WiMAX Advanced:
Deployment Scenarios
Based on Input from WiMAX Operators and Vendors

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1. Executive Summary

Recognizing service providers' need for flexibility to manage an ever-increasing demand for broadband data, the WiMAX Forum embraced a network evolution path to accommodate harmonization and coexistence across multiple broadband wireless access technologies within the WiMAX Advanced network. The acquisition and merger of several operators around the globe provide the opportunity for network operators for inherent multi-technology networks. These operators need vendor support to retain as many elements as possible from their current deployments, including their tower sites, RAN, backhaul, core networks, provisioning, and billing systems. Many of these operators also need regulatory provisions to allow them using their existing spectrum for the new networks and services without any restrictions on their spectrum licenses. Governments in many countries have allocated the spectrum for a specific wireless technology or a specific service (say nomadic, fixed, or mobile services), and the re-assigning procedure normally requires significant effort and cost.

WiMAX Advanced provides a path for existing WiMAX operators to benefit from coexistence of WiMAX and other IMT-2000/IMT Advanced technologies and leveraging the economies of scale associated with other ecosystems.

This paper provides deployment options to the existing WiMAX operators based on the results of a survey conducted by the WiMAX Forum across its key members in the first quarter of 2014. Three common deployment (co-existence) scenarios are discussed and evaluated, and seemingly adequate spectrums and availability of multimode terminals play key roles in facilitating successful deployments and operations.

2. Introduction

2.1. WiMAX Deployments

Mobile WiMAX was the first 4G technology supporting all IP and OFDMA wireless broadband technology with advanced antenna systems. WiMAX network deployments around the world initiated broadband wireless competition and adoption in many countries. The WiMAX Forum developed a few system profiles for WiMAX deployment in the 2.3 GHz, 2.5 GHz, and 3.5 GHz bands with channel bandwidths of 3.5 MHz, 5 MHz, 7 MHz, 8.75 MHz, and 10 MHz; both time and frequency division multiplexing (TDD and FDD); and other necessary features in order to have interoperable products. However, all of the commercial WiMAX deployments are based on un-paired TDD spectrum only.

More than 477 operators have deployed WiMAX networks in 150 countries and provided wireless broadband services for more than 25 million subscribers and approximately 1 billion covered POPs around the world. Although WiMAX deployments around the world outnumber any other 4G technology significantly, many of these WiMAX networks are relatively small, targeting small cities or communities or private institutions. In addition to that, the majority of these WiMAX networks are mainly offering fixed services.

Some of the largest and mature Mobile WiMAX deployments are: Sprint/Clearwire in the US in the 2.5/2.6 GHz bands, UQ Communications in Japan in the 2.5 GHz band, KT/SKT in South Korea, and YTL Communications in Malaysia in the 2.3 GHz band. There are also WiMAX deployments in fast-growing Asian and African countries. WiMAX networks have also offered fixed or nomadic wireless broadband services with more than 300 deployments in many developing and emerging markets in Africa, Middle East, Eastern Europe, and Latin America mainly in 3.5/3.6 GHz spectrum band. Examples of these markets are Wateen, WiTribe, and Mobilink in Pakistan with about 500,000 subscribers; MobinNet in Iran with close to 700,000 subscribers; and over 40 WiMAX deployments in African countries.

WiMAX operators in these countries have developed a unique business case to deliver differentiated all-IP mobile broadband and/or high performance fixed/nomadic services to meet the needs of data-centric customers with performances that outperform wireless 3G and fixed DSL networks significantly.

2.2. 3GPP TDD Spectrum Band Assignment

About 25 commercial WiMAX Advanced networks all over the world are mainly operated on 2.3GHz, 2.6GHz, and 3.5GHz. The different TDD spectrum allocation in different regions is a challenge for WiMAX Advanced globalization and roaming. Figure 1 lists the standardized TDD spectrum for WiMAX Advanced deployment, and Figure 2 lists the major countries and regions that focus on frequency bands for WiMAX Advanced.

3GPP TDD	Frequency	Bandwidth
Band 33	1900 - 1920	20
Band 34	2010 – 2025	15
Band 35	1850 - 1910	60
Band 36	1930 - 1990	60
Band 37	1910 – 1930	20
Band 38	2570 - 2620	50
Band 39	1880 - 1920	30
Band 40	2300 - 2400	100
Band 41	2496 - 2690	194
Band 42	3400 - 3600	200
Band 43	3600 - 3800	200
Band 44	703 - 803	100

Figure 1: 3GPP TDD Band, Frequencies, and Bandwidths

Frequency	3GPP Bands	Region
1.9GHz/2.0GHz	33, 34,35, 36, 37, 39	Australia, China, Europe, Japan, Russia, South Africa, South Asia
2.3GHz	40	Africa, Canada, China, India, Latin America, Russia, South Korea, South Asia, the Middle East
2.6GHz	41	Africa, Brazil, China, Europe, Japan, India, Latin America, North America, Saudi Arabia
3.5GHz/3.7GHz	42, 43	Australia, Europe, Latin America, North America, Russia

Figure 2: TDD Bands in Major Countries and Regions

3. Technology Aspects

3.1. WiMAX Frame Structure

The IEEE802.16e PHY supports both Time Division Duplexing (TDD) in WiMAX Release 1 and Frequency Division Duplexing (FDD) operation in WiMAX Release 1.5. However, all existing WiMAX deployments use TDD mode of operation as defined in WiMAX Release 1.

Figure 3 illustrates the OFDMA frame structure for TDD mode where each 5 msec radio frame is flexibly divided into DL and UL subframes. The DL and UL subframes are separated by small Transmit/Receive and Receive/Transmit Transition Gaps (TTG and RTG, respectively) to prevent DL and UL transmission collisions.

IEEE802.16 allows different values for size of TDD S-OFDMA frame duration. The choice of frame duration is a tradeoff between the delay and latency performances (such as handoff delay, etc.), and overhead performances. WiMAX has selected a value of 5ms for the frame size. As seen in Figure 3, the S-OFDMA frame is mainly composed of 4 parts—a downlink (DL) subframe, an uplink (UL) subframe, and two gaps between DL and UL, which are called Transmit/Receive Transition Gap (TTG) and Receive/Transmit Transition Gap (RTG). These are the time gaps between the DL and UL portion (TTG) and the UL and DL portion (RTG) when BTS switches transmission to receiving (TTG) or vice versa (RTG) and MS switches otherwise. It is needed for the BTS to turn around. These gaps are needed for the BS to ramp down or up, the BS TX/RX antenna to switch to actuate, and BS switch to receive or transmit.

In the DL subframe, the first symbol is called the preamble. The preamble is one OFDM symbol containing a known Pseudo Noise (PN) sequence carrying a particular ID called IDCell (a number from 0 to 31) and segment ID (from 0 to 2) with different PAPR values. The total number of sequences is 114. It is used for initial timing and carrier synchronization, network scanning, and cell identification. It can be used for a coarse channel estimation as well as Signal to Noise and Interference (SINR) calculation.

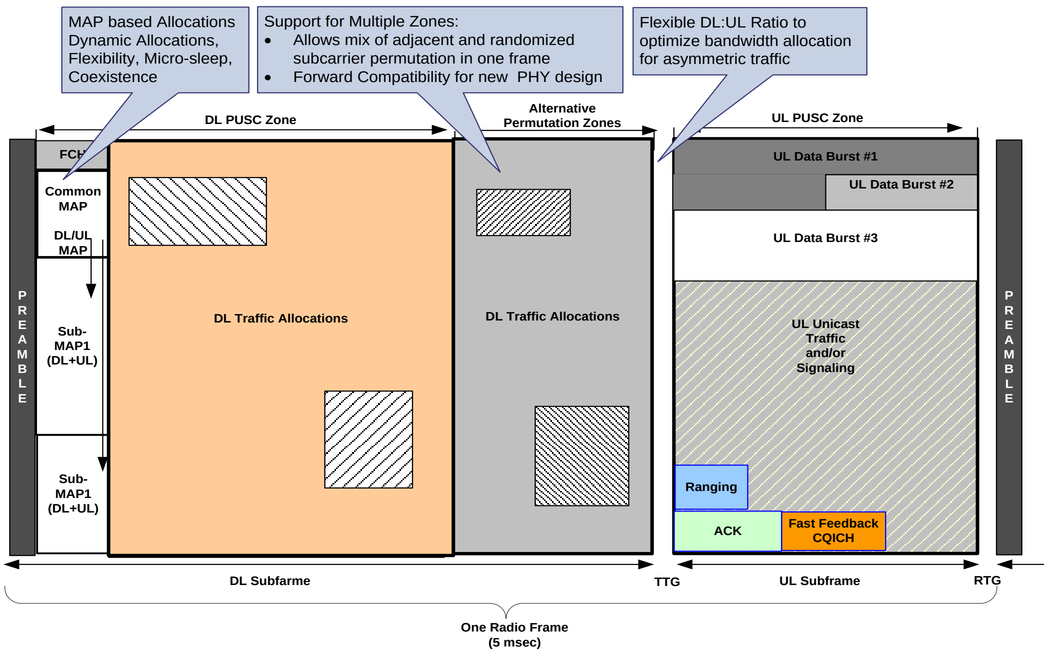

Figure 3. Frame Structure and Channelization for TDD System

The rest of the frame is divided into zones. A zone is nothing but a group of OFDMA symbols taking the same permutation scheme, such as PUSC or AMC, etc. Within each zone, we have segments, which are consisted of one or more subchannels through one or more adjacent symbol that creates a single instance of MAC data unit.

If PUSC (Partial Usage Subchannelization) is used both in DL and UL, since each PUSC slot in DL and UL span over 2 and 3 OFDMA symbols, consecutively, the number of symbols in DL must be odd and the number of symbols in UL must be a multiple of 3. Considering TTG = 0.105714 ms, and RTG = 0.06 ms, the remaining 5ms - 0.105714ms – 0.06ms = 4.834286ms is divided into a total of 47 OFDM symbols, each having a size of 102.857µs (47 x 102.857µs + 105.714 µs + 60 µs = 5ms). Out of these 47 symbols, only a limited number of combinations are allowed for DL:UL separation, which is configured as shown in Figure 4.

Downlink		Uplink	
Symbols	Duration (ms)	Symbols	Duration (ms)
35	3.6	12	1.234286
34	3.497143	13	1.337143
33	3.394286	14	1.44
32	3.291429	15	1.542857
31	3.188571	16	1.645714
30	3.085714	17	1.748571
29	2.982857	18	1.851429
28	2.88	19	1.954286
27	2.777143	20	2.057143
26	2.674286	21	2.16

Figure 4. WiMAX Possible DL:UL Configurations

The majority of WiMAX deployments use 29:18, 32:15, and 35:12 configurations to support the requirement of data-centric traffic in which the amount of DL traffic is higher than UL traffic. The 29:18 configuration, the most common mode, is depicted in Figure 5.

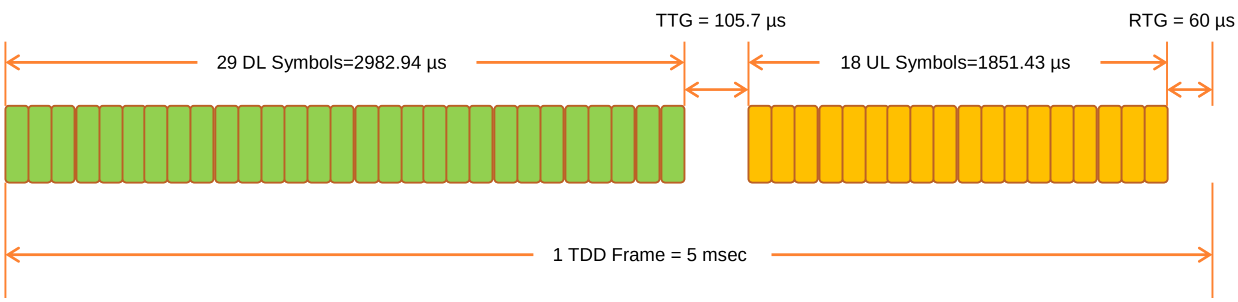

Figure 5. WiMAX TDD Frame Structure with 29:18 DL:UL Configuration

3.2. WiMAX Core

Mobile WiMAX network architecture is based on the WiMAX Forum's Network Working Group (NWG) specification. The main components of WiMAX network architecture are shown in Figure 6. The components are:

- Mobile station (MS),
- Access Service Network Gateway (composed of base station (BS) and Access Service Network Gateway (ASN-GW)), and
- Connectivity Service Network (CSN), which is comprised of AAA, HA, and possibly IMS core.

NWG defined two core architectures for WiMAX deployments:

- Mobile-IP (MIP) architecture – this architecture enables two modes of Client MIP and Proxy MIP and requires HA entity to support MIP functionally. The major purpose of this architecture is to support large mobile networks with multiple ASN-GWs and enable mobile data roaming between the operators.
- Simple-IP architecture – this architecture enables stand-alone ASN-GW core and avoids using HA element in the network. Most of the WiMAX networks use Simple-IP architecture.

The ASN-GW can be seen as a network entity, connecting Base Station (BS) and Connectivity Service Network (CSN), and broadly helps in service flow management, mobility, authentications, accounting as well as Mobile IP

(MIP) management in home and visiting networks for roaming devices. Interaction between ASN-GW and BS can be one-to-many or many-to-one. The same kind of interface between ASN-GW and CSN is also possible.

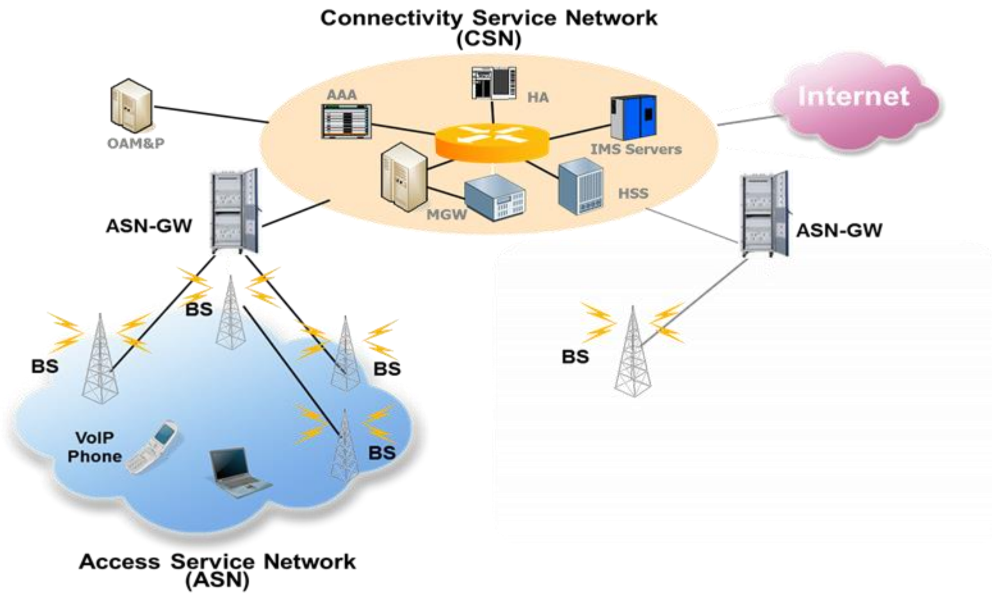

Figure 6. WiMAX Network Architecture

The ASN-GW is a combination of control plane and data (bearer) plane routing or bridging functionality. The ASN-GW operational functionalities are present as corresponding functionalities in the Base Station and CSN. At any particular moment of time, a subscriber in the network has to associate with exactly one default ASN-GW while several ASN-GWs along with the serving ASN-GW can collectively provide services.

ASN-GW is responsible for the following functionalities in a WiMAX network:

- Effective traffic load sharing among attached base stations to ensure user Quality of Service (QoS): A serving BS can have home and visiting subscribers with limited bandwidth spectrum, which may not be sufficient for providing services with guaranteed QoS for any further incoming subscribers.
- Handling mobility at the ASN and CSN levels for efficient use of radio spectrum and network resources: Handover can happen at different levels in ASN or CSN. In all cases, the role of ASN-GW's control bearer plane is crucial for effective and smooth network connectivity.
- Accounting and billing in the WiMAX network: ASN-GW can effectively participate in accounting and billing at the ASN as well as CSN levels.

4. Operator and Vendor Survey

WiMAX Forum working groups recently developed requirements for WiMAX Advanced. The main objective is to identify a few realistic scenarios for WiMAX Advanced deployment. To this end, a questionnaire was developed and sent to operators to respond to. The responses have been used to develop the most common and realistic deployment scenarios. This enhances the ecosystem so that vendors would find it attractive to develop the required equipment. Similar questionnaires were developed for device and infrastructure vendors to better understand the vendors' status on developing multi-technology WiMAX and WiMAX Advanced equipment.

4.1. WiMAX Operator Survey

Seven major WiMAX operators responded to the survey. Figure 7 shows the questions presented to WiMAX operators and the integration of the responses provided by some WiMAX operators. The complete responses of the operators are also below.

Question	Responses
How much Spectrum do you own? And what are the BWs?	Most Common Bands: 40, 42 2nd common bands: 38, 41
Is your deployment nationwide? If not, what is the percentage of the country you cover?	Some Yes, some No
How much of the spectrum is currently used for WiMAX deployment?	Widely ranges from 15MHz up to 200 MHz. But most common BWs are 20 and 30 MHz.
What is the estimated number of your subscribers?	> 30K - 9M per operator
Do you plan to co-exist WiMAX Advanced and WiMAX networks or you are only considering migration?	Co-exist, and migrate to WiMAX Advanced for some later on.
How much of the spectrum you are planning to use for WiMAX Advanced? What BW?	Mostly 20 MHz - 40MHz
Do you envision having some or your entire spectrum shared between WiMAX and WiMAX Advanced? Or they are planned to be completely disjoint?	Some of the spectrum shared, and some specific
If the answer to the previous question is affirmative, do you envision having a shared BW in the same geographical area?	Mostly Yes
Do you plan to add WiMAX Advanced as an overlay to your existing WiMAX Network to cover the same geographic area; or, do you plan to deploy WiMAX Advanced as separate coverage to your WiMAX network?	Co-site
Are you planning to complete your coverage with WiMAX and WiMAX Advanced or you think WiMAX Advanced and WiMAX would cover the same are?	No, Mostly co-site
Are you planning to have a disjoint set of devices, some supporting WiMAX only and some WiMAX Advanced only?	Mostly Yes
Do you envision having dual mode WiMAX and WiMAX Advanced devices?	Mostly Yes
If yes to previous question is affirmative, are you planning to support inter-technology WiMAX-WiMAX Advanced handover?	Some Yes, and some No
If the answer to previous question is affirmative, what are your hand-off performance requirements in terms of hand-off delay and any other performance metrics?	Delay of 150 ms
Are you planning to upgrade your WiMAX core to support WiMAX Advanced as well?	Some Yes, and some No
How flexible you are migrating from RADIUS to Diameter? With 1=Very Inflexible and 5=Very Flexible	Mostly Flexible, if the technology allows
What is the usage of WiMAX Advanced network? Data only or Data + VoIP? Please answer in two case, early deployment and future development	Some Voice & Data, some start with Data only and later transfer to Voice + data

Are you planning to deploy carrier grade Voice on your WiMAX Advanced network or Skype-type voice?	Mostly Carrier Grade
Do you currently own a circuit switch voice network?	Mostly No
If the answer to previous question is affirmative, what is the coverage of your circuit switch network as compared to your WiMAX Network? How about your planned WiMAX + WiMAX Advanced coverage?	Nationwide
If you do not own a circuit switch network, are you currently using other operator's circuit switch network, e.g. as MVNO?	No
In the future, do you plan to use another operator’s circuit-switch network?	Mostly No

Figure 7. Result of Operator Survey

4.2. WiMAX Infrastructure Vendor Survey

Two infrastructure vendors responded to the survey. Figure 8 shows the questions presented to WiMAX infrastructure vendors and the integration of the responses provided by them. The complete responses are also below.

Questions	Responses
Do you provide Base Station products for WiMAX?	Yes
In which spectrum(s) for the Base Station products for WiMAX?	2.3, 2.5, 3.3, 3.5, 3.6, and 5 GHz
What is the bandwidth(s) supported?	5, 7, and 10MHz
Do you have Base Station products for WiMAX Advanced?	Yes
In which WiMAX Advanced band(s) are the Base Station products for WiMAX Advanced?	Band 38, 40, 41, 42, and 43
What is the bandwidth(s) supported?	20MHz
If you have base station products for both WiMAX and WiMAX Advanced, are they the same products supporting both technologies?	Yes
If you have base station products for both WiMAX and WiMAX Advanced, have you upgraded or will you upgrade existing WiMAX products to WiMAX Advanced? How? Do you only add a channel card to existing WiMAX products?	New base station was developed to support WiMAX and WiMAX Advanced channel card. Also, there is SDR-based equipment, which only needs software upgrades to support WiMAX Advanced.
If you have base station products for both WiMAX and WiMAX Advanced, would you separate RRH for WiMAX & WiMAX Advanced? What is the bandwidth that each RRH supports?	Separate RRH with 20MHz WiMAX Advanced and 10MHz WiMAX. One-Box base stations are also available.

If you have base station products for both WiMAX and WiMAX Advanced, and if WiMAX and WiMAX Advanced are in the same band (not necessarily in the same bandwidth), do you use multi-band antenna and where could the same antenna support both technologies?	No
If co-located and separate antennas are used, what is the level of coupling between the two Radios at the antenna ports?	-70db
Is your WiMAX system flexible to use a different TDD DL:UL ratio to alleviate device-->BS and BS-->interferences?	Yes
Do your WiMAX Advanced products support all TDD frame structure configurations to avoid interference with WiMAX? Is it flexible to mute some subframes, such as Uplink Pilot Time Slot (UpPTS)?	Yes/Yes
For BS-BS co-location, how much guard band do you require between WiMAX and WiMAX Advanced channels?	No guard band is used
How do you envision eliminating interference in WiMAX Advanced control channel (PUCCH)?	Try to set configuration not to have interference from WiMAX.
Does your infrastructure support inter-technology handover (HO) between WiMAX Advanced and WiMAX? What are the performance metrics in terms of HO delay?	HO is not supported.
Does your infrastructure support Load Balancing or inter-technology scheduling between WiMAX Advanced and WiMAX?	No
How do you plan to upgrade the WiMAX Core to WiMAX Advanced Core as well?	A plan may be available for vendor's own WiMAX core.
Do you require fork-lifting the existing WiMAX Core and replacing with WiMAX Advanced Core, while supporting WiMAX co-existence?	No
Can you re-use the existing WiMAX Core network elements, such as ASN-GW and HA and AAA, as part of the WiMAX Advanced Core elements?	No/Yes
How do you recommend upgrading the existing core network to support Diameter in addition to RADIUS?	ASN GW support both or Radius support for WiMAX Advanced Core can be implemented.
Can your existing PCRF be re-used in WiMAX Advanced Core?	No
Can your Home Agent (HA) be upgraded to play the role of IP assignment in WiMAX Advanced that Packet GateWay (P-GW) plays?	No
Do you support Circuit Switch Fall Back in your WiMAX Network?	No

Do you currently support Voice over Internet Protocol (VoIP) in your WiMAX network?	Yes
Do you support Circuit Switch Fall Back in your WiMAX Advanced Network?	Yes/No
Do you currently support VoIP in your WiMAX Advanced network?	Yes

Figure 8. Result of Infrastructure Vendor Survey

4.3. WiMAX Chipset-Device Vendor Survey

One chipset/device and three other device vendors responded the survey. Figure 9 shows the questions presented to WiMAX chipset/device vendors and the integration of the responses provided by them. The complete responses are also below.

Questions	Responses (chipset vendor)	Responses (device vendors)
Do you provide chipsets for WiMAX?	Yes	No
What type of authentication modes do you support?	IEEE802.16 Standardized modes	N/A
Is your WiMAX chipset flexible to use a different TDD DL:UL ratios to alleviate device-->BTS and BTS-->device interferences?	Yes	N/A
Do you support DL MIMO and interference rejection on your WiMAX Chipset?	Yes	N/A
Do you support UL MIMO on your WiMAX Chipset?	Yes	N/A
Do you support Payload Header Suppression or ROHC on your WiMAX chipset?	Yes	N/A
What type of Encryption modes do you support on your WiMAX chipset?	Yes	N/A
Do you have chipsets for WiMAX Advanced?	Yes	No
What type of Transmission modes (Tx Mode 1 to 9) do you support on WiMAX Advanced Chipset?	TM1 ~ TM9	N/A
Do you support ROHC on your WiMAX Advanced chipset?	Yes	N/A
What type of Encryption modes do you support on your WiMAX Advanced Chipset?	No Clear Response	N/A
Do you provide devices for WiMAX?	Yes	Yes
Who provides the chipset?	N/A	GCT, Sequans, Mediatek, Broadcom
Would you please list the WiMAX device form factors?	N/A	USB, Mifi, Handsets, Personal Router for Bus, Train, etc., Embedded Module, Dongle, Indoor & Outdoor Unit, USBD, PCIe, LGA, Hotspot, Smartphone, Tablet, Chromebook, Router, etc.

Do you provide devices for WiMAX Advanced?	N/A	Mostly yes
Who provides the chipset?	N/A	GCT, Sequans, Qualcomm
Would you please list the WiMAX Advanced device form factors?	N/A	USB, Mifi, Handsets, Embedded Module, Dongle, Indoor & Outdoor Unit, USBD, PCIe, LGA, Hotspot, Smartphone, Tablet, Chromebook, Router, LGA Module, etc.
If you provide chipsets or devices for WiMAX, in which WiMAX Spectrum(s)?	2.3/2.5/3.5/3.6 GHz	2.3/2.5/3.5/3.6 GHz
If you provide chipsets or devices for WiMAX, what is the bandwidth(s) supported?	10 MHz	Mostly 10 MHz, some 5 and 7
If you provide chipsets or devices for WiMAX Advanced, in which WiMAX Advanced bands?	Bands 33 all the way to Band 41	Bands 38, 39, 40, 41
If you provide chipsets or devices for WiMAX Advanced, what is the bandwidth(s) supported?	5, 10, 15, 20 MHz	5, 10, 15, 20 MHz
Do you provide a dual mode WiMAX-WiMAX Advanced chipset / device?	Yes	Mainly yes
If yes, are you using dual Radio or the same RFIC switches between the two radios?	Not Clear response	Not clear response
Do your WiMAX Advanced products support all TDD frame structure configurations to avoid interference with WiMAX? Is it flexible to mute some subframes, such as Uplink Pilot Time Slot (UpPTS)?	Yes, the rest of the response not clear	N/A
How do you plan to eliminate interference in WiMAX Advanced control channel (PUCCH)?	Response not clear	N/A
Your device supports (check all that apply):	Dual-SIM operation. A combination of EAP and SIM Operation., Inter-technology handover (HO) between WiMAX Advanced and WiMAX.	Dual-SIM operation. A combination of EAP and SIM Operation., Inter-technology handover (HO) between WiMAX Advanced and WiMAX.
If your device supports inter-technology HO between WiMAX Advanced and WiMAX, what are the performance metrics in terms of HO delay?	Operator requirement	N/A
Can your device support both Diameter and RADIUS Core networks?	Yes	yes
What other technologies other than WiMAX and WiMAX Advanced are supported on your chipset?	LTE FDD	LTE FDD
What is the host software on your device?	N/A	Mostly Linux
What type of interfaces and peripherals are supported on your device?	N/A	USB2.0 host/slave; SDIO2.0/3.0 host/slave; RGMII (Ethernet); UART; SPI; SIM; NAND, Sockets, USB, PCI Connections

Does your device support Circuit Switch Voice?	No	One yes, the rest No
Can your device fall back to a circuit switch network for voices?	No	No
You currently support Voice over Internet Protocol (VoIP) (check all that apply):	Over WiMAX Advanced	Some over WiMAX Advanced, some WiMAX

Figure 9. Result of Chipset/Device Vendor Survey

5. WiMAX and WiMAX Advanced Co-existence Scenarios

For operators looking to utilize both WiMAX and WiMAX Advanced technologies within the same network, there are a multitude of spectrum, RAN Network, core network, device, and market opportunity trade-offs to assess. With proper planning and consideration, operators can leverage much of their existing network to support coexistence of WiMAX and WiMAX Advanced RAN and core equipment, and end-user devices.

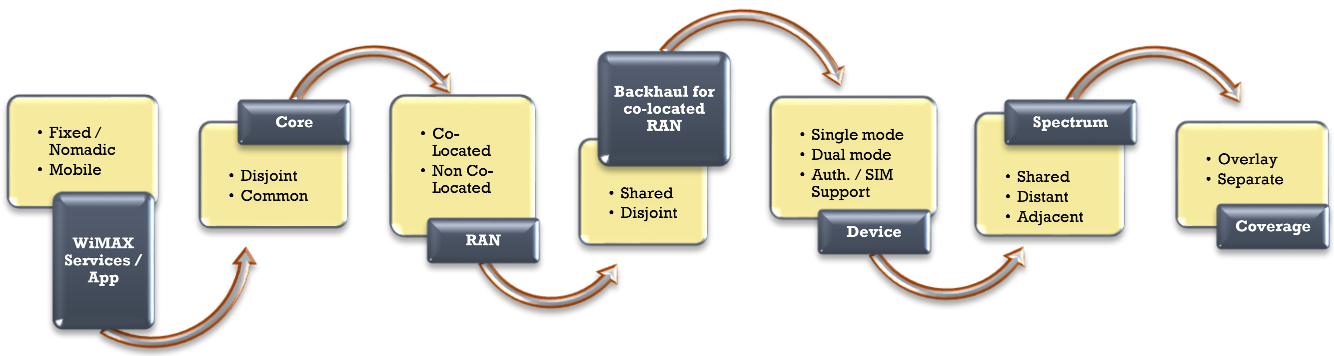

Figure 10. Parameters Affecting WiMAX and WiMAX Advanced Co-existence

Figure 10 depicts the parameters affecting the WiMAX and WiMAX Advanced co-existence. Depending upon how an operator has chosen to deploy WiMAX and WiMAX Advanced as coexisting network technologies, they will need to address the following:

- Spectrum – Depending upon an operator's spectrum allocation, they will need to determine the best way to optimize their frequency channel plans to allow WiMAX and WiMAX Advanced to coexist. Additionally, the isolation requirements and recommendations between the two technologies will need to be defined in order to preserve system performance for each technology according to relevant standard specifications.
- Core – In regards to the core network, the goal is to define an optimal network architecture that will facilitate WiMAX and WiMAX Advanced coexistence from both a timing and financial perspective. With a goal of maximizing the sharing of deployed core network assets, an operator can define an approach, which allows a multi-technology network operation.
- RAN – With significant potential investment in deployed RAN equipment, operators should look to the sharing of their infrastructure to support coexistence between WiMAX and WiMAX Advanced. To do so, they will need to take into consideration the equipment requirements to optimize the networks. These requirements will differ based on the selection of the uplink/downlink duplexing mode used for WiMAX Advanced. For WiMAX coexisting with WiMAX Advanced, specific frame alignment strategies are needed to ensure proper synchronization between the two TDD technologies. Using this approach, operators may be able to operate a multi-technology network while sharing their existing assets with appropriate planning and coordination. Since the majority of existing WiMAX deployment use WiMAX

Release 1, in this paper, we will consider WiMAX Release 1 and WiMAX Advanced co-existence scenarios.

- Devices – Operators seeking to leverage multi-technology network footprints will need to depend upon a robust device ecosystem that supports multimode operation. Various device architectures supporting single and dual-mode WiMAX/WiMAX Advanced operations are expected to be implemented. These architectures will depend upon device type (e.g., notebook, tablet, smartphone, handheld, etc.). Factors affecting device architecture selection include the availability of single or dual-mode WiMAX/WiMAX Advanced baseband chipsets from the same vendor, the existence of multiple component/subsystem or baseband chipset vendors for the same device, etc. The selection of the specific device architecture will dictate commercial and cost profiles, each of which is expected to have its respective advantages and disadvantages. The specific configuration and level of complexity greatly depends on whether the devices are required to support interworking or inter-technology handoff. Another device characteristic defining the success of co-existence scenarios is the authentication procedure supported by the device.
- Backhaul – If the technologies are deployed on the same tower, the backhaul must support an aggregation of both traffics. So, the backhaul capacity would be impacted by this deployment. Moreover, the backhaul plans must support QoS of each traffic to divide the capacity between both technologies conveniently.
- Services/Application – WiMAX Advanced is mainly deployed for mobile 4G broadband services while the WiMAX is deployed for both fixed/nomadic and mobile services. The co-existence scenario needs to support both scenarios.
- Coverage – WiMAX and WiMAX Advanced can co-exist within the same geographic area where either WiMAX Advanced is overlaid over existing WiMAX network or WiMAX Advanced is deployed in new markets where WiMAX is not deployed. The former scenario is used to increase the network capacity and spectrum utilization, and the latter is used to increase the 4G broadband coverage using new WiMAX Advanced technology.

In this Section, we will recommend scenarios for most of the areas described above with the goal of enabling operators to efficiently support coexisting multi-technology network operation. The recommendations consider efficiency in terms of time, cost, and technology sharing throughout. This document is intended for use as a basis for aligning network build-outs and device specifications in order to drive economies of scale and development within the multi-technology WiMAX/WiMAX Advanced ecosystem.

5.1. Radio Interface Aspects of Co-existence

5.1.1. Frame Alignment

The requirement of WiMAX and WiMAX Advanced coexistence depends on the spectrum they are deployed in. If the frequencies of WiMAX and WiMAX Advanced deployment are far from each other so that no co-channel interference or out of band emission is incurred from one to another, then no provision is required in terms of WiMAX or WiMAX Advanced frame configuration.

However, if the technologies are deployed in the same frequency channel (co-channel), or the deployed carriers are adjacent or so close that the out of band emission or RF overloading and blocking could be caused, then the major requirement could be summarized as it is comprehensively described in section 10 of the WiMAX Forum® Mobile System Profile document named as WMF-T23-001-R022v02.

The frame structure of the two technologies have to be re-configured in such a way that there is no time-overlap between the UL subframe of one network and the DL subframe of the other one, and vice versa. The designs of both WiMAX and WiMAX Advanced include adjustable configuration settings, which are selected by the system operator. These include the time period allocated to DL transmission, the time period allocated to UL transmission, and guard periods. Interference between the systems is minimized by ensuring the appropriate time-alignment between WiMAX frame and WiMAX Advanced frame such that neither system transmits its DL subframe while the other system is transmitting its UL subframe. This can be achieved by synchronizing the frame structure for WiMAX and WiMAX Advanced systems in time and using the appropriate DL/UL configurations for each system.

In order to time-align WiMAX Advanced with WiMAX, the WiMAX Advanced system must use a 5ms switching period as well as a similar downlink and uplink transmission period. As specified in Figure 6**Error! Reference source not found.**, WiMAX Advanced supports four TDD configurations with a 5ms switching period, i.e. configurations 0, 1, 2, and 6. Of these, configuration 6 does not have identical DL/UL transmission sequences in the first and the second half-frames on the WiMAX Advanced frame; the identical transmissions are necessary to make the 10 ms WiMAX Advanced frame compatible with the 5 ms WiMAX frame. Therefore, only configurations 0, 1, and 2 (in Figure 6) are potentially compatible WiMAX Advanced configurations for WiMAX and WiMAX Advanced coexistence.

The time-alignment between the WiMAX frame and the WiMAX Advanced frame can be supported for several WiMAX modes, as shown in Figure 3 and appropriate WiMAX Advanced configuration (0, 1, or 2) along with appropriate special subframe configuration.

The most common DL/UL ratio for WiMAX in the 10 MHz channelization is 29:18. Frame alignment with WiMAX Advanced for this configuration results in a performance trade-off. The issue with using the default WiMAX mode and WiMAX Advanced 5ms switching point is illustrated in Figure 11. Note that in this figure, the WiMAX Advanced frame starts 1ms later than WiMAX frame. The specific case of WiMAX (29:18) is shown in Figure 11, where the operation of the WiMAX and WiMAX Advanced systems is compared, indicating that the WiMAX system cannot complete downlink transmission (BS transmit) before the WiMAX Advanced system starts uplink transmission (BS receive). Consequently, WiMAX will cause interference to the WiMAX Advanced system. Therefore, a solution needs to be found to address the frame alignment between the default WiMAX (29:18) configuration and WiMAX Advanced frame partitioning.

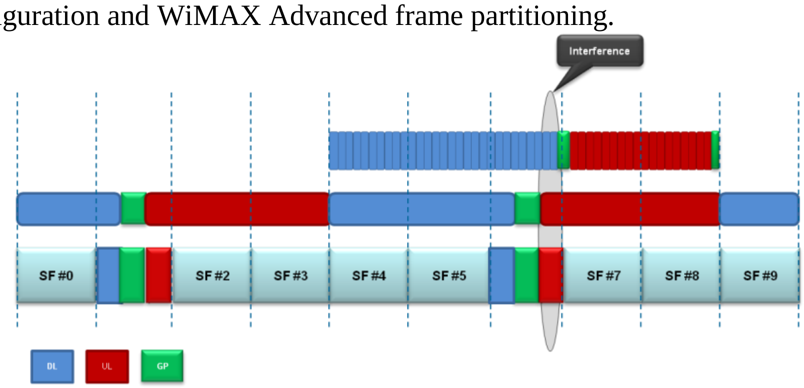

Figure 11. Comparison in Time of WiMAX and WiMAX Advanced System Operation

WiMAX Advanced frame configuration 1 has similar transmission periods to the typical WiMAX 29:18. In addition to that, the special subframe format 4 provides an approximate match to the WiMAX 29:18 frame with only a 2% overlap between BS and MS transmission periods. Two options may be employed to eliminate the 2% overlap in DL transmission period of WiMAX and the UL transmission period of WiMAX Advanced:

1. WiMAX DL symbols to be dropped to eliminate the overlap (see Figure 12). If the WiMAX DL period is reduced by two symbols, then there will be no overlap between the WiMAX DL and WiMAX Advanced UL. This results in an effective reduction in data carrying resources of 24 to 22 symbols (i.e. 8.3%) to the WiMAX DL with no loss to the WiMAX Advanced system.
2. WiMAX Advanced UpPTS may be dropped or punctured to eliminate the overlap. This approach does not degrade DL or UL data throughput for WiMAX. However, additional PRACH (Physical Random Access Channel) resources may need to be allocated in other parts of the WiMAX Advanced UL

subframes to compensate for the reduced PRACH resources in the UpPTS, thereby degrading the WiMAX Advanced UL data throughput slightly. Furthermore, with this approach the WiMAX Advanced frame may need to be Advanced by 2.85~20us in order to exclude even the smallest possibility if interference between the two systems.

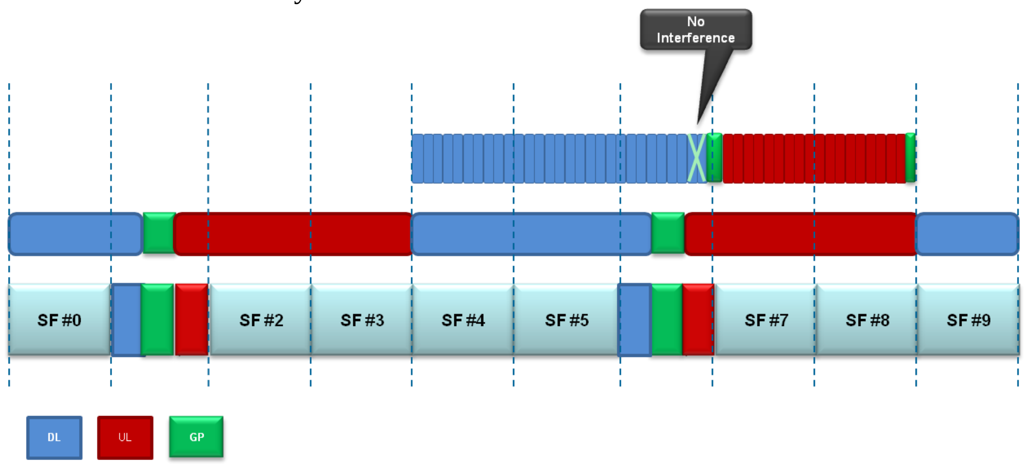

Figure 12. Muting WiMAX DL Symbols to Align WiMAX Advanced and WiMAX Frames

In conclusion, considering the default configured DL:UL ratio of commercially deployed WiMAX systems and by configuring the coexisting WiMAX Advanced system to use UL-DL allocations 1 or 2 (in Figure 3) and selecting appropriate configuration of the DwPTS, and GP, and UpPTS of a neighboring WiMAX Advanced system, it can be ensured that both systems operate with TDD frame synchronization.

5.1.2. RAN Equipment

For WiMAX Advanced and WiMAX co-existence, existing WiMAX RAN equipment could be potentially shared with WiMAX Advanced. The RAN equipment considered are Base Stations (BSs), Channel Cards, Base Band Units (BBU), Chassis, Remote Radio Heads (RRH), Antennas, and External Filters. BS modem baseband cards are available as either single-technology cards (requiring one card for WiMAX and one card for WiMAX Advanced) or dual-technology cards (utilizing one card for both WiMAX and WiMAX Advanced).

Many of the existing BBUs are built in such a way that they are capable of accepting multiple channel cards supporting different access technologies. As a result, a single BBU could easily be shared by both WiMAX and WiMAX Advanced systems. Depending upon the specific vendor or product, existing RRHs typically support WiMAX only. However, there are modern WiMAX RRHs available in the marketplace that are capable of being upgraded via software to support other TDD technologies, such as WiMAX Advanced. The dual mode RRH can support both technologies simultaneously. Antennas can also be shared between the two TDD technologies. The only requirement for both RRH and antenna is that DL and UL of the two technologies must not time-overlap with each other as has been discussed in previous sections.

In Figure 13, the coexistence of the WiMAX and WiMAX Advanced technologies is depicted. One WiMAX Advanced channel card (operating independently of the WiMAX channel card) is added to the existing BBU. In addition, the RRH is software upgraded to support both WiMAX and WiMAX Advanced technologies. It is possible to use a common Element Management System (EMS) for both technologies, as shown in Figure 13, or use two separate EMSs for WiMAX and WiMAX Advanced.

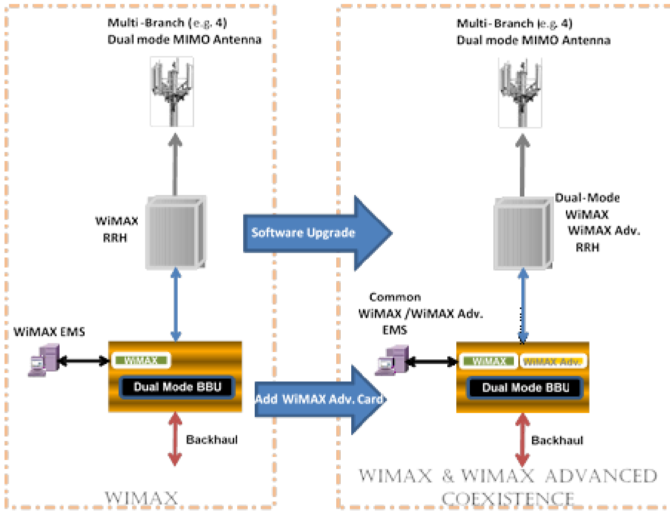

Figure 13. WiMAX and WiMAX Advanced RAN Equipment Sharing with Different Channel Cards

Additional common type of cell site equipment is one-box high power base station consisting baseband and remote radio head in the single enclosure and installed on top of tower closed to the antenna. Such base station equipment enables WiMAX to WiMAX Advanced upgrade by software only remotely.

5.2. Core Aspects of WiMAX and WiMAX Advanced Co-existence

For co-existing WiMAX and WiMAX Advanced, three scenarios below are possible.

1. In the first scenario, the core networks are separate and neither access network shares any components.
2. In the second approach, only the core elements dealing with user and device billing/accounting and authentication are shared, but other elements such as ASN-GW, S-GW, MME, P-GW, etc. are separate. Optionally, PGW and HA can be co-located and same IP session can be kept during hand off between WiMAX and WiMAX Advanced.
3. In the third scenario called common core scenario, existing gateways are upgraded so that the gateways are shared between the two networks.

5.2.1. Separate Core Network Scenario

This scenario is useful for operators that have green-field deployments of WiMAX Advanced or WiMAX in standalone markets. However, due to difficulty, and complexity of developing common core elements, and considering the business impacts of such developments, this would be the mainstream solution for WiMAX and WiMAX Advanced co-existence. Optionally, PGW and HA can be combined and IP session can be kept as same during hand off between WiMAX and WiMAX Advanced. With common AAA, same PGW or HA allocating same IP address is selected. The terminal can get same IP address from the PGW or HA and the user can enjoy session continuity.

This deployment architecture has the following features:

- Two separate core networks for WiMAX and WiMAX Advanced
- No session continuity unless P-GW and HA are co-located
- No PCC (Policy Control and Charging) integration
- Separate user subscription profile
- Separate device management

This deployment architecture offers minimal service disruption to users for existing WiMAX operators but because there is no re-use of the WiMAX network elements this deployment architecture involves the potential for higher Capital Expenditures (CAPEX) than the alternative of sharing core network elements.

5.2.2. Separate Core Network Scenario with Common AAA

This scenario is also useful for operators that have green-field deployments of WiMAX Advanced or WiMAX in standalone markets. In this scenario, In this case, only the core elements dealing with user and device billing/accounting and authentication are shared, but other elements such as ASN-GW, S-GW, MME, P-GW, etc. are separate.
Due to difficulty, and complexity of developing common core elements, and considering the business impacts of such developments, this scenario would have higher business justification than the third scenario.

This deployment architecture has the following features:

- Two separate core networks for WiMAX and WiMAX Advanced
- No session continuity
- No PCC (Policy Control and Charging) integration
- Common user subscription profile through WiMAX Advanced HSS
- Separate device management

This deployment architecture offers non-significant service disruption to users for existing WiMAX operators, but the amount of WiMAX element re-use would be minimal as well. Therefore, this involves the potential for considerable Capital Expenditures (CAPEX) than the alternative of sharing core network elements.

5.2.3. Common Core Scenario

To achieve common core architecture for WiMAX and WiMAX Advanced co-existence, new WiMAX Advanced core functions could be added, largely by software upgrades to the existing WiMAX components. This scenario is depicted in Figure 14.

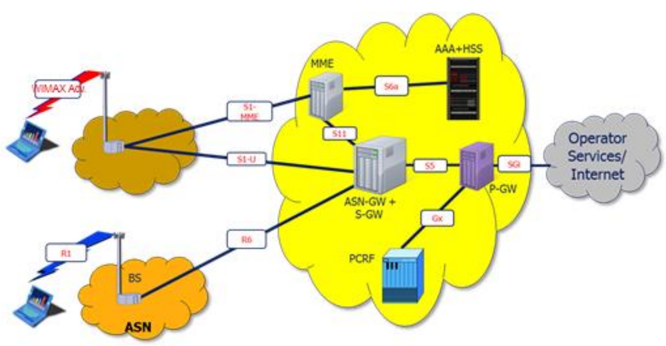

Figure 14. Common core for WiMAX and WiMAX Advanced

As depicted in this figure, one element of the evolution to the common core network is as follows: the Serving Gateway (S-GW) function is added as a software upgrade or a hardware upgrade to the ASN-GW, the PDN Gateway (P-GW) function is added as a software upgrade or a hardware upgrade to HA, the Mobility Management Entity (MME) function can be added as a new hardware component or as a software upgrade to ASN-GW, the Home Subscriber Server (HSS) function can be added as a software upgrade or a hardware upgrade to the WiMAX AAA, and the Policy and Charging Rules Function (PCRF) can be added via a new hardware component for serving both WiMAX and WiMAX Advanced. For the operators not looking at session continuity between WiMAX and WiMAX Advanced, a Simple IP deployment scenario may make sense with combined ASN-GW, S-GW, and P-GW. Optionally, the MME could be either a combined or a standalone chassis. This allows for a flat architecture.

However, this scenario incurs development complexities, and considering the business impacts of such developments, it is not expected that existing infrastructure vendors would develop this new common core elements, or operators would be willing to invest on such developments.

5.3. Device Impacts

In order to co-exist WiMAX Advanced and WiMAX on the same network, there are two choices for device development and procurement.

In the first choice, separate single mode devices are used for WiMAX Advanced and WiMAX. In this case, the existing WiMAX devices would stay in the market, and new WiMAX Advanced-only UEs would be provided to new customers, or customers with upgrading their devices. In this case, single mode devices would operate for WiMAX and WiMAX Advanced, and even though the cost and complexity of device development would be minimized, no WiMAX Advanced and WiMAX interworking/handoff would be possible.

In the second scenario, the existing WiMAX devices would stay in the market, and dual-mode WiMAX/WiMAX Advanced devices would be provided to new customers or current customers who upgrade their devices. The variety of the device architectures will depend on the type of the device and form factor, the level of component or subsystem integration, the availability of single or dual-mode WiMAX/WiMAX Advanced baseband chipsets, etc. Figure 15 depicts a high level architecture for dual-mode devices with two separate chipsets and RFICs. Depending on whether a single base-band chipset would support both technologies or not, or a single RFIC is required or not, different combinations exist for device implementation.

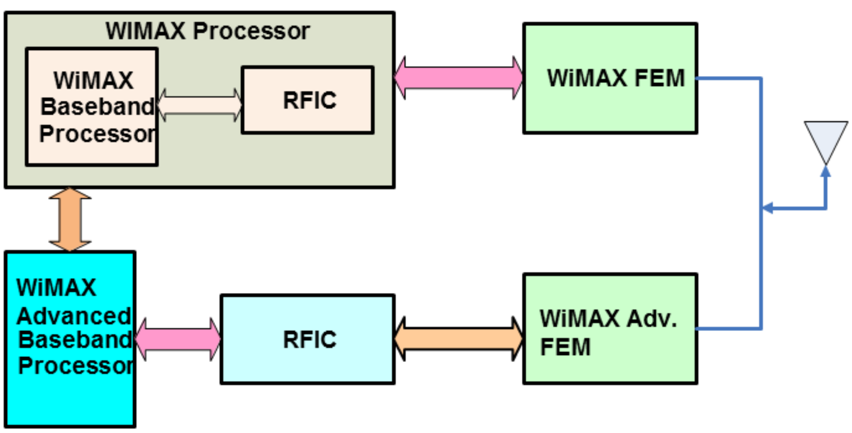

Figure 15. Dual Mode Devices with Dual-chipset and Dual-RFIC Architecture

Such device options are expected to be available for operators who intend to target coexisting WiMAX and WiMAX Advanced networks. It is noted that the support for 3G/2G technologies should also be considered, as some WiMAX operators may want to take advantage of the broader device ecosystem and provide wholesale services to other operators in their respective countries.

Moreover, dual RFIC devices can support seamless hand off between WiMAX and WiMAX Advanced networks since each session can be established before handing off to the target system and this will minimize disruption of hand off.

5.4. Co-existence Deployment Scenarios

Depending upon a mix of variables including spectrum availability, market rollout plans, and many other factors, operators may choose to deploy WiMAX and WiMAX Advanced together in one of several different scenarios. Three coexistence scenarios are considered within the scope of the paper.

5.4.1. Full WiMAX Advanced Overlay with WiMAX

One likely scenario for WiMAX operators assumes a full (100%) WiMAX Advanced macro network overlay over the WiMAX coverage area for a given market. The operator will utilize additional spectrum within the market to introduce WiMAX Advanced base station equipment and RF coverage to overlay the existing WiMAX coverage for 100% of the geographic area. To do so, operators should look to fully co-locate their WiMAX Advanced base stations with their existing WiMAX base stations. This is a practical overlay method in terms of time-to-market, interference management, and maintenance of network coverage. With some vendor solutions, there is a further ability to utilize the same Base Band Units (BBUs) and Remote Radio Heads (RRHs) for both technologies. To achieve this co-existence scenario, it is needed to overlay WiMAX Advanced RAN on top of the WiMAX network, and deploy multi-mode WiMAX-WiMAX Advanced devices or WiMAX Advanced devices to the existing WiMAX product portfolio.

5.4.2. Partial WiMAX Advanced Overlay with WiMAX

In partial overlay scenario, WiMAX Advanced network overlay in addition to, or on top of, the WiMAX coverage for a given market. Operators could look to this model either as a “hot-zone” approach or as a coverage extension to deployment within targeted geographic areas. The operator will utilize additional spectrum within the market to introduce partial WiMAX Advanced coverage. Here again, for practical reasons, operators should co-locate their WiMAX Advanced base stations with their WiMAX base stations within the common coverage area. However, in order to make this scenario feasible, the operator needs to seed the market with a high percentage of multi-mode WiMAX-WiMAX Advanced devices, which will have the ability to connect with either the existing WiMAX base stations or with the WiMAX Advanced base stations, where available.

5.4.3. No Overlay between WiMAX Advanced and WiMAX

With no overlay between the WiMAX Advanced and WiMAX networks, we assume the deployment of disparate and geographically separate WiMAX and WiMAX Advanced networks. The operator will utilize discrete spectrum within different markets to introduce WiMAX Advanced-only coverage for 100% of a defined geographic area. For purposes of this whitepaper, it is assumed there is no contiguous coverage between WiMAX and WiMAX Advanced networks in this scenario. Once the WiMAX Advanced network has been optimized, the operator can look to seed the market with multi-mode WiMAX-WiMAX Advanced devices, which will have the ability to roam between the technologies and respective markets. To achieve this co-existence scenario, it is needed to install WiMAX Advanced base stations in the Green-field market, seed the market with multi-mode WiMAX-WiMAX Advanced devices, and start procuring new multi-mode WiMAX-WiMAX Advanced devices.

5.5. WiMAX-WiMAX Advanced Co-existence Scenarios Based on Survey

As described in previous Sections, depending on frequency and spectrum plans, overlay approaches, operator business strategies, as well as core network availabilities, several scenarios for WiMAX and WiMAX Advanced might be used. However, according to the results of the surveys presented in Section 4, we need to develop a few realistic scenarios for WiMAX-WiMAX Advanced co-existence, so that operators requiring a certain co-existence/migration scenario, the ecosystem could be enhanced, and device and infrastructure equipment vendors find it attractive to develop required equipment. This Section provides these realistic scenarios.

5.5.1. WiMAX Advanced Overlay with Additional Spectrum

Description - This scenario assumes a full WiMAX Advanced macro network overlay with the WiMAX coverage area for a given market using additional spectrum on either the existing or a new frequency band. For example, a WiMAX operator with 30 MHz bandwidth on 2.3 GHz and newly secured bandwidth of 20 MHz on 2.3 GHz or 2.6 GHz can launch its WiMAX Advanced overly network under this scenario meanwhile 10 and 20 MHz channel bandwidth are set for WiMAX and WiMAX Advanced, respectively. Based on the operators' strategy, this scenario enables them to completely migrate from the WiMAX network to WiMAX Advanced after the entire network is rolled out and all existing WiMAX customers have been migrated to WiMAX Advanced. This scenario considers two separate core networks (WiMAX and WiMAX Advanced). Figure 16 illustrates how an operator can deploy an overlay WiMAX Advanced network when it comes to consider changes in RAN part. An operator may choose not to go on up to the last stage (WiMAX Advanced only network) while maintaining the two technologies and extra units are more difficult and expensive.

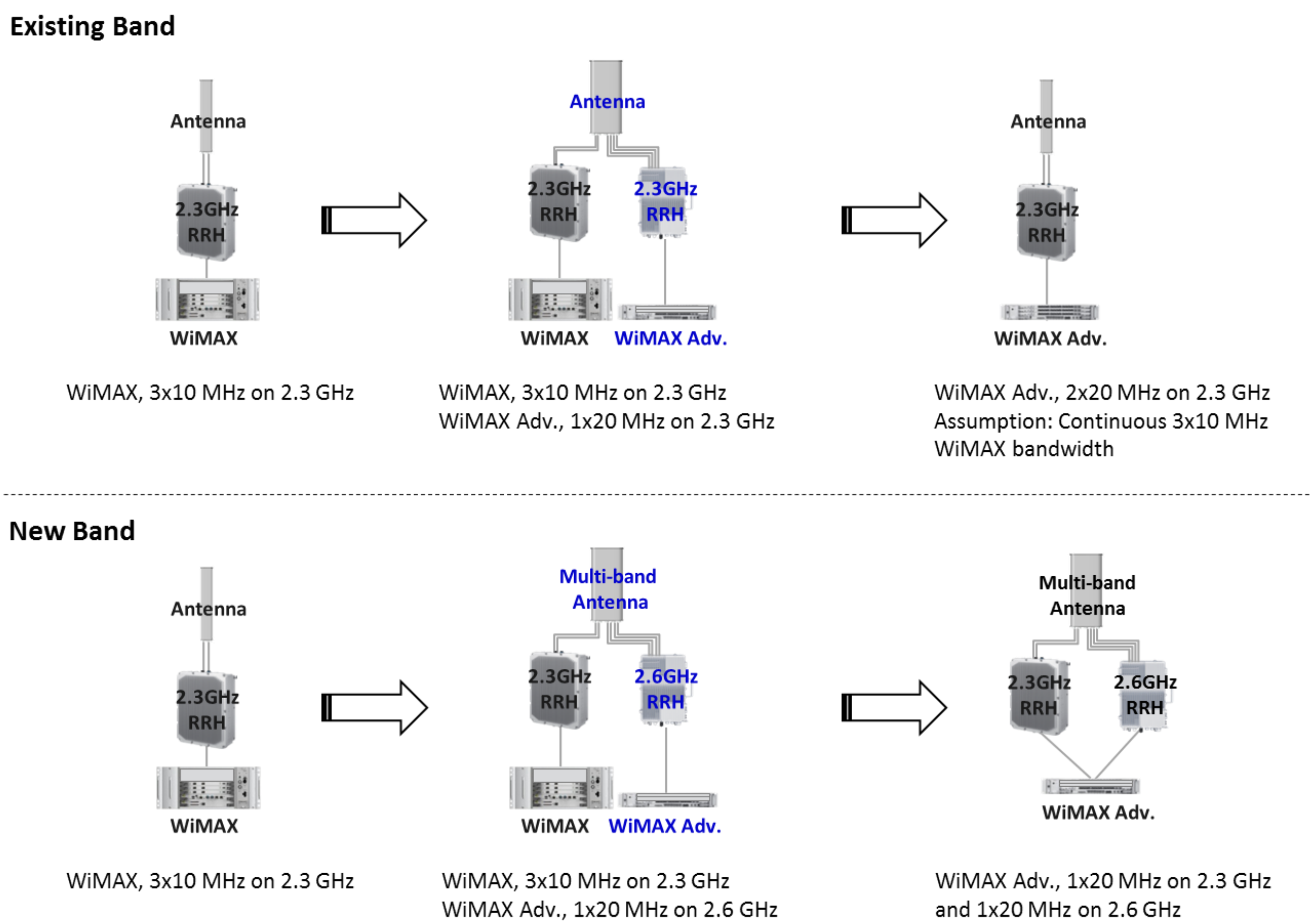

Figure 16. Transition from WiMAX to WiMAX Advanced under the scenario of WiMAX Advanced Overlay with additional spectrum

Pros and Cons - This transition may bring about expansions in terms of the cell throughput, especially when it uses 2x20 MHz bandwidth (Carrier Aggregation) in comparison with that of one channel of 10 MHz in WiMAX system. However, service disruptions are inevitable during the WiMAX Advanced channel cards and Remote Radio Head (RRH) installation.
Recommendations/Requirements - Availability of dual mode and/or multi-band devices considerably improves user experience during rollout of WiMAX Advanced network. Some vendors may provide software defined radios (SDRs) which only requires a software upgrade instead of adding WiMAX Advanced channel cards and remote radio heads.

5.5.2. WiMAX Advanced Overlay without Additional Spectrum

Description - This scenario involves a full WiMAX Advanced macro network overlay within the WiMAX coverage area for a given market reusing existing spectrum. For instance, a WiMAX operator with contiguous 42 MHz bandwidth on 2.3 GHz is able to deploy its WiMAX Advanced overly network under this scenario. Based on the operators' strategy, this scenario enables them to keep the WiMAX network up and running even when a full WiMAX Advanced network is deployed. This scenario considers two separate core networks (WiMAX and WiMAX Advanced) and reuse of 20 MHz of WiMAX spectrum for WiMAX Advanced with adequate guard bandwidth meanwhile 10 and 20 MHz channel bandwidths are set for WiMAX and WiMAX Advanced, respectively. Figure 17 shows how an operator can deploy an overlay WiMAX Advanced network when it comes to consider changes in RAN part.

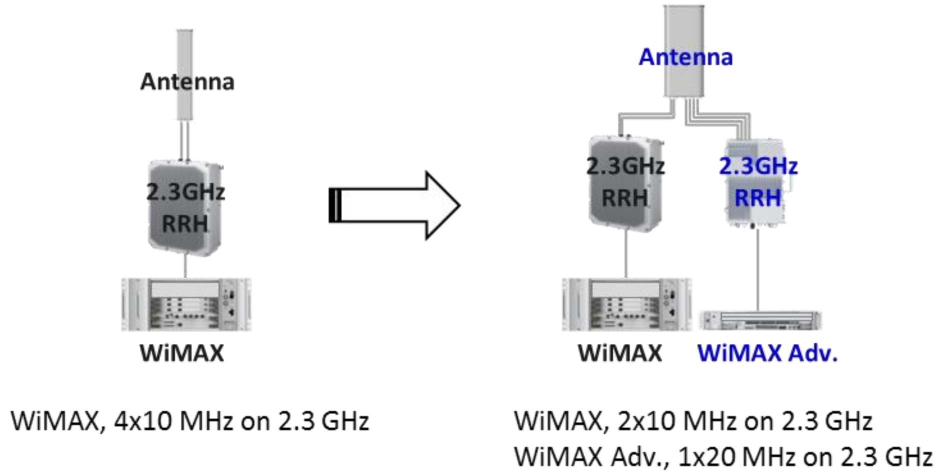

Figure 17. Transition from WiMAX to WiMAX Advanced under the scenario of WiMAX Advanced Overlay without additional spectrum

Pros and Cons - The process of carving out spectrum may involve migrating some of the existing WiMAX customers to WiMAX Advanced network imposing difficulties, service degradations, and expenses to both operators and customers. However, the burden of securing additional spectrums is lifted on day one. Moreover, service disruptions are inevitable during the WiMAX Advanced network installation and antenna tunings.
Recommendations/Requirements - Availability of dual mode and/or multi-band devices can help not only inter-technology handover, but also WiMAX users to utilize WiMAX Advanced resources. Some vendors may provide software-defined radios (SDRs), which only require a software upgrade instead of adding WiMAX Advanced channel cards and remote radio heads. Reuse of existing spectrum in use for WiMAX to be used for WiMAX Advanced deployment present significant challenges to the operation of existing WiMAX network and subscriber. Detailed planning and strategies should be considered for such deployment scenario.

5.5.3. WiMAX Advanced Hot-zones within WiMAX Coverage with Additional Spectrum

Description - This scenario assumes WiMAX Advanced hot-zones within the WiMAX coverage area for a given market using additional spectrum on either the existing WiMAX or a new frequency band. For example, a WiMAX operator with 30 MHz bandwidth on 2.3 GHz and newly secured bandwidth of 20 MHz on 2.3 GHz or 2.6 GHz can launch WiMAX Advanced hot-zones under this scenario meanwhile 10 and 20 MHz channel bandwidths are set for WiMAX and WiMAX Advanced, respectively. Based on the operators' strategy, this scenario enables them to gradually deploy WiMAX Advanced overlay by increasing hot-zones in a cost/market-aware manner and finally shut down the WiMAX network when a full WiMAX Advanced is deployed and WiMAX Advanced devices are readily available among all existing WiMAX customers. This scenario considers two separate core networks (WiMAX and WiMAX Advanced). Changes and evolutions in RAN part can be the same as those depicted in Figure 16.
Pros and Cons - This transition may bring about expansions in terms of the cell throughput especially when it uses 2x20 MHz bandwidth (Carrier Aggregation) in comparison with that of one channel of 10 MHz in WiMAX system. However, service disruptions are inevitable during the WiMAX Advanced network installations and tuning. As long as hot-zones coverage areas are limited and not contiguous, offering mobile services on WiMAX Advanced without a multi-mode WiMAX and WiMAX Advanced device may result in customer dissatisfaction.

However, one can use these hot-zones coverage area to offer fixed and nomadic services to customers within the defined WiMAX Advanced coverage areas.
Recommendations/Requirements - Availability of dual mode and/or multi-band devices considerably improves user experience. Some vendors may provide software-defined radios (SDR), which only require a software upgrade instead of adding WiMAX Advanced channel cards and remote radio heads. It is recommended to apply this scenario when it comes to target a full overlay WiMAX Advanced network in a conservative manner in terms of controlling the attributed capital and operational expenditures and making sure of the market response.

6. Conclusion

This paper's primary purpose is to provide the 4G ecosystem with specific technical and implementation considerations for the coexistence of WiMAX and WiMAX Advanced technologies within the same network. The recommendations included herein utilize likely deployment scenarios and associated challenges. While this paper primarily focuses on the technical implementation aspects of the radio access network, core network, spectrum management, and device capabilities perspective, the practical concerns of cost, flexibility, and the customer experience should also be taken into consideration. Additionally, the included scenarios outline practical implementation considerations that should be beneficial for all operators in the 4G ecosystem regardless of frequency band, spectrum allocation, or deployment scenario.

For operators looking to utilize both WiMAX and WiMAX Advanced technologies within the same network, there are multitudes of spectrum, RAN network, core network, device availability and go to market opportunities and trade-offs to assess. There are complexities with coexisting networks, but with proper planning and consideration, operators can leverage much of their existing RAN, Core, BSS/OSS infrastructures for rollout of the network, which includes coexisting WiMAX and WiMAX Advanced RAN equipment, core equipment, and end-user devices. With the industry focused on meeting the exponential market demand for wireless broadband services, all available network and spectrum resources will be required.