Deploying License-Exempt WiMAX Solutions

Executive Summary

Existing and potential wireless Internet service providers (WISPs) and vertical markets such as government and education are considering the benefits associated with Worldwide Interoperability for Microwave Access (WiMAX), specifically the flexibility and cost reduction benefits associated with the license-exempt portion of WiMAX. However, the popularity of WiMAX is causing concern among some operators who fear that standardizing the license-exempt broadband wireless spectrum may lead to overcrowding, while other operators hope to establish new solutions that can accommodate the sharing of spectrum and infrastructure locations.

This paper provides WISPs and vertical markets with technical information related to deployment of a license-exempt WiMAX solution. It compares license-exempt and licensed WiMAX solutions and highlights benefits such as cost-effectiveness and deployment flexibility. License-exempt challenges such as where to place infrastructure equipment and how to minimize interference are also examined.

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Introduction

WiMAX technology is a worldwide wireless networking standard that addresses interoperability across IEEE 802.16* standard-based products. WiMAX technology offers greater range and bandwidth than the wireless fidelity (Wi-Fi) family of standards and provides a wireless alternative to wired backhaul and last mile deployments that use Data Over Cable Service Interface Specification (DOCSIS) cable modems, Digital Subscriber Line technologies (xDSL), T-carrier and E-carrier (T-x/E-x) systems, and Optical Carrier Level (OC-x) technologies.

WiMAX technology can reach a theoretical 30-mile coverage radius and achieve data rates up to 75 Mbps, although at extremely long range, throughput is closer to the 1.5 Mbps performance of typical broadband services (equivalent to a T-1 line), so service providers are likely to provision rates based on a tiered pricing approach, similar to that used for wired broadband services.

The IEEE 802.16 Working Group develops standards that address two types of usage models: a fixed usage model (IEEE 802.16-2004) and a portable usage model (802.16 REV E, scheduled for ratification in 2005).

WiMAX has been designed to address challenges associated with traditional wired access deployment types such as:

- **Backhaul.** Uses point-to-point antennas to connect aggregate subscriber sites to each other and to base stations across long distances.
- **Last mile.** Uses point-to-multipoint antennas to connect residential or business subscribers to the base station.
- **Large-area coverage access.** Uses base stations, subscriber stations, and Wi-Fi solutions, such as mesh networks, to cover a large area and provide access to 802.16 REV E clients. (Also referred to as hot zones.)

This paper focuses on license-exempt fixed deployments, including backhaul and last mile, based on the IEEE 802.16-2004 standard as shown in the highlighted areas of Figure 1.

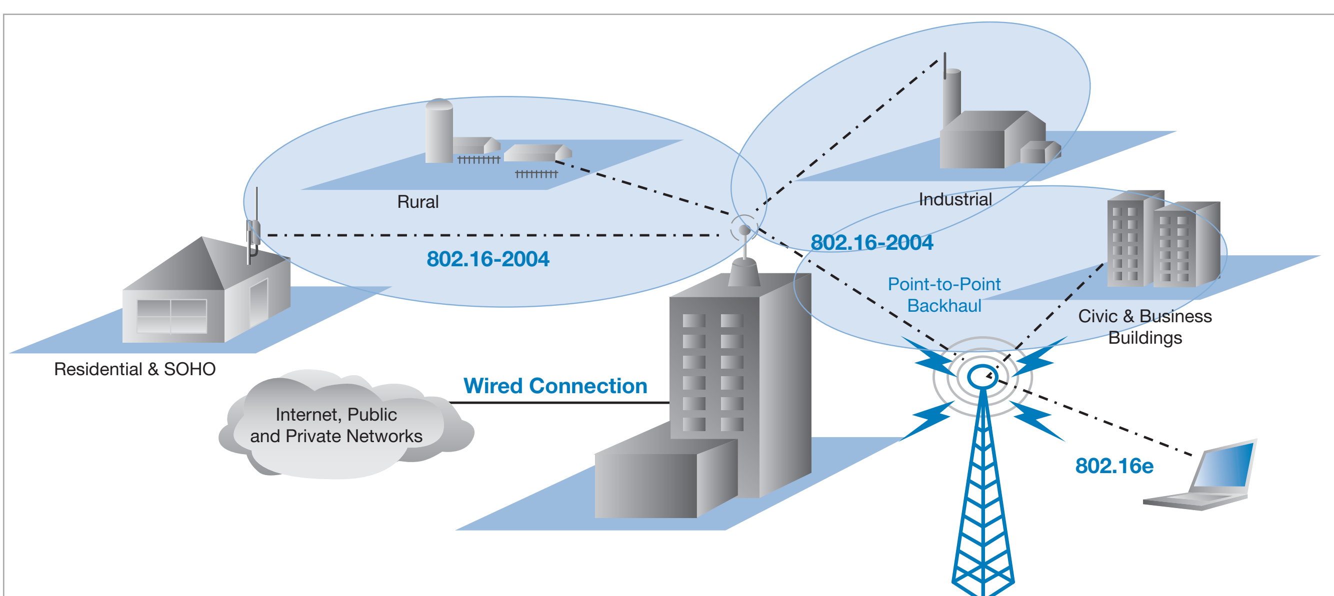
Benefits of Adopting a WiMAX Fixed Solution

The ability to operate a standardized solution in both a licensed and a license-exempt band is one of the benefits of WiMAX solutions for deployments around the world.

Both licensed and license-exempt WiMAX solutions provide significant advantages over wired solutions. The adoption of license-exempt and licensed WiMAX solutions is being driven by the following additional benefits:

- **Scalability.** The 802.16-2004 standard supports flexible radio frequency (RF) channel bandwidths and reuse of these frequency channels as a way to increase network capacity. The standard also specifies support for Transmit Power Control (TPC) and channel quality measurements as additional tools to support efficient spectrum use. The standard has been designed to scale up to hundreds or even thousands of users within one RF channel. Operators can re-allocate spectrum through sectoring as the number of subscribers grows. Support for multiple channels enables equipment makers to provide a means to address the range of spectrum use and allocation regulations faced by operators in diverse international markets.

Figure 1. Fixed WiMAX deployment and usage models.



- **Cost effectiveness.** The wireless medium used by WiMAX enables service providers to circumvent costs associated with deploying wires, such as time and labor.
- **Flexibility.** A wireless medium enables deployment of an access solution over long distances across a variety of terrains in different countries.
- **Standard-based.** The WiMAX Forum helps support interoperability and coordination between vendors developing 802.16-2004 compliant products by testing and certifying the compliance of products.

Comparing Licensed and License-Exempt WiMAX Technologies for Fixed Access

Governments around the world recognize the value of innovations associated with open standards and license-exempt solutions and have established frequency bands available for use by licensed and license-exempt WiMAX technologies. However, to impose some control over license-exempt solutions to mitigate the potential for interference, some governments stipulate power requirements for high-power and low-power operations.

Each geographical region defines and regulates its own set of licensed and license-exempt bands, as shown in Table 1. To meet global regulatory requirements and allow providers to use all available spectrums within these bands, the 802.16-2004 standard supports channel sizes between 1.5 MHz and 20 MHz.

Table 1. Worldwide allocation of licensed and license-exempt bands.

Country/Geographic Area	Bands Used
North America, Mexico	2.5 GHz and 5.8 GHz
Central and South America	2.5 GHz, 3.5 GHz and 5.8 GHz
Western and Eastern Europe	3.5 GHz and 5.8 GHz
Middle East and Africa	3.5 GHz and 5.8 GHz
Asian Pacific	3.5 GHz and 5.8 GHz

Licensed Bands: 2.5 GHz and 3.5 GHz

The 2.5 GHz band has been allocated in much of the world, including North America, Latin America, Western and Eastern Europe and parts of Asia-Pacific as a licensed band. Each country allocates the band differently, so the spectrum allocated across regions can range from 2.6 GHz to 4.2 GHz. A system operating in the licensed band has an advantage over a system operating in an unlicensed band in that it has a more generous downlink power budget and can better support indoor antennas.

In the US, the Federal Communications Commission (FCC) has created the Broadband Radio Service (BRS), previously called the multi-channel multipoint distribution system (MMDS), for wireless broadband access. The restructuring that followed has allowed for the opening of the 2.495 GHz to 2.690 GHz bands for licensed solutions such as 2.5GHz in WiMAX.

In Europe, the European Telecommunications Standards Institute (ETSI) has allotted the 3.5 GHz band, originally used for wireless local loop (WPLL), for licensed WiMAX solutions.

License-Exempt Band: 5 GHz

The majority of countries around the world have embraced the 5 GHz spectrum for license-exempt communications. The 5.15 GHz and 5.85 GHz bands have been designated as license-exempt in much of the world. Approximately 300 MHz of spectrum is available in many markets globally, and an additional 255 MHz of license-exempt 5 GHz spectrum is available in highly populated markets like the United States. Some governments and service providers are concerned that interference resulting from the availability of too many license-exempt bands could affect critical public and government communication networks, such as radar systems. These countries and entities have become active in establishing limited control requirements for 5 GHz spectrums. For example, the United Kingdom is currently introducing restrictions on certain 5 GHz channels and considering enforcement of the use of the DFS (Dynamic Frequency Select) function.

In Mexico, regulations requiring the use of spectrum “to benefit the people” have influenced the government to take a protectionist and revenue generating approach toward licensing. The Mexican government is moving toward licensing at least one of the 5 GHz bands, with 5.8 GHz currently a primary candidate.

Table 2 describes the availability of frequency bands for WiMAX.

Table 2. Bands and frequencies available for WiMAX.

Band	Frequencies	License Required?	Availability
2.5 GHz	2.5 to 2.69 GHz	Yes	Allocated in Brazil, Mexico, some Southeast Asian countries and the U.S. (The WiMAX Forum* also includes 2.3 GHz in this band category because it "expects to cover [2.3 GHz] with the 2.5 GHz radio.") Ownership varies by country.
3.5 GHz	3.3 to 3.8 GHz, but primarily 3.4 to 3.6 GHz	Yes, in some countries	In most countries, the 3.4-GHz to 3.6-GHz band is allocated for broadband wireless.
5 GHz	5.25 to 5.85 GHz	No	In the 5.725-GHz to 5.85-GHz portion, many countries allow higher power output (4 watts), which can improve coverage.

Source: WiMax Forum*

Benefits of Licensed and License-Exempt Bands

The benefits of licensed and license-exempt WiMAX solutions over wired solutions are cost-effectiveness, scalability, and flexibility. However, what is sometimes overlooked is that each band provides a different set of advantages for different usage models. In Table 3, a list of advantages for both solutions is shown.

Table 3. Benefits of licensed and license-exempt solutions.

Licensed Solution Advantages	License-Exempt Solution Advantages
Better quality of service	Fast rollout
Better non-line-of-sight (NLOS) reception at lower frequencies	Lower costs
Higher barriers for entrance	More worldwide options

Licensed Solutions: Advantages and Usages

To deploy a licensed solution, an operator or service provider must purchase spectrum. The purchasing of spectrum is a cumbersome process. In some countries, filing the appropriate permits to obtain licensing rights may take months, while in other countries, spectrum auctioning can drive up prices and cause spectrum acquisition delays. This higher barrier to entrance, coupled with exclusive ownership of a band, enables service quality improvements and reduces interference.

WiMAX licensed solutions have significant advantages. The higher costs and exclusive rights to spectrum enable a more predictable and stable solution for large metropolitan deployments and mobile usage.

The lower frequencies associated with licensed bands (2.5 GHz and 3.5 GHz) enable better NLOS and RF penetration. However, licensed bands are not without interference issues. As service providers deploy more networks, they must contend with mutual interference resulting from within their own network. Proper design and implementation can alleviate these problems. In summary, licensed solutions offer improved quality of service (QoS) advantages over licensed-exempt solutions.

License-Exempt Solutions: Advantages and Usages

The costs associated with acquiring licensed bands are leading many WISPs and vertical markets to consider license-exempt solutions for specialized markets, such as rural areas and emerging markets. License-exempt solutions provide several key advantages over licensed solutions, including lower initial costs, faster rollout, and a common band that can be used in much of the world. These benefits are fueling interest and have the potential for accelerating broadband adoption.

Service providers in emerging markets, such as developing countries or mature countries with underdeveloped areas, can reduce time to market and initial costs by quickly deploying a license-exempt solution without timely permits or auctions. Even mature areas can benefit from license-exempt solutions. Some service providers can use a license-exempt solution to provide last mile access for home, business, or backhaul or as a supplemental network backup for their licensed or wired networks.

A license-exempt solution is regulated in terms of the transmission output power, although a permit is usually not required. A device or service can use the band at any time as long as output power is controlled adequately. Providers who are particularly concerned about QoS, for example, may find that a licensed solution provides them with more control over the service.

A service provider wanting to serve an emerging or underdeveloped market with a business class service can use a license-exempt solution, with proper network design including site surveys and specialized antenna solutions, to offer certain Service Level Agreements (SLAs) for their specialized markets. However, a license-exempt solution should not be looked upon as a replacement for a licensed solution. Each serves a different market need based on tradeoffs between cost and QoS. License-exempt solutions and licensed solutions each offer certain advantages to providers. The availability of both allows providers and emerging markets to fulfill a variety of usage needs.

Service providers wanting to add mobility to their wireless broadband network should consider first a licensed WiMAX solution for improved QoS, then a Wi-Fi Mesh solution for solutions requiring an immediate need, and then a licensed-exempt solution. A licensed WiMAX solution offers better control across large areas, enhanced scalability, QoS, and flexibly for users on the go, while Wi-Fi Mesh can cover smaller areas at a lower cost and can use a Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) protocol to handle multiple users within a small region.

For these reasons, license-exempt WiMAX solutions are focused on rural areas, emerging markets, and point-to-point applications and can provide, for example, an extremely cost-effective backhaul solution.

More importantly, the fluctuations in the number and location of users and the limited control of the spectrum offered by a license-exempt solution may result in more interference. Network statistical data can be used to plan for volatility. However, mobility-related issues such as transmitting RF signals to and from a moving target are more easily addressed using a licensed solution. Therefore, mobile applications are best suited for a licensed WiMAX solution.

Large underdeveloped areas or underserved areas, such as an isolated college campus or farm, are better suited for license-exempt WiMAX solutions, where the cost benefits and coverage area can be better utilized. WiMAX license-exempt solutions are suitable for the following applications:

- Point-to-point, long distance solutions in scarcely populated environments
- Point-to-multipoint solutions in rural communities (including some developing countries)
- Areas with small RF in-band noise or where interference in the unlicensed band can be controlled within the geography, such as large enterprise campuses, military barracks, and shipyards
- Where cost is the major factor governing a decision between competing wireless technologies
- When ownership of equipment is an option to the end user

WiMAX licensed solutions are suitable for the following applications:

- Large-coverage, point-to-multipoint applications
- Ubiquitous broadband mobile services
- When licensing enables control over the usage of spectrum and interference
- When cost is not the primary issue for choosing the technology, because the technology has been optimized for this application (other technologies such as 3G data overlays will cost more and have worse performance)
- When services and base station equipment can only be leased from a carrier or service provider

Technical Differences Between Licensed and License-Exempt Bands

Both WiMAX licensed and license-exempt solutions are based on the IEEE 802.16-2004 standard, which uses orthogonal frequency-division multiplexing (OFDM) in the physical (PHY) layer. OFDM provides benefits such as increased signal-to-noise ratio (SNR) of subscriber stations and improved resiliency to multipath interference and outdoor environments.

Duplexing refers to the process of creating bi-directional channels for uplink and downlink data transmission. Time division duplexing (TDD) and frequency division duplexing (FDD) are both supported by the 802.16-2004 standard. Licensed solutions use frequency division duplexing (FDD) while license-exempt solutions use time division duplexing (TDD).

FDD requires two channel pairs that are separated to minimize interference, one for transmission and one for reception. Most FDD bands are allocated to voice, because the bi-directional architecture of FDD allows voice to be handled with minimal delays. FDD, however, adds additional components to the system and therefore increases costs.

FDD is used in third-generation wireless (3G) networks, which operate at a known frequency and are designed for voice applications. The majority of coding schemes used in 3G networks have limitations for data throughput. As network traffic increases or decreases, the geographical area covered by the transmitter may shrink or grow, a phenomenon called "cell breathing". Also, when a user sharing a channel stops transmitting, the transmission rate is reduced proportional to

Table 4. Comparison of TDD and FDD.

	TDD	FDD
Description	A duplexing technique used in license-exempt solutions and which uses a single channel for both the uplink and downlink.	A duplexing technique utilized in licensed solutions that uses a pair of spectrum channels, one for the uplink and another for the downlink.
Advantages	• Enhanced flexibility because a paired spectrum is not required • Easier to pair with smart antenna technologies • Asymmetrical	• Proven technology for voice • Designed for symmetrical traffic • Does not require guard time
Disadvantages	• Cannot transmit and receive at the same time	• Cannot be deployed where spectrum is unpaired • Spectrum is usually licensed • Higher cost associated with spectrum purchase
Usage	• "Bursty", asymmetrical data applications • Environments with varying traffic patterns • Where RF efficiency is more important than cost	• Environments with predictable traffic patterns • Where equipment costs are more important than RF efficiency

the number of users to minimize interference, resulting in a lower transmit power level. Variations in range and transmission power level may be acceptable for voice applications, but they provide challenges for data networks.

TDD becomes useful in environments where channel pairs are not available due to regulation restrictions, or where license-exempt frequencies can be used. TDD provides a single channel for both upstream and downstream transmissions. A TDD system can dynamically allocate upstream and downstream bandwidth depending on the amount of traffic. This asymmetric transfer is well suited for Internet traffic where large amounts of data may be pulled across the downlink.

A TDD system operates by first transmitting downstream from the base station to the subscriber station. After a short guard time, typically 1ms, the subscriber station then transmits on the same frequency in the upstream direction.

TDD and FDD solutions are not interoperable since they use different bands and duplexing techniques. A side-by-side comparison of TDD and FDD is shown in Table 4.

In summary, FDD and TDD each serve a purpose. FDD operates in two separate channels, one for receiving traffic and the other for transmitting traffic. The spectrum granted for FDD technologies is licensed in equal sized bands. Guard times between upstream and downstream bursts are not required, enabling a full duplex implementation. FDD does not support a Wi-Fi Mesh solution.

In a TDD solution, one channel is used for both transmitting and receiving traffic. Guard times are required between upstream and downstream bursts. TDD can support Wi-Fi Meshing. TDD uses two distinct sets of time slots on the same frequency for the uplink and downlink, while FDD uses two distinct frequencies for the uplink and downlink.

An FDD solution costs more because it requires more hardware to support the separate uplink and downlink channels. The cost is justified by the more efficient use of bandwidth and improved QoS. Licensed solutions use FDD because of its robust duplex nature as well as the fixed spectrum modulated by frequency. This enables carrier class QoS, which cannot be fully achieved in unlicensed solutions.

Challenges of Deploying a License-Exempt WiMAX Solution

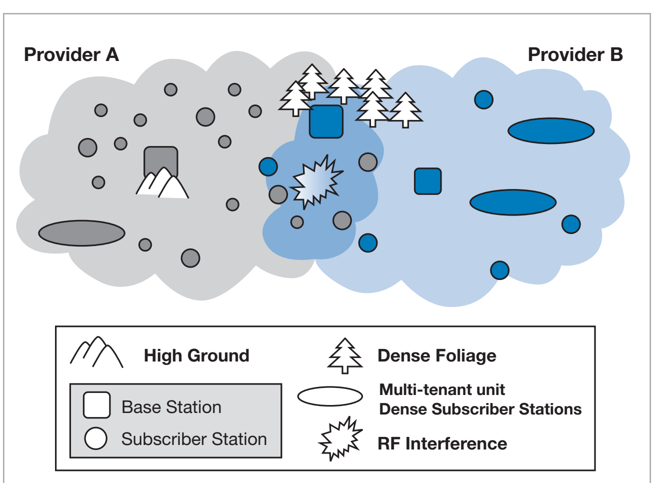
Licensed and license-exempt WiMAX solutions face common challenges related to government regulations, infrastructure placement, and interference. However, license-exempt solutions have more to prove in environments where licensed solutions are seen as more stable and reliable.

The benefits of a license-exempt WiMAX solution, including cost-effectiveness and easier entrance for new providers, can lead to additional hurdles. Easier entrance and lower costs allow more operators to deploy solutions. More deployments mean increased RF usage, a higher possibility of interference, and more competition for prime real estate for deployment. RF interference and the physical placement of the infrastructure are the primary challenges associated with deploying a license-exempt solution.

The example in Figure 2 shows how two service providers, Provider A and Provider B, have implemented license-exempt solutions to serve a specialized market—a rural community. They have implemented their solutions within close proximity of each other. Figure 2 illustrates some of the challenges they are now facing.

Provider A and Provider B are both operating in the same band and must contend for bandwidth. In addition, Provider A's base station is deployed on higher ground, while Provider B's base station is deployed within a dense forest at sea level. Therefore, Provider A is less likely to experience RF interference than Provider B due to a better base station physical placement.

Figure 2. Example of license-exempt solutions implemented within close proximity of each other.



The 802.16-2004 standard allows for near line of sight operation (NLOS) and better resiliency to multipath interference than the 802.11* standard and revisions. This enables operators to deploy base stations further away from subscriber stations and within areas that have obstructed views to the subscriber, such as within a forest or among buildings in a densely populated area. The ability of a solution based on the 802.16-2004 standard to cope with multipath interference allows it to operate in various locations under extreme conditions, although deploying the solution in more favorable conditions can improve performance.

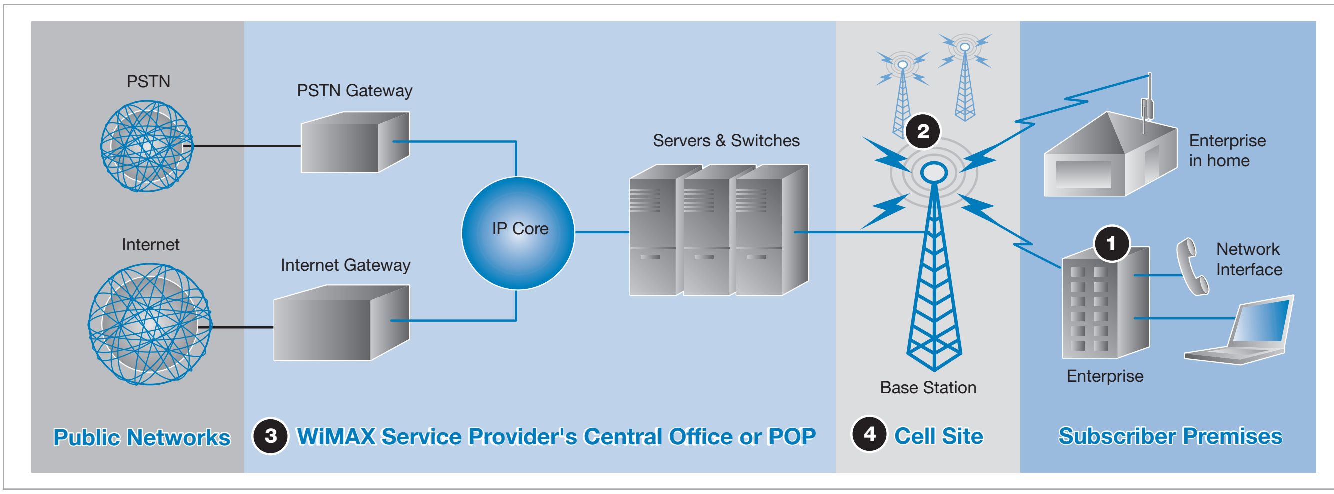
In Figure 2, Provider B can still deliver services to its subscribers, but because Provider A has a better location, Provider A's subscribers experience less interference than those of Provider B. The potential for interference requires that license-exempt products reserve a large interference margin, and therefore some throughput and coverage have to be sacrificed. Interference is less of an issue in rural areas, but in urban areas, it can become challenging to deliver license-exempt services using point-to multipoint equipment due to the high density of wireless devices.

Thus, two major challenges to overcome in deploying a WiMAX solution are:

- **RF interference** – An interfering RF source disrupts a transmission and decreases performance by making it difficult for a receiving station to interpret a signal. Forms of RF interference frequently encountered are multipath interference and attenuation. Multipath interference is caused by signals reflected off objects resulting in reception distortion. Attenuation occurs when an RF signal passes through a solid object, such as a tree, reducing the strength of the signal and subsequently its range. Overlapping interference from an adjacent base station can generate random noise.

  License-exempt solutions have to contend with more interference then licensed solutions, including intra-network interference caused by the service provider's own equipment operating in close proximity, and external network interference. Licensed solutions must only contend with inter-network interference. For license-exempt solutions, RF interference is a more serious issue in networks with centralized control than in a shared network because the base station coordinates all traffic and bandwidth allocation.

Figure 3. A properly deployed license-exempt WiMAX solution.



- **Infrastructure placement** – Infrastructure location refers to the physical location of infrastructure elements. Infrastructure placement can be an issue for both licensed and license-exempt solutions. However, infrastructure placement presents some special considerations for license-exempt solutions. Service providers are quickly deploying solutions in specific areas to stake out territory with high subscriber density and spectrum efficiency. Such areas include higher ground, densely populated or population growth areas, and areas with a less crowded RF spectrum. In addition, the physical structure that houses or supports the base station must be RF compatible, A metal farm silo, for example, may distort signals, or a tree swaying in the wind may change signal strength.

Solving the Challenges of Deploying a License-Exempt WiMAX Solution

In a license-exempt network, proper network design and infrastructure placement are critical. Interference mitigation through planning can greatly reduce interference and improve the quality of a service as shown in Figure 3 and described below:

- **Subscriber site (1)** – Professional installation of a subscriber station should include site surveys to gather information, such as RF activity within the area, and determine antenna types and tilt angles required for optimum RF reception.
- **Antennas (2)** – In addition to redundant links and proper antenna tilt angles, array gain and diversity gain can help optimize RF reception.
  - **Array Gain** – The gain achieved by using multiple antennas so that the signal adds coherently.
  - **Diversity Gain** – The gain achieved by using multiple paths, so that if a signal is compromised in one of the paths, overall performance is still maintained. Effectively, diversity gain refers to techniques used at the transmitter or receiver to achieve multiple "looks" at a fading channel. These schemes improve performance by increasing the stability of the received signal strength in the presence of wireless signal fading. Diversity may be exploited in the spatial (antenna), temporal (time), or spectral (frequency) dimensions.
- **Central office (CO) or point-of-presence (POP) (3)** – The CO or POP is the provider's network operation center. The proper design and deployment of the network operation center includes:
  - Identifying user requirements
  - Professional installation of base stations and antennas with appropriate tilt angles
  - Providing a broadband service with typically at least 1Mbps per subscriber
  - Connecting properly to the backbone
  - Connecting to voice services, such as public switched telephone networks (PSTNs), and media gateways
  - Implementing traffic management, routers, and firewalls
  - Establishing a means to collect network statistics
- **Forward deployed base station or cells (4)** – Providing 24/7 access, a sturdy RF-friendly structure, and shielding from weather elements can help reduce interference and improve quality of service.

Addressing Issues with Infrastructure Placement

Infrastructure placement establishes the foundation for the service provider's network. When choosing a location for deployment, a service provider must ensure that it can obtain 24/7 access to the site, that the building or location does not contain physical material that is not RF friendly, and that the infrastructure provides protection against weather-related elements, such as wind and lightning.

Obstacles such as trees and buildings frequently block signal paths in urban areas and some rural areas. NLOS performance is greatly improved with 802.16-2004 due to its improved resistance to multipath interference. Even with no direct line-of-sight (LOS) between the base station and the subscriber station, signals can be received after they reflect off buildings or other obstructions. Factors such as these make a preliminary site survey indispensable.

Infrastructure placement provides a solid market advantage for incumbents. The cost and time involved in obtaining building permits, leases, and roof space present significant barriers to those without an already established infrastructure.

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Addressing Issues with Interference and QoS

Interference is the disruption or degradation of a transmitted signal by extraneous RF energy. Interference impedes the ability of an RF receiver to distinguish between the transmitted signal and the background RF energy that exists at that specific point in time.

Causes of extraneous RF energy include:

- **Noise** – RF energy sources that are not in the same RF spectrum but still affect the RF receiver due to harmonics or 'bleed-over' into adjacent RF frequency bands or channels. A cellular telephone system, for example, may generate this type of noise.
- **Direct spectrum overlap by unidentified sources** – RF energy sources that are in the same RF spectrum but cannot be identified by the RF receiver because they use a different RF protocol or encoding/modulation scheme.
- **Direct spectrum overlap by identified sources** – RF energy sources that are in the same RF spectrum and can be identified by the RF receiver because they use the same protocol and encoding/modulation scheme as the RF receiver. For example, two 802.11b* DSSS Direct Sequence Spread Spectrum (DSSS) installations may be able to 'hear' each other whether they are on the same physical structure or not.

Extraneous RF energy can be addressed by:

- **Standards** – The IEEE 802.16-2004 standard implements OFDM sub-channelization and supports adaptive modulation, allowing data rates and link quality to be balanced dynamically, based on link quality and channel conditions.

  Often overlooked, but essential to eliminating unwanted RF interference, is the design approach taken in the 802.16-2004 MAC layer. The multipoint nature of the MAC layer allows hundreds of fixed sites to share a single base station within miles. The 802.16-2004 MAC layer dynamically assigns bandwidth to mobile devices using time-division multiple access (TDMA). In contrast, the 802.11 Media Access Control (MAC) layer uses carrier sensing and contention mechanisms to provide bandwidth control.
- **Proper network design** – Includes implementing a site survey, and ensuring 24/7 access to structures and base stations. Interference caused by most extraneous (far field effect) RF energy sources can be reduced and QoS improved by locating wireless network connectivity points, such as

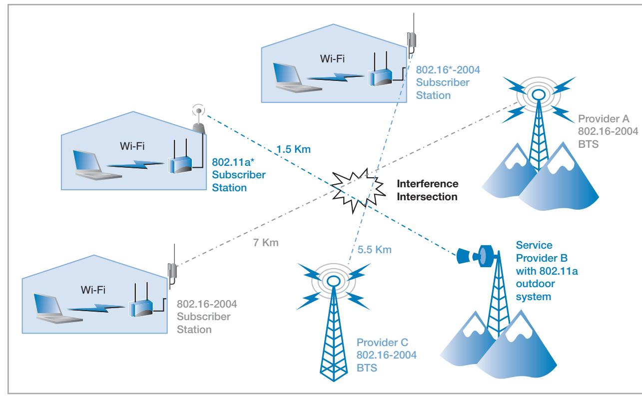
towers and access points, close to clients and by providing multiple connectivity choices so that a client can select the 'best' RF connection at a particular time. Low latency supports delay-sensitive applications such as video or voice over IP (VoIP) and prioritization for data traffic. Implementing Global Positioning Systems (GPSs) within base stations and using GPS-based synchronization can prevent problems at inter-sector and inter-base station levels by identifying the base station location and location of possible inter-base station interference as well as synchronizing RF transmit times.

- **Power amplifiers and antenna technologies** – Implementing sectoring and antenna polarization to help minimize the effects of interfering RF energy sources at a distance from the receiver (far field effects). Controlling antenna direction and power may help mitigate interference but may increase costs. OFDM channelization controls noise and helps manage the spectrum as shown in Figure 5.
- **Filtering** – Implementing band-pass filters to minimize the effects of RF energy sources that are outside the operating spectrum of the receiver or within a specific channel of the operating spectrum (both local and far field effects).
- **Shielding** – Implementing RF shielding within the receiver housing to ensure that localized RF energy sources are not 'bleeding' into the equipment in ways other than through the antenna or coax (local field effects).
- **Reuse** – Implementing a channel or frequency reuse pattern so that the receiver does not create its own extraneous RF energy source (local field effect).
- **Synchronization of signals with other providers** – Coordinating frequency usage and transmit times through provider-to-provider collaboration can reduce and limit many interference issues. For example, some wireless service providers in California are banding together to address interference issues. The group is called the Wireless Broadband Access Coordination Network (BANC).

Although, these best practice methods can improve the quality of RF communications in a WiMAX license-exempt network, they do not ensure trouble-free service. Service can only be guaranteed in the controlled environment provided by a licensed solution. However, specialized markets, such as rural areas, point-to-point deployments, and emerging markets, can benefit from license-exempt solutions and these deployment methods.

Coexisting with Other License-Exempt Wireless Networks

Figure 4. Contending with other wireless networks.



The popularity of Wi-Fi has led to the emergence of many Wi-Fi hotspots and WLANs. These large deployments have some operators concerned about the coexistence of WiMAX and Wi-Fi. A WiMAX license-exempt solution can operate in close proximity to a Wi-Fi network as long as channels are available and proper network design methods have been used. WiMAX enables providers to offer extended wired and Wi-Fi coverage in cities more economically and with wider coverage than with just Wi-Fi alone.

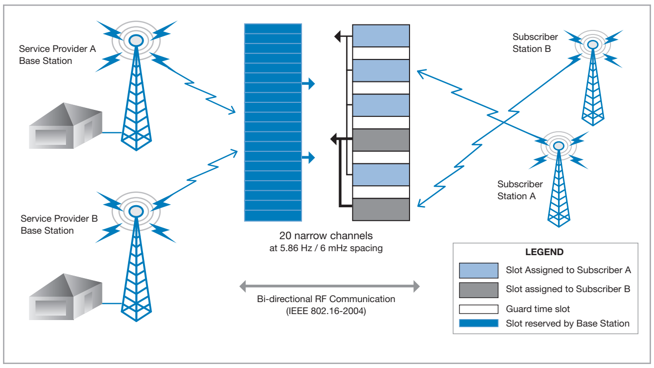
The majority of Wi-Fi networks deployed today are based on the 2.4 GHz IEEE 802.11bg* standard and do not operate in the same frequency range as license-exempt WiMAX solutions. However, some network operators have deployed solutions based on the 802.11a* standard and revisions in the 5 GHz spectrum, which can add noise to a WiMAX environment, as shown in Figure 4.

WiMAX networks will not recognize 2.4 GHz (802.11bg) transmissions because they don't operate in this band. However, Wi-Fi transmissions in the 5 GHz (802.11a) may result in congestion and add noise to a WiMAX network. Generally, the Wi-Fi Clear Channel Assessment (CCA) function does not recognize WiMAX transmissions and treats such transmissions as noise. Noise degradation of a signal usually occurs when stations are in close proximity (within meters of each other).

Improving License-Exempt WiMAX Deployments Using Antenna Techniques

Several examples of license-exempt WiMAX deployments are described below and illustrated in Figure 5.

Figure 5. Improving resiliency using channelization and smart antenna technology.



Antenna technology can by used to improve transmissions in two ways—through using diversity techniques and through using advanced antenna systems and switching techniques. These techniques can improve resiliency and signal-to-noise ratio but do not guarantee the transmission will not be affected by interference.

Diversity Techniques – Diversity techniques, such as multiple antennas, receivers, or transmitters, reduce multipath fading by providing alternate paths for the signal. The system selects the appropriate receiver or transmitter depending on the implemented technique. Appropriate space-time codes are applied to determine the best path. The availability of alternate paths enables improved network resiliency.

Advance Antenna Systems and Switching – This approach uses a beam forming and steering technique in which the angle, path and width of the beam is altered. By focusing the beam at a given point through power and RF coding, the quality of a signal can be improved.

Examples of the use of antenna technology to improve transmissions are described below:

- *Example 1*: WiMAX enables centralized transmission control allowing the base station to control and coordinate transmissions. This capability makes possible the use of several multiple-antenna techniques to increase the range and reliability of WiMAX systems. The IEEE 802.16-2004 standard supports optional multiple-antenna techniques such as Alamouti Space-Time Coding (STC), Adaptive Antenna Systems (AAS), smart antennas, and Multiple-Input Multiple-Output (MIMO) systems. The Alamouti STC transmission scheme transmits information on two base station antennas. By sending two consecutive transmissions in time, it transmits information in space and time, maximizing transmit diversity gain. Cyclic delay diversity is another transmit diversity scheme that can be used in a WiMAX system. Both schemes have the advantage that they can be implemented at the base station, where the higher costs of multiple antennas and associated RF chains can be more easily absorbed. This shifts costs away from the subscriber station, which enables faster market penetration.

  The advantages of using multiple-antenna technology over single-antenna technology are:

  - An Adaptive Antenna System (AAS) allows multiple overlapped signals to be transmitted simultaneously using Space Division Multiple Access (SDMA), which is a technique that exploits the directional properties of antennas. Adaptive modulation adapts the modulation to link conditions, providing the best spectral density for a given SNR. Multiple Antenna technologies, such as AAS, allow for maximal ratio combining to combine multiple receive paths to maximize SNR.
  - Using the Automatic Request (ARQ) protocol for retransmission can impact system performance by allowing the receiver to request a re-transmission when an error is detected.
  - Forward Error Correction (FEC) coding improves accuracy and reliability in the presence of RF interference by allowing errors to be corrected without requesting retransmission of the original information.

- Determining the amplitude and/or phase modulation attributes allows a provider to better immunize the network for delay in a scheduled packet trip. A database of statistics related to a license-exempt or licensed WiMAX network can help a provider better anticipate problems and address them through modulation mapping and planning.

- *Example 2*: WiMAX supports DFS in the 5 GHz band. DFS was originally designed to avoid interference with radar systems. Some vendors enable DFS to be used to change channels automatically or manually to address interference issues. DFS sets an interval (usually 1 ms) within which the base station coordinates a network transmission stop or quiet time during which it identifies noisy channels so that it can avoid using them.
- *Example 3*: Spectrum etiquettes have been established for DFS and TPC (required in the US and Europe). For DFS, the auto function is to check to see if a channel is in use and, if it is, find another channel to use. For the TPC, a transmission is to use only as much power as is needed.
- *Example 4*: Channelization of narrow bands enables greater resiliency across the network. With more narrow bands, interference can be more easily identified and addressed. Narrow band channelization reduces bandwidth for an individual subscriber but can provide greater overall network resiliency.

Conclusion

WiMAX technology represents an expanding opportunity for service providers, equipment manufacturers, and chipset suppliers operating in both licensed and license-exempt bands. Initially, WiMAX solutions will be based on the IEEE 802.16-2004 specification, allowing fixed access for point-to-point and point-to-multipoint use. A robust technology ecosystem, based on worldwide standards, is expected to evolve over time, ultimately yielding the dual benefits of interoperability and volume economics.

As with any new and evolving technology, numerous factors must be understood to ensure a successful deployment. This paper has focused on several specific issues related to license-exempt deployments, including RF interference and infrastructure placement.

RF interference results in a complex and ever changing environment. It should be respected and understood by service providers, but not feared. Solutions for dealing with RF interference include proper network design, use of advanced antenna technologies, point-to-point deployments, identification of appropriate markets for WiMAX technology, filtering, shielding, frequency reuse, and synchronization with other providers. These solutions will help address some RF-interference issues.

A robust network design is based on site surveys, statistics gathering, and coordination of RF use with neighboring providers to directly address interference issues. WiMAX license-exempt solutions based on robust network design are poised to become a dependable and resilient solution for specialized markets. Business class WiMAX services can and will soon be deployed in both licensed and license-exempt bands.

Acronyms

AAS: Adaptive Antenna systems
AES: Advanced Encryption Standard
ARPU: Average Revenue per User
BPSK: Binary Phase Shift Keying
BRS: Broadband Radio Service
CAPEX: Capital Expenditure
CLEC: Competitive Local Exchange Carrier
CPE: Customer Premise Equipment
CSMA/CA: Carrier Sense Multiple Access/ Collision Avoidance
DFS: Dynamic Frequency Select
DOCSIS: Data-Over-Cable Service Interface Specification
DSL: Digital Subscriber Line
DSSS: Direct Sequence Spread Spectrum
FCC: Federal Communications Commission
FBWA: Fixed Broadband Wireless Access
FLASH-OFDM: Fast Low-latency Access with Seamless Handoff OFDM
FDD: Frequency Division Duplexing
FDM: Frequency Division Multiplexing
FHSS: Frequency Hopping Spread Spectrum
FTTN: Fiber to the Node
FTTP: Fiber to the Premise
GPS: Global Positioning Systems
IEEE: Institute of Electrical and Electronics Engineers
ILEC: Incumbent Local Exchange Carrier
ISM: Industrial, Scientific, and Medical
ISP: Internet Service Provider
LOS: Line of Sight
MAC: Media Access Control
MIMO: Multiple-Input Multiple-Output
MSO: Multiple Service Operator
NLOS: Non Line of Sight
OEM: Original Equipment Manufacturer
OFDM: Orthogonal Frequency Division Multiplexing
OFDMA: Orthogonal Frequency Division Multiple Access
OPEX: Operative Expenditure
PCMCIA: Personal Computer Memory Card International Association
PHY: Physical Layer
PMP: Point to Multipoint
PTP: Point to point
POP: Point of Presence
QAM: Quadrature Amplitude Modulation
QoS: Quality of Service
QPSK: Quadrature Phase Shift Keying
SME: Small to Medium Enterprise
SOHO: Small Office, Home Office
TDD: Time Division Duplexing
VoIP: Voice over IP
Wi-Fi: Wireless Fidelity
WiMAX: Worldwide Interoperability for Microwave Access
WISP: Wireless ISPs
WLAN: Wireless Local Area Network
WMAN: Wireless Metropolitan Area Network
WWAN: Wireless Wide Area Network

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