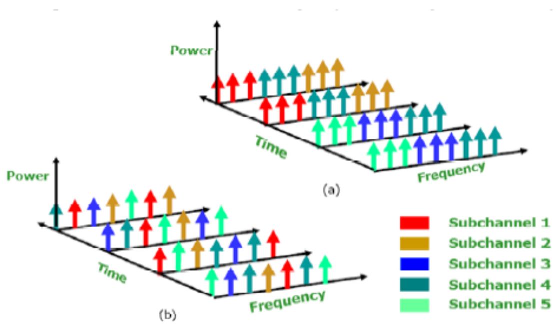

Figure 4: Sub-Channelization Examples: (a) ASM Method, (b) DSM Method.

The simple transceiver structure of OFDMA also enables feasible implementation of advanced antenna techniques such as MIMO with reasonable complexity. Lastly, OFDMA employed in mobile WiMAX is scalable in the sense that by flexibly adjusting FFT sizes and channel bandwidths with fixed symbol duration and subcarrier spacing, it can address various spectrum needs in different regional regulations in a cost-competitive manner [7].

Time Division Duplex (TDD) and Frequency Division Duplex (FDD)

The mobile WiMAX Release 1 Profile has only TDD as the duplexing mode even though the baselines IEEE Standards contain both TDD and FDD. Even though future WiMAX Releases will have FDD mode as well, TDD is in many ways better positioned for mobile Internet services than FDD.

First of all, Internet traffic is asymmetric typically with the amount of downlink traffic exceeding the amount of uplink traffic; thus, conventional FDD with the same downlink and uplink channel bandwidth does not provide the optimum use of resources. With TDD products, operators are capable of adjusting downlink and uplink ratios based on their service needs in the networks [7].

The ratio between the uplink and downlink defines how the frequency channel is shared. A 2:1 ratio means the channel is used two-thirds of the time for the downlink and one-third of the time for the uplink (Figure 5).

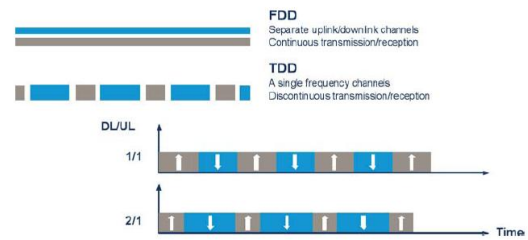

Figure 5: Overview of FDD and TDD [13]

In addition, TDD is inherently better suited to more advanced antenna techniques such as Adaptive Antenna System (AAS) or Beamforming (BF) than FDD due to the channel reciprocity between the uplink and downlink. Mobile Internet with increased multimedia services naturally requires the use of advanced antenna techniques to improve capacity and coverage [7].

Release 1.5 of WiMAX Forum is focused on optimization introducing optimized FDD/HFDD operations and Optimization of FDD/HFDD operations is based on splitting the 802.16 frame into partitions to be used by two distinct groups of mobiles having separated the control channels such as downlink and uplink MAPs, fast feedback channels and HARQ ACK channels. Such a solution allows for the reuse of the design of Release 1.0 (TDD) chipsets while not compromising on the system performance in order to address FDD markets around the world [7].

Multiple Input Multiple Output and Beamforming (MIMO and BF)

Various advanced antenna techniques have been implemented in the mobile WiMAX Release 1 profile to enable higher cell and user throughputs and improved coverage. As a matter of fact, mobile WiMAX was the first commercially available cellular technology that actually realized the benefits of MIMO techniques promised by academia for years. With its downlink and uplink MIMO features, both operators and end-users enjoy up to twice the data rates of Single-Input

Single-Output (SISO) rate, resulting in up to 37 Mbps for downlink and 10 Mbps for uplink sector throughput using just 10 MHz TDD channel bandwidth [7].

Mobile WiMAX also enhances the cell coverage with its inherent BF techniques. Coupled with TDD operation, its powerful BF mechanism allows base stations to accurately form a channel matching beam to a terminal station so that uplink and downlink signals can reach reliably from and to terminals at the cell edge, thus effectively extending the cell range (Figure 6) [7].

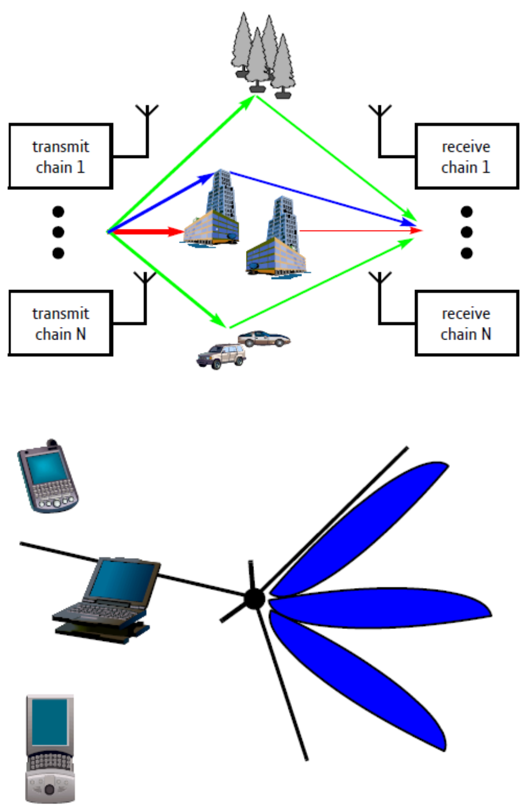

Figure 6: MIMO and BF [12]

Closed-loop operations for MIMO and BF are optionally considered to further improve the throughput and coverage beyond Release 1.0 which contains only open-loop MIMO and BF features [7].

Full Mobility Support

Full mobility support is another strength the mobile WiMAX products. The baseline standard of mobile WiMAX was designed to support vehicles at highway speed with appropriate pilot design and Hybrid Automatic Repeat Request (HARQ), which helps to mitigate the effect of fast channel and interference fluctuation. The systems can detect the mobile speed and automatically switch between different types of resource blocks, called subchannels, to optimally support the mobile user. Furthermore, HARQ helps to overcome the error of link adaptation in fast fading channels and to improve overall performance with its combined gain and time diversity [7].

Multiple Handover Mechanisms

Handover procedures include numerous means of optimization. In particular, to reduce time expenses for the mobile to find the central frequency and acquire parameters of the neighbor base station, the mobile can apply a scanning process when the mobile is away from the serving base station to scan the wireless media for neighbor base stations. Information collected during scanning such as central frequencies of the neighbor base stations can then be used in actual handover. WiMAX implementations support a variety of handover mechanisms that allow subscriber devices to maintain a connection while traveling at vehicular speeds. In some deployment scenarios, scanning can be performed without service interruption. For this purpose, information about the central frequency and the parameters of the neighbor base stations is periodically advertised by the serving base station. To shorten the time needed for the mobile to enroll into the new cell the network is capable of transferring the context associated with the mobile from the serving base station to the target base station [7].

All of these means provide a potential for high optimization in terms of handover latency. Under ideal conditions the interval of service interruption may be as short as several 5 ms frames. The specific handover optimization scheme used in a particular handover depends on the information available to the mobile [7].

IP Core Network

The use of a common IP platform simplifies inter-working with other wired and wireless technologies. Support for IP Multimedia

Subsystem (IMS) and Multi-Media Domain (MMD) further facilitates inter-working and removes existing redundancies in the core network. With IMS and MMD, network operators can develop applications independently of the access technology within a flexible, layered architecture in which application module can easily be modified or reused. To foster integration with other technologies, the WiMAX forum has established the Networking Working Group which closely collaborates with service providers, the IEEE, ETSI, 3GPP and 3GPP2 to assure a unified network architecture that facilitates inter-working, roaming and infrastructure sharing with current and emerging cellular and wired technologies [14].

WiMAX NETWORK ARCHITECTURE

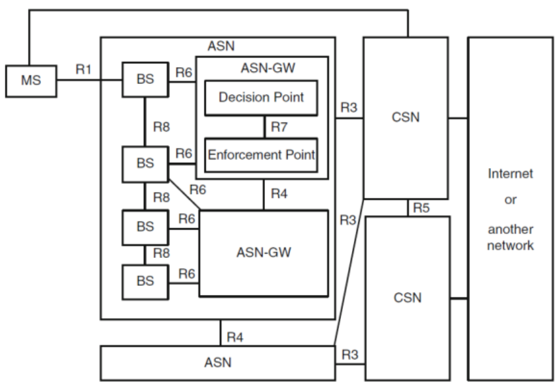

Figure 7: Network architecture of mobile WiMAX (WiMAX Forum 2005–2007).

The basic domains of WiMAX network are:

User Terminals

User terminals includes Mobile, portable and fixed devices with WiMAX support. This could be for example cellular phones, MIDs (Mobile Internet Devices), UMPCs (Ultra Mobile PCs), laptops, or Desktops.

Access Service Network (ASN)

ASN provides a way to connect user terminals using OFDMA air interface to an IP backbone with session continuity (a session is not drop when user moves between wireless environments). An ASN consists of BSs and Access Gateways. The set of network functions in ASN include:

- Network discovery and selection of the preferred CSN/NSP (Network Service Provider) Network entry with IEEE 802.16e-2005 based layer 2 connectivity and AAA proxy.
- Relay function for IP Connectivity.
- Radio Resource Management.
- Multicast and Broadcast Control.
- Foreign agent functionality for inter-ASN mobility
- Paging and Location Management.
- Data forwarding.
- Service flow authorization.
- Quality of Service.
- Admission Control and Policing.

Access Service Network – Gateway (ASN-GW)

The ASN Gateway (ASN-GW) is a logical entity that aggregates the control plane and security functions as a Decision Point (DP). The ASN-GW may also perform bearer plane routing or bridging function as Enforcement Point (EP). Interface between DP and EP is unexposed and DP can be shared among BSs.

Connectivity Service Network (CSN)

CSN is defined as a set of network functions that provide IP connectivity services to the mobile subscribers. A CSN consists of network elements such as routers, AAA (Authentication, Authorization, and Accounting) proxy/servers, user databases and Inter-working gateway devices. A CSN is deployed by a NSP. AAA or Home Agent residing in CSN allocates the IP address. AAA also performs authentication, authorization, and accounting. Communication is through a RADIUS protocol. The policy server residing in the CSN is responsible to store the policy and QoS information of each subscriber, which is communicated to ASN during service flow creation. CSN is also responsible to access other IP networks.

Base Station (BS)

The WiMAX BS is a logical entity that implements an interface to air link and IP network. The BS embodies IEEE 802.16e-2005 PHY and MAC layers as well as one or more ASN functions to facilitate communication to ASN-GW and other BSs. The IEEE 802.16e-2005 BS instance represents one sector with one frequency assignment and a single BS may have connectivity to more than one ASN-GW for load balancing or redundancy or both. A physical BS may have multiple BSs since BS is defined as a logical entity. The key component of BS is scheduler, which is responsible to allocate uplink and downlink resources in the air link [8].

THE WIMAX FUTURE

Mobile WiMAX is the next revolution in wireless technology that will enable pervasive, high-speed connectivity to meet the ever-increasing demand for broadband Internet on the go. Delivering the next leap in the mobile network evolution with fourth generation (4G) wireless, WiMAX will drive a wide array of devices well beyond what's available today, including notebooks, phones, consumer electronic devices, Mobile Internet Devices (MIDs), and more [9].

Based on the IEEE 802.16e standard, mobile WiMAX is designed to deliver superior data rates and scalability, lower costs, and reduced network complexity. WiMAX is continuously evolving. It started with Fixed WiMAX based on the IEEE 802.16-2004 followed by the IEEE 802.16e- 2005 standard upon which Mobile WiMAX is based and the latest is being developed in the IEEE 802.16m project. The mobile WiMAX System Profile Release 1.0 presented the features and devices to be implemented in WiMAX systems. The other two, Releases 1.5 and Release 2.0 are short-term and long-term migration of Release 1. The goal of Release 2.0 is to meet International Mobile Telecommunications (IMT)-Advanced requirements for next-generation mobile networks. Table 1 summaries some of the key requirements of 802.16m [7].

The low-cost, all-IP network architecture and backwards compatibility with existing 2G and 3G cellular network deployments makes WiMAX easier and more cost-effective to deploy and operate than current mobile wireless data solutions. As a result, it has already garnered broad support from leading operators—both wired line and wireless—and device manufacturers around the world.

CONCLUSION

The speed of adoption of mobile broadband reflects the accelerating pace of change in consumer behavior, as much as the faster pace of change in technology itself. With the growing demand for broadband connectivity as the main driver, operators have picked WiMAX as a future-proof, all–IP broadband technology that is available today from a growing number of suppliers — one that is faster and less expensive to deploy than fixed technologies [1]. With the ability to carry more data traffic than current wireless networks, WiMAX is intended to meet increasing demands for mobile data.

WiMAX offers greater choice, fixed, nomadic, portable and mobile broadband at low CPE prices for end users and better economics, reduced investment risk and new revenue generation opportunities for Service Providers. Also, it offers mass production of chipsets, a platform for innovation and cooperation for equipment vendors [15].

To capture a significant share of the broadband opportunity over the next five years, WiMAX will therefore require relentless commitment from all players across the value chain. Significant funding is needed to cover startup costs and establish a competitive business. WiMAX faces considerable competitive pressures and does not readily enjoy the economies of scale that its competition has [11].

Table 1: Key Requirements of IEEE 802.16m [7].

<table>
<tr><th>Item</th><th>Requirements</th></tr>
<tr><td>Carrier frequency</td><td>Licensed band under 6 GHz</td></tr>
<tr><td>Operating bandwidth</td><td>5–20 MHz
Other bandwidths can be considered as necessary</td></tr>
<tr><td>Duplex</td><td>Full-duplex FDD, Half-duplex FDD, TDD</td></tr>
<tr><td>Antenna Technique</td><td>Downlink ≥ (2Tx, 2Rx)
Uplink ≥ (1Tx, 2Rx)</td></tr>
<tr><td>Peak data rate (peak spectral efficiency)</td><td>
<table>
<tr><th>Type</th><th>Link direction</th><th>MIMO</th><th>Normalized peak data rate (bps/Hz)</th></tr>
<tr><td>Baseline</td><td>Downlink</td><td>2 × 2</td><td>8.0</td></tr>
<tr><td></td><td>Uplink</td><td>1 × 2</td><td>2.8</td></tr>
<tr><td>Target</td><td>Downlink</td><td>4 × 4</td><td>15.0</td></tr>
<tr><td></td><td>Uplink</td><td>2 × 4</td><td>5.6</td></tr>
</table>
</td></tr>
<tr><td>Data latency</td><td>Downlink < 10 ms, Uplink < 10 ms</td></tr>
<tr><td>State transition latency</td><td>max 100 ms</td></tr>
<tr><td>Handover interruption time</td><td>Intra-frequency handover latency <30 ms
Inter-frequency handover latency <100 ms</td></tr>
<tr><td>Throughput and VoIP capacity</td><td>
<table>
<tr><th></th><th>Downlink</th><th>Uplink</th></tr>
<tr><td>Average sector throughput (bps/Hz/sector)</td><td>2.6</td><td>1.3</td></tr>
<tr><td>Average user throughput (bps/Hz)</td><td>0.26</td><td>0.13</td></tr>
<tr><td>Cell edge user throughput (bps/Hz)</td><td>0.09</td><td>0.05</td></tr>
<tr><td>VoIP capacity (active calls/MHz/sector)</td><td>30</td><td>30</td></tr>
</table>
</td></tr>
<tr><td>MBS
Spectral efficiency</td><td>Inter-base station distance 0.5 km > 4 bps/Hz
Inter-base station distance 1.5 km > 2 bps/Hz</td></tr>
<tr><td>Enhanced MBS</td><td>Max MBS channel reselection interruption times:
intra-frequency <1 s; inter-frequency <1.5 s</td></tr>
<tr><td>LBS
Position accuracy</td><td>Handset-based: 50 m (67% of cdf), 150 m (95% of cdf)
Network-based: 100 m (67% of cdf), 300 m (95% of cdf)</td></tr>
</table>

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