Mobile WiMAX:

The 4G Revolution Has Begun.

Version 1.0

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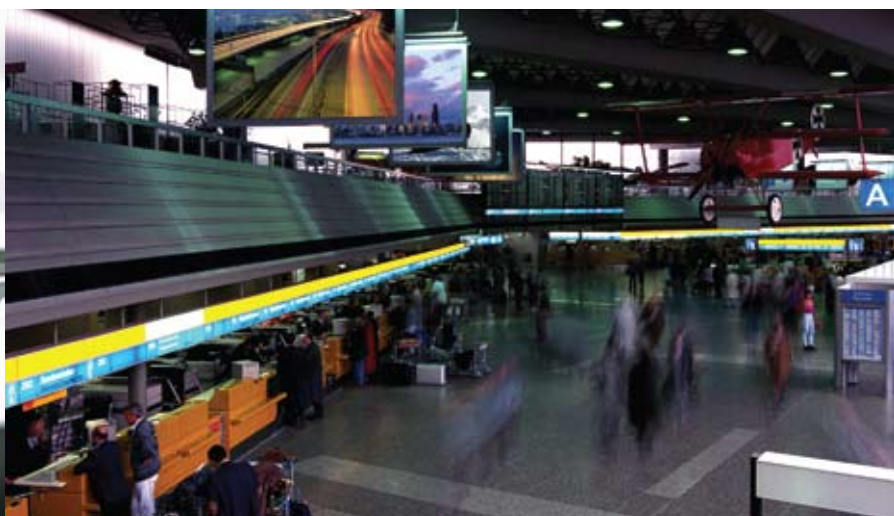
Business is increasingly becoming a mobile activity,

and as a result the wireless networks and services used to support that development are growing in importance. In both the business-to-business and business-to-consumer (B2B and B2C) environments, the availability of more reliable, higher-capacity wireless data networks is one of the keys to expanding the reach of business into the mobile environment. This transformation is occurring in the context of an overall enterprise shift toward all-IP communications. "IP," or Internet Protocol, describes both the format and the switching technology that drives the core of the Internet. Originally envisioned as a general-purpose data transport, IP has now expanded to support voice and video communications over an integrated IP backbone.

Recognizing these developments, the wireless industry is now aligning itself to take advantage of these trends. The moniker that is used to identify that transition is 4th Generation or 4G, and it is used to describe two primary technologies, WiMAX and Long Term Evolution (LTE). While there are some differences in the implementations, they share a number of key characteristics:

• **Higher Capacity:** WiMAX and LTE will use very similar state-of-the-art radio technologies to deliver several times the transmission capacity of existing 3G wireless services.

• **Reliability:** Using advanced signal encoding and smart antenna technologies, WiMAX and LTE will also deliver a major advance in network reliability, even in the most challenging radio environments, such as densely populated urban environments.

• **All-IP Communications:** Whereas in the past, wireless services were divided along voice and data lines, 4G technologies such as WiMAX and LTE are based on the concept of an all-IP network. This means there exists a single IP pipe that is capable of supporting voice, data and video communications.

For the end user, this transition will mean a new wireless platform that delivers a far wider range of applications with performance and reliability that mimic the desktop experience. Now, rather than settling for a wireless experience with performance that limits the range and utility of applications, wideband voice, high-quality video and lightning-fast downloads will be available to users regardless of whether they are in the office or on the go.

While both WiMAX and LTE promise these capabilities, only WiMAX is available today. With a comprehensive migration plan to evolve from our current 3G infrastructure, Sprint 4G powered by WiMAX is delivering the benefits of 4G to customers in selected markets years ahead of the first LTE rollouts. Because WiMAX networks are already being deployed, users can begin taking advantage of 4G today.

The Basic Technology of Wireless

As shown in Figure A below, the overall structure of a mobile network involves a number of elements, all of which contribute to the service that is provided.

• **Mobile Switching Center (MSC):** The MSC is the mobile central office; mobile operators typically maintain one or more per city. With Sprint 4G, that facility is called a WiMAX Service Center or WSC. The MSC complex includes other elements, including Authentication, Authorization and Accounting (AAA) servers; Access Service Node Gateways (ASN-GWs), Media Gateways and Media Gateway Controllers (MGWs/MGCs); Home Subscriber Servers (HSSs); and interfaces to Operations, Administration, Maintenance and Provisioning (OAM&P) systems. The MSCs or WSCs in turn are interconnected with a signaling network to support users who are roaming in other cities.

• **Cell Towers/Base Stations (BSs):** These are the visible towers that support the radio connection between the mobile

network and the users. The BS is comprised of antennas and radio transmission equipment. Different carrier frequencies are typically assigned to each BS, and in busy cells, the coverage area can be divided into three 120° sectors, allowing three different carrier channels to be used, effectively tripling the cell's capacity.

• **Backhaul Network:** The invisible part of the network is the web of wired and wireless communication links that connect each of the BSs to the MSC or WSC. A single 4G cell site will require tens of megabits of capacity. Providing higher capacity 4G services has required mobile operators to invest heavily in the upgrading of their backhaul facilities.

• **Mobile Devices:** The last part of the picture is the user's mobile device. Initially that was a simple voice device, but users are increasingly opting for smartphones. The move to 4G will allow a wider range of netbooks, laptops, personal digital assistants (PDAs) and even consumer electronics devices to connect over the network.

Figure A: Sprint 4G Network Structure
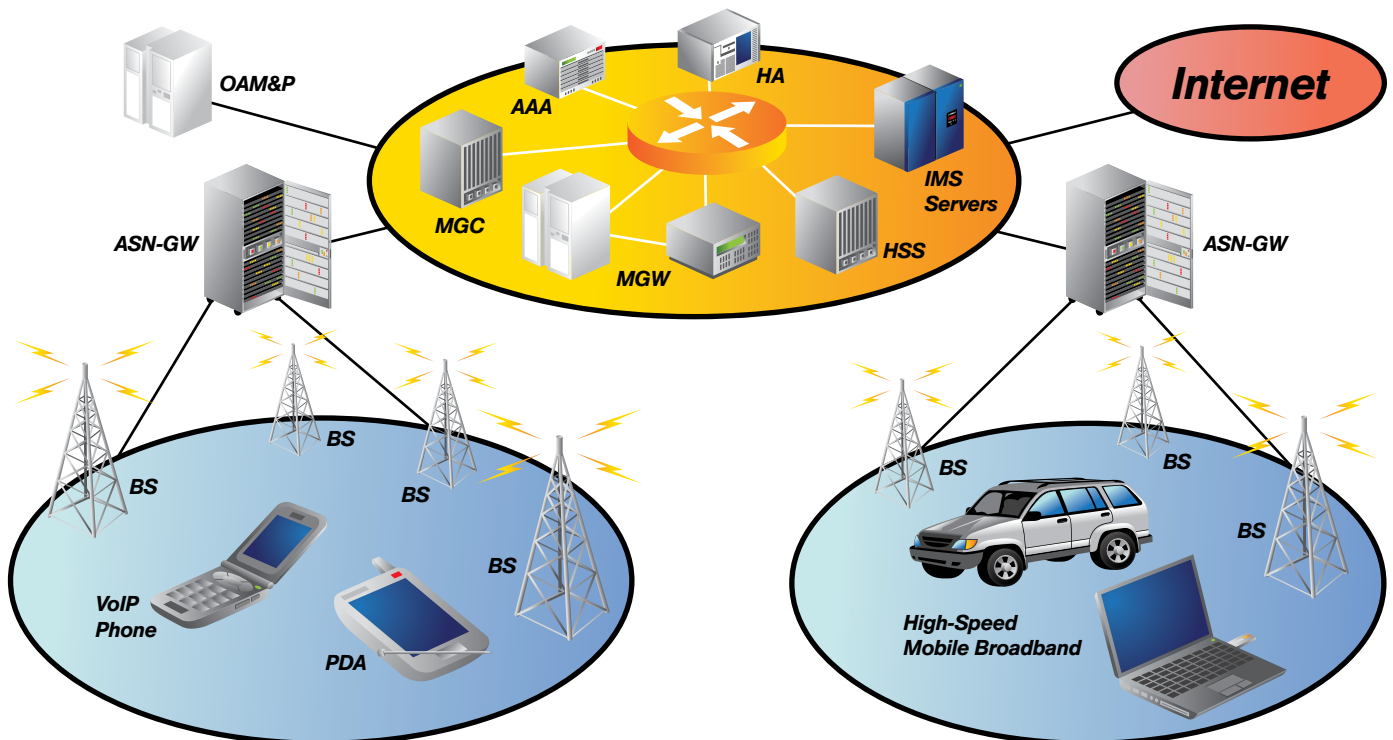
Determining Radio Network Capacities

The first major issue in a radio transmission network is determining the system's capacity. The primary limitations on a radio network's capacity are defined by the amount of radio spectrum available and the efficiency with which it can be used. *Spectrum* is the term used to describe the swath of radio frequencies the mobile operator is authorized to use in a given area; spectrum capacity is measured in *hertz* or *cycles per second*. The prefixes *kilo-*, *mega-* and *giga-* before *hertz* refer to thousands, millions and billions of cycles per second, respectively. Without going into the engineering details, the more spectrum a mobile operator owns, the more raw transmission capacity they possess.
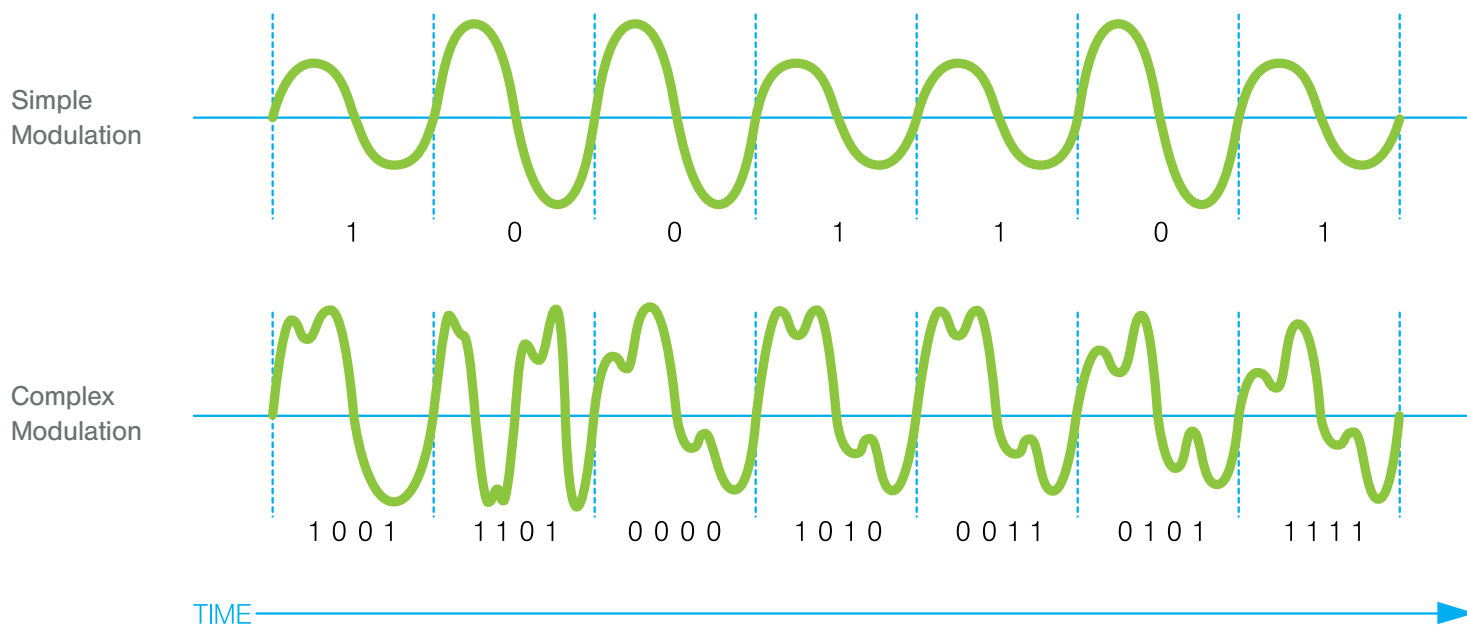
Data devices measure transmission capacity not in *hertz* but in *bits per second*. What determines the data transmission capacity of a radio network is 1) how much radio spectrum the mobile operator has, and 2) the *bandwidth efficiency* or the number of bits per second they can push across each cycle (i.e., bits per second per hertz). With each successive generation of wireless technology, engineers have worked to pack in more bits onto each cycle of radio spectrum.

4G Radio Technologies – MIMO and OFDM

Both WiMAX and LTE use the same two key technologies to increase the efficiency of their available radio spectrum: Multiple Input-Multiple Output (MIMO) antenna systems and Orthogonal Frequency Division Multiplexing (OFDM). This paper will describe each of these later, but as shown in Figure B below, the key factor is that each technology should offer roughly the same bandwidth efficiency, so the mobile operator with the most radio spectrum will be able to deliver the greatest transmission capacity.

The other challenge mobile operators face is the requirement to increase bandwidth efficiency without sacrificing reliability. Both WiMAX and LTE use adaptive modulation, where a higher efficiency transmission format is used for devices that are closer to the BTS, while using a lower efficiency (but more reliable) format is used for devices that are farther away or receiving a weaker signal (e.g., a user in an elevator or on the edge of a cell tower's coverage area). As shown in Figure C on page 9, a more complex transmission format can carry more information (i.e., more bits per second). However, even minor distortions in the transmission can cause the receiver to misinterpret that more complex signal, causing errors.

Figure B: Comparison of Modulation Techniques

Simple Modulation

1   0   0   1   1   0   1

Complex Modulation

1 0 0 1   1 1 0 1   0 0 0 0   1 0 1 0   0 0 1 1   0 1 0 1   1 1 1 1

TIME →

Note: The complex modulation can carry more information (i.e., bits per second) but it will also fail more rapidly in the presence of noise or interference.

To further improve reliability, the radio link can also incorporate Forward Error Correction (FEC) coding. The idea of FEC is to send redundant copies of the information, allowing the receiver to detect and correct a certain percentage of the errors that are encountered. Sending that redundant information reduces the transmission capacity of the channel, but increases the reliability; the more redundant information that is included, the more success the receiver will have in correcting errors. WiMAX, LTE and the earlier 3G wireless transmission systems all utilize a combination of adaptive modulation and varying degrees of FEC coding to improve reliability.

Channel Sharing, Latency and Quality of Service (QoS)

Another challenge in modern radio networks is sharing capacity. In early radio networks (i.e., 1G and 2G) where voice was the primary application, a user was assigned a dedicated channel for the duration of their call. Data applications are characterized by bursts of transmission (e.g., downloading a Web page) followed by long periods of inactivity (e.g., reading the Web page). To support this type of transmission efficiently, 3G and 4G wireless data networks use packet switching techniques to share one radio channel among a number of users. While sharing allows greater efficiency, it can also result in increased latency or delay in transporting a message as more users begin sending on the channel. That increased latency has little effect on data applications like email and texting. However, it can introduce problems for streaming applications such as voice and video. When latency increases, videos can freeze and audio transmissions can be interspersed with gaps, resulting in a poor user experience.

The solution to the difficulties introduced by packet switching is to recognize the requirements of the different traffic types and design the network to give preference to the more time-sensitive applications. The generic name for this capability is Quality of Service (QoS). The 4G networks have incorporated protocols that can prioritize time-sensitive voice and video packets, allowing voice and data traffic to share the same channels while still delivering adequate performance for each.

Security

Security is the last major challenge with wireless. The 1st Generation cellular services featured weak authentication and no over-the-air encryption. As radio transmissions are sent through free space, anyone with a radio receiver tuned to the correct frequency can eavesdrop on the transmission. Furthermore, unauthorized users can potentially jump on the network or hijack the credentials of legitimate users. Since the inception of 2nd Generation networks, however, mobile operators have greatly improved network and airlink security, and those problems have largely disappeared. With the move to 4G networks, mobile operators will be using some of the strongest enterprise security mechanisms available today with the ability to incorporate even stronger protections as time goes on.

Radio presents some unique challenges in terms of capacity, reliability, latency and security, but the wireless industry has continued to develop new technologies to address those challenges. Let's take a look at some of the milestones that have characterized that development.

Evolution of Wireless Data Services

The evolution of our public wireless networks is generally depicted in four distinct generations, each of which is characterized by a number of key technical innovations.

First Generation (1G):

In the early 1980s, the first generation networks introduced the concept of cells to increase the number of channels that could be supported. The radio technology was rather rudimentary by current standards and utilized an analog transmission standard called Advanced Mobile Phone Service (AMPS); those systems operated in the 824 to 890 MHz frequency band. Data options included cellular modems and a packet-based service called Cellular Digital Packet Data (CDPD) that delivered maximum data rates around 9600 bps.

Second and Third Generation (2G/3G)

The 2G networks appeared in the early 1990s with the opening of the 1.9 GHz Personal Communications Service (PCS) bands. This greatly increased the amount of radio spectrum mobile operators had to work with and spurred a number of successive improvements in network capabilities. The 2G networks made use of digital radio technologies like CDMA, TDMA and GSM, which supported a far larger number of calls in the same radio spectrum than 1G AMPS networks. The move to digital radio technology also allowed for data services like 1xRTT, GPRS and EDGE, which eventually lead to the introduction of even higher capacity 3G data services, including EVDO, EVDO Rev A,

W-CDMA and HSPA. The theoretical and typical upstream and downstream data rates delivered by the 2G and 3G cellular technologies are summarized in Table 1 on page 7.

IP Multimedia Subsystem (IMS)

One important bridge that came about with 3G was the development of IP Multimedia Subsystem (IMS). IMS describes an IP-based packet core that can interconnect between legacy circuits-based networks and Internet-type packet services. The transition to 4G will result in interconnecting 3G and 4G networks for seamless roaming, integration of wireline and convergence services, and a consistent desktop-like user experience regardless of the access or endpoint.

Fourth Generation (4G):

The 4G WiMAX networks are now being commercially deployed, and the LTE standards have recently been finalized. In the U.S., WiMAX is being deployed primarily in the 2.5 GHz BRS band, while LTE is targeted for the 700 MHz band. Besides operating in different frequency bands, they use different access protocols. Despite this, they do have major attributes in common:

• **Radio Technology:** Both standards utilize Multiple Input-Multiple Output (MIMO) antenna technologies and incorporate

Orthogonal Frequency Division Multiplexing (OFDM) signal modulation. WiMAX uses OFDM on both the uplink and the downlink; in LTE networks, the downlink uses OFDM and the uplink uses a Single Carrier Frequency Division Multiple Access (SCFDMA). They also make use of adaptive modulation and several levels of Forward Error Correction (FEC) coding.

• **Higher Capacity, Greater Reliability:** The result of these state-of-the-art radio technologies is far greater bandwidth efficiency (i.e., more bits per hertz), along with greater reliability. The 4G systems will provide several times the transmission rate of the 3G systems.

• **All-IP Core:** Where the earlier technologies had been geared primarily for the requirements of voice, 4G systems will integrate voice and data services over an all-IP architecture. This builds on the earlier implementation of the IP Multimedia Subsystem (IMS), and will be key in integrating all the various media types into a single pipe and integrated user experience.

Table 1: Comparison of 2G/3G Cellular Data Services

Family	Technology	Theoretical Maximum Rate (bps)		Typical Transmission Rates (bps)	
		Outbound	Inbound	Outbound	Inbound
CDMA	1xRTT	614 K	614 K	50-70 K	50-70 K
	EVDO Rev 0	2.458 M	153 K	300-500 K	30 K
	EVDO Rev A	3.072 M	1.8 M	600 K-1.4 M	500-800 K
	EVDO Rev B	14.475 M	5.4 M	N/A	N/A
GSM	GPRS	163 K	163 K	20-40 K	20-40 K
	EDGE	474 K	474 K	100-120 K	100-120 K
	W-CDMA	2.688 M	2.304 M	200-250 K	100 K
	HSDPA	14.4 M	2.3 M	800-900 K	260-280 K
	HSUPA	14.4 M	5.4 M	N/A	N/A

Source: Intel "Understanding WiMAX and 3G for Portable/Mobile Broadband Wireless Networks," Nov. 2004, and industry sources.

Wi-Fi and WiMAX

While describing the evolution of wireless networks, it is also important to consider another widely successful wireless technology, wireless LAN, or Wi-Fi. Wi-Fi and WiMAX share a common ancestry in that both are products of the Institute of Electrical and Electronics Engineers (IEEE) 802 committees. Originally focused on wired networks like Ethernet (i.e., IEEE 802.3), in the mid-1990s the IEEE 802 committees began expanding their scope to address wireless networks as well. The 802.11 committee was tasked with developing the standards for wireless LANs (WLANs), and the 802.16 committee set to work on standards for wireless metropolitan area networks (MANs) that led to the development of WiMAX.

The IEEE is a worldwide standards body that develops standards using a process governed by a rigorous set of rules to ensure due process, openness, consensus and balance. The result is an open standard based on industry-wide consensus that leads to a larger ecosystem of suppliers, a wider variety of products and, ultimately, to lower costs. So, while Wi-Fi and WiMAX address different areas of the wireless market, they share the same foundation in a set of worldwide standards.

Each of the key 802-series standards is supported by a vendor consortium that ensures multivendor interoperability and long-term technological stability. The wireless LAN manufacturers have banded together in the Wi-Fi Alliance, while the wireless MAN manufacturers formed the WiMAX Forum. These vendor organizations play a critical role in the adoption of a new technology. For each important development in the standards, the vendor consortium develops a series of tests to ensure that the capability is implemented consistently in each vendor's product. For WiMAX, those devices are tested and certified in independent WiMAX Forum Designated Certification Laboratories[1]. That certification is essentially an industry guarantee that the device will interoperate with any other certified device. The Wi-Fi Alliance has had tremendous success with their certification program, and the WiMAX Forum is now following in that same track.

So while Wi-Fi and WiMAX are often compared, they really address two different sets of requirements. Wi-Fi is used primarily in private local networks operating on readily available unlicensed frequency bands; Wi-Fi transmissions have a maximum transmission range of 100m. The use of unlicensed frequency bands means that Wi-Fi transmissions are subject to interference from other users. WiMAX is typically provided by mobile operators over licensed frequency bands, and transmissions have a range of several miles. Given their different design parameters, WiMAX will not replace Wi-Fi, but rather the two will work side-by-side, each targeting the applications for which it was developed. As they are both grounded in the same framework of open international standards, we can anticipate the same type of industry-wide acceptance for WiMAX that we have already seen for Wi-Fi.

WiMAX, The First 4G Technology

WiMAX is short for Worldwide Interoperability for Microwave Access. It describes a 4G metro-area wireless technology defined in the IEEE 802.16 standards and promoted by the WiMAX Forum. Using our extensive holdings of 2.5 GHz BRS spectrum, Sprint, along with our partner Clearwire Communications, is currently deploying the first nationwide 4G WiMAX network in the U.S. There are a number of factors that argue for WiMAX as the preferred 4G environment:

- **Timeframe:** While LTE vendors are hoping to initiate trials in the 2010/2011 timeframe, Sprint 4G is already available in a number of cities across the country, with plans to cover 120 million people by year-end 2010.

- **Real-World Experience:** A few small-scale LTE trials have been conducted primarily in the U.S., but there are already 502 WiMAX networks operating in 145 countries around the world.

- **Open Standards:** WiMAX is based on IEEE developed international standards. Just as we have seen with Wi-Fi, open standards can lead to a larger, more diverse ecosystem, and lower prices to consumers. Where LTE implementations may still incorporate variations based on the mobile operator's business objectives, the WiMAX community is committed to the concept of open standards and multivendor interoperability throughout.

- **Royalty-Free Technology:** To further ensure lower prices to consumers, the WiMAX Forum supports the Open Patent Alliance (OPA) model offering open, transparent, predictable and nondiscriminatory access to core technologies with the objective of delivering a fair royalty rate to all.

- **WiMAX Forum:** The development of those WiMAX devices will be supported by the WiMAX Forum, whose stringent certification process will ensure support for manufacturers and full interoperability for users.

- **Frequency Bands:** Sprint 4G is deploying WiMAX in 2.5 GHz bands that we have been using since the late 1990s, while LTE will be deployed in the newly released 700 MHz bands that have yet to be tested for data transport.

- **Global Reach:** Mobile operator plans for deploying LTE vary widely, but WiMAX networks are now in commercial use around the world and the WiMAX Forum has already begun work on intercarrier roaming plans.

[1] There are currently WiMAX Forum Designated Certification Laboratories in the U.S., Spain, Korea, China and Taiwan.

WiMAX Standards

WiMAX standards define a wide range of potential implementation options a mobile operator might choose. While that can lead to some short-term confusion, it allows mobile operators great flexibility with regard to how they deploy a WiMAX network and the services they will be able to offer.

The first consideration is the two different WiMAX standards, defined as follows:

• **Fixed Location WiMAX:** The original focus of WiMAX development was for a fixed location radio technology that could be used in place of cable modem or DSL service for Internet access and possibly other applications. That fixed location WiMAX is described in the IEEE 802.16-2004 specifications.

• **Mobile WiMAX:** The specifications also describe mobile WiMAX where a user could move through the coverage area and their connection would be handed off from base station to base station; that mobile version is described in IEEE 802.16-2005. Sprint 4G is based on the mobile version of WiMAX, which can provide a fixed-location wireless alternative to DSL and cable modem services, while also supporting a higher-capacity alternative to mobile cellular 2.5G/3G services.

From a technical standpoint, the WiMAX standards address Layers 1 and 2 of the OSI Reference Model. Layer 1 deals with the radio transmission specifications and Layer 2 defines the access protocol, security and session establishment functions. The overall design assumes an all-IP core for the network. There are several important options offered at each layer:

WiMAX Layer 1 Features:

• **Frequency Band:** The WiMAX standards covers transmissions anywhere in the frequency band between 2 GHz and 66 GHz. Currently, there are WiMAX profiles for transmission in the 2.3 GHz, 2.5 GHz and 3.5 GHz bands. There has also been a proposal to develop a WiMAX profile for the newly released 700 MHz band.

• **Channel Bandwidth:** Where earlier radio standards had specified a single channel bandwidth, WiMAX is defined for channel bandwidths of 1.25, 2.5, 5, 10 and 20 MHz, providing mobile operators tremendous flexibility and deployment options.

• **Signal Modulation:** The primary signal modulation technique for WiMAX is Orthogonal Frequency Division Multiplexing (OFDM), which has proved to be both more bandwidth-efficient and more reliable than earlier techniques (see Figure C). In an OFDM system, the channel bandwidth is divided into a number of narrower sub-channels, and the bit stream is divided and sent in parallel over all of them. Specifically, WiMAX uses Scalable OFDM (SOFDM), where the number of sub-channels varies from 128 in a 1.25 MHz channel to 2048 in a 20 MHz channel. The mobile WiMAX standard also uses an enhanced technique on the inbound channel called Orthogonal Frequency Division Multiple Access (OFDMA) where different groups of sub-channels can be assigned to different users allowing multiple users to transmit inbound simultaneously.

Figure C: Available Radio Spectrum

Available Radio Spectrum

BS

f

Sub-channel

Multiple Users

Mobile Subscribers
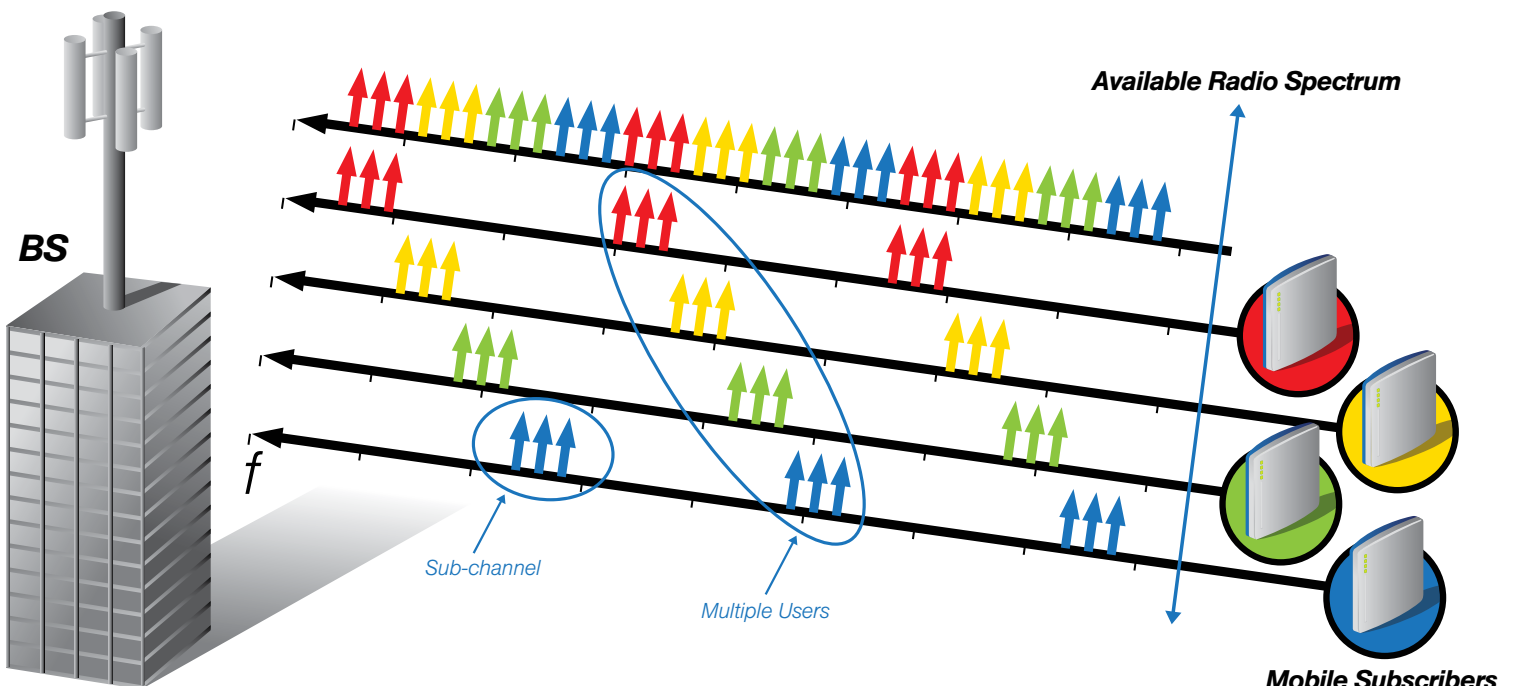
- **Multiple Input-Multiple Output (MIMO) Antenna System:** The other major element in the WiMAX radio link is an optional MIMO antenna system. In a MIMO system, multiple transmitters generate signals that are sent from different antennae spaced some distance apart; that basic technique is called *spatial diversity*. The key element is that all of the transmit signals are sent at the same frequency. Normally, if you send multiple signals in the same frequency channel, they will interfere with one another and the information will be lost. With the spatial diversity feature of a MIMO system, the different signals can be distinguished at the receiver by the unique configuration of multipath images each one exhibits (Note: *Multipath* refers to echoes of the original signal created by its reflecting or refracting off physical obstructions in the environment). Because of that ability to identify each transmit signal by the configuration of multipath images, multiple transmissions can share the same radio frequency.

  MIMO is used two different ways in WiMAX. First, the spatially diverse channels can be used to carry two copies of the same information to increase reliability; that technique is called Space-Time Coding or MIMO Matrix A. The more interesting capability is where the bit stream is divided into a number of substreams or *transmit chains*; the result is that with a 2-chain MIMO system, you can send twice the amount of information in the same amount of radio spectrum. That second option is called *spatial multiplexing* or MIMO Matrix B. In short, a MIMO system has the ability to make one radio channel perform like multiple independent channels, either increasing the reliability or multiplying the carrying capacity. Initial WiMAX deployments will use 2 transmitters and 2 receivers (i.e., a 2x2 configuration), though the standards define configurations up to 4x4.

- **Frequency Division Duplex versus Time Division Duplex (FDD/TDD):** This last Layer 1 option deals with how the radio frequency is divided for inbound and outbound transmission. FDD systems assign one set of frequencies for inbound and a separate set of frequencies for outbound transmissions; traditional 1/2/3G cellular networks use this technique. In TDD systems, inbound and outbound transmissions are sent alternately on the same channel. Generally, this is more efficient if there is more traffic flowing in one direction than the other as is typical in Web browsing. The WiMAX standards allow the operator to use either FDD or TDD.

The maximum data rates for Scalable OFDMA using channels of different bandwidths and coding schemes are summarized in Table 2.

Table 2: Scalable OFDMA Data Rates per Channel (Mbps)

Channel Bandwidth	Modulation	QPSK	QPSK	16 QAM	16 QAM	64 QAM	64 QAM
	FEC Coding	1/2	3/4	1/2	3/4	2/3	3/4
1.75 MHz		1.04	2.18	2.91	4.36	5.94	6.55
3.5 MHz		2.08	4.37	5.82	8.73	11.88	13.09
5 MHz		4.16	6.28	8.32	12.48	16.63	18.7
7 MHz		4.15	8.73	11.64	17.45	23.75	26.18
10 MHz		8.31	12.47	16.63	24.94	33.25	37.4
20 MHz		16.62	24.94	33.25	49.87	66.49	74.81

Source: "Wireless Broadband Spectrum Recommendation," A. N. Muragappan, June 2006

WiMAX Layer 2 Features:

- **Security:** The WiMAX standards specify that over-the-air transmissions should be encrypted, and that encryption can use either the 168-bit Digital Encryption Standard (3-DES) or the newer Advanced Encryption Standard (AES). Sprint 4G will employ AES and an authentication system based on X.509 certificates. This paper will look at the security capabilities of the Sprint 4G network in a moment.

- **Quality of Service (QoS):** In the WiMAX access protocol, outbound transmissions are broadcast to all stations in a cell or sector in a format that includes a device and a connection address; each station picks off and decrypts the frames addressed to it (Note: Each connection will use a unique encryption key). Inbound transmissions use a Request/Grant

access mechanism in which a station wishing to access the inbound channel sends a request to the base station, which in turn issues a grant allowing the user exclusive use of some portion of the inbound transmission capacity. As the base station controls all inbound transmissions, it can eliminate inbound collisions and, most importantly, it can implement QoS capabilities, where more time-sensitive inbound transmissions (e.g., voice and video) are given precedence over others.

Each WiMAX connection is specified to support one of five available QoS categories:

· *Unsolicited Grant Service (UGS):* Short, consistent delay service for real-time Voice over IP (VoIP) services, where a station is allocated dedicated inbound transmission capacity.

· *Real-Time Polling Service (rtPS):* Another short, consistent delay service for streaming audio and video where the base station polls each user on a scheduled basis.

· *Extended Real-Time Polling Service (ertPS):* Short, consistent delay service for VoIP applications with voice activity detection.

· *Non-Real-Time Polling Service (nrtPS):* Prioritized variable-delay data service with a minimum reserved rate for File Transfer Protocol (FTP) traffic.

· *Best Effort (BE):* An IP-like best effort data service for Web surfing and general purpose data transfers.

The QoS categories, their characteristics and targeted applications are summarized in Table 3. With the range of implementation options available, WiMAX can describe networks with widely different sets of capabilities. Let's take a look at how WiMAX will be deployed in Sprint 4G in the next section.

Table 3: Comparison of WiMAX QoS Service Capabilities

QoS Category	Applications	QoS Specifications
UGS *Unsolicited Grant Service*	*VoIP*	• *Maximum Sustained Rate* • *Latency Tolerance* • *Jitter Tolerance* • *Grant Interval*
rtPS *Real-Time Polling Service*	*Streaming Audio or Video*	• *Minimum Reserved Rate* • *Maximum Sustained Rate* • *Latency Tolerance* • *Traffic Priority*
ertPS *Extended Real-Time Polling Service*	*VoIP with Voice Activity Detection/ Silence Suppression*	• *Minimum Reserved Rate* • *Maximum Sustained Rate* • *Latency Tolerance* • *Jitter Tolerance* • *Traffic Priority*
nrtPS *Non-Real-Time Polling Service*	*File Transfer Protocol (FTP)*	• *Minimum Reserved Rate* • *Maximum Sustained Rate* • *Traffic Priority*
BE *Best-Effort Service*	*Data Transfer, Web Browsing*	• *Maximum Sustained Rate* • *Traffic Priority*

Source: "IP Design for Mobile Networks," Mark Grayson, Kevin Shatzkamer, Scott Wainner

Sprint 4G — Powered by WiMAX

Sprint 4G is the first nationwide mobile WiMAX network in the U.S. and it is being deployed by Sprint and our business partner Clearwire Communications. In 2008, the two companies combined their 2.5 GHz Broadband Radio Service (BRS) frequency holdings under Clearwire, which is now 51% owned by Sprint. Additional investors include Google, Comcast, Time Warner Cable and Bright House Networks. Plans call for Sprint 4G services to be available to 120 million people in the U.S. by the end of 2010.

Network Configuration

As shown in Figure A on page 3, the overall layout of a WiMAX network will be similar to a traditional cellular network. In each operating city there will be a central office facility called a WiMAX Service Center (WSC), a backhaul network and a number of base stations. The WSCs will be monitored by WiMAX Regional Centers (WRCs) in Atlanta and Seattle, and a WiMAX National Center (WNC) in Las Vegas.

Given that it operates at a higher frequency than the Sprint 1.9 GHz CDMA network, a WiMAX network will require roughly 20% more cells to cover the same area. Sprint has been operating 2.5 GHz networks since the late 1990s and has developed considerable expertise in working with this frequency band. Given the amount of spectrum available, the base station coverage area can typically be divided into three 120° sectors, each of which will use a different carrier frequency, essentially tripling the capacity of a cell. As the traffic grows, additional channels can be added to a cell, and busy cells can be further divided into groups of smaller cells.

LTE proponents have made much of the capabilities of the

700 MHz spectrum they will use for their initial deployments in parts of the United States, in particular noting that those lower frequencies have better building penetration characteristics and hence will provide better indoor coverage. In reality, the difference is in the order of 5 to 7 dB, and the longer transmission range of 700 MHz signals will make it more difficult to control *co-channel interference*, the interference between the base stations using the same frequency. As WiMAX and LTE use very similar radio technologies, the bandwidth efficiency should be roughly equal and, in the end (see Figure C on page 9), having more spectrum available is a far greater advantage than the frequency band it occupies.

Initial LTE services are planned for the 700 MHz spectrum the FCC auctioned in 2008. In each major market, the 700 MHz A- and B-Blocks provide a total of 24 MHz and the C-Block (Open Device Block) has a total of 22 MHz. **Sprint/Clearwire have an average of 120 MHz of 2.5 GHz BRS spectrum in most major markets.**

For backhaul (see Figure D), the network will use a combination of high-capacity microwave radio and fiber optic links; the microwave backhaul will not utilize any of the 2.5 GHz spectrum that is used for customer access. Given the difficulty of extending fiber to every base station, the first leg from the base station will typically be a microwave link to an aggregation point that connects onto a fiber optic ring. Both the microwave and fiber links are wholly owned and configured in redundant rings for greater reliability. That backhaul network can deliver up to 100 Mbps of capacity to each cell site.

Figure D: WiMAX Service Center
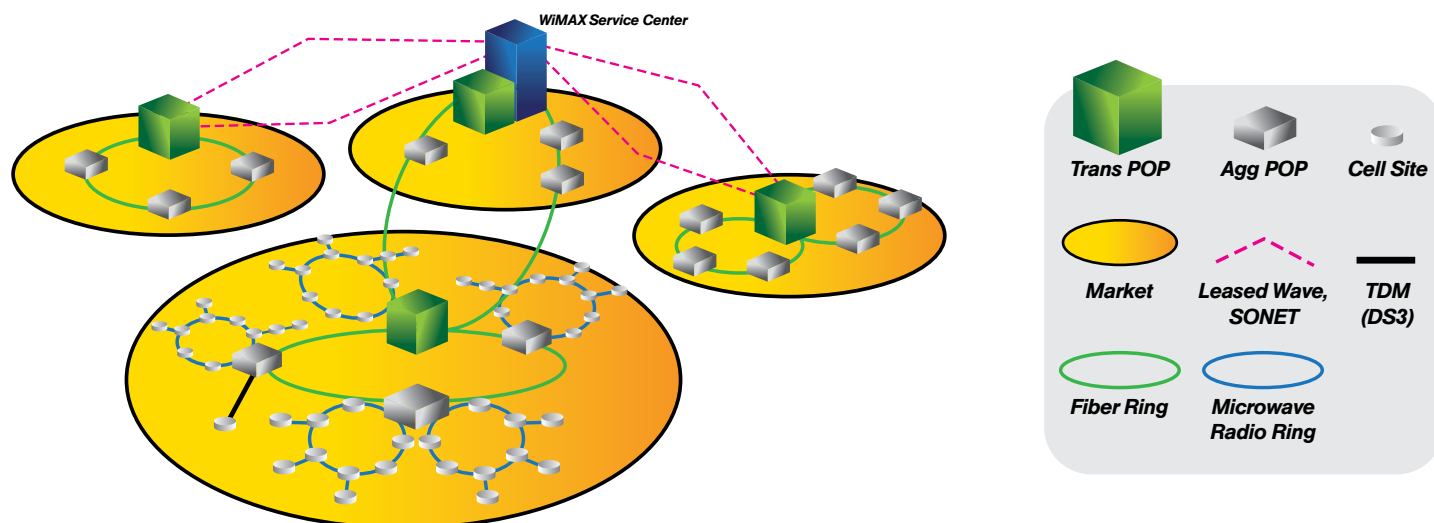
Radio Link Interface

The subscriber access for Sprint 4G will use a 10 MHz 2x2 MIMO configuration operating TDD; the plan is to begin upgrading to 4x4 MIMO as radio equipment with that capability is introduced. The peak and expected average data rates are summarized in Table 4. LTE proponents have published some performance "expectations;" however, those are typically "theoretical maximums." Sprint 4G performance is based on actual commercial deployments. It is important to note that those capacities are for the initial 10 MHz TDD deployment using 2x2 MIMO. As enhanced versions of the WiMAX radio equipment become available, those technologies will be introduced into the network, further increasing the capacity. In any event, these rates are several times what is found with existing 3G services.

Table 4: Sprint 4G Performance (Initial Deployment on a 10 MHz TDD Channel)

	Downlink	*Uplink*
Peak Data Rate	*12 Mbps*	*5 Mbps*
5 MHz	*3 to 5 Mbps*	*.5 to 1.5 Mbps*

Latency and QoS Capabilities

While the WiMAX standards specify a number of QoS categories, the Sprint 4G service will support Best Effort service exclusively at the outset. While identified as "Best Effort," network testing indicates that the expected latency will be in the order of 80 to 100 milliseconds one-way, or roughly half of what we see in current 3G offerings. As time goes on and the equipment matures, plans call for the introduction of Unsolicited Grant Service (UGS) and Real-Time Polling Service (rtPS) as well, which would allow for VoIP and streaming audio and video applications.

Given the initial coverage footprint, Sprint 4G is being introduced primarily as a high-capacity data service and will continue to depend on the CDMA network to support traditional mobile voice services. However, with a one-way latency of 80 to 100 milliseconds, the network performance should fall within the capacity and delay requirements of most VoIP applications. So while Sprint will not be offering WiMAX voice handsets at the outset, laptop VoIP softphones should operate effectively over the Sprint 4G network. LTE providers are still determining how to best accommodate legacy 3G users in a 4G deployment.

Security Features

Sprint 4G is designed from the outset with state-of-the-art security capabilities consistent with the requirements of the Personal Card Industry (PCI), Health Insurance Portability and Accountability Act (HIPAA) and other industry security mandates. All WiMAX devices and base stations will have X.509 certificates allowing for mutual authentication based on IEEE 802.1x Extensible Authentication Protocol (EAP)-Transport Layer Security (TLS). Once authenticated, over-the-air transmission will utilize encryption based on the Advanced Encryption Standard (AES) using cipher block chaining (CBC) mode and a 128-bit key.

While EAP-TLS and AES encryption will protect the over-the-air transmission, many customer applications call for end-to-end security. There are several options for how that secure connection could be extended to the customer's data center. First, a customer can implement secure tunnel communications from their firewall, through the Internet and over the Sprint 4G connection using SSL, IPsec, PPTP or L2TP. The Sprint 4G service can also interconnect with Sprint Data Link[SM] service that extends a secure VPN tunnel connection from the WiMAX Service Center over an MPLS VPN, IP VPN (IPsec), Frame Relay or traditional dedicated line connection all the way to the customer's data center. Further, the service also supports static IP addressing for firewall traversal and other specialized requirements.

WiMAX Devices and 3G/4G Integration

To access Sprint 4G, users will require a WiMAX radio modem. While Sprint 4G is being rolled out across the country, some provision must be made for roaming users. On Sprint dual-mode operation devices, WiMAX is the default interface, so if the user is in a WiMAX coverage area, their device will automatically select the WiMAX network. If the user roams into an area where there is no Sprint 4G signal available, the device will jump onto the Sprint EVDO Rev A network. The result is that roaming users can get uninterrupted service on our fastest network available in their area.

As WiMAX modems are built to open standards, they can be provided by a number of different suppliers and in a number of

different form factors.

• **Stand-alone WiMAX Modems:** For stationary implementations, a stand-alone WiMAX modem can be used that connects to the user's device with either an Ethernet or USB interface.

• **USB Dongle:** For laptop users, the initial implementation will likely be a modem built on a USB dongle.

• **Internal Interfaces:** Intel has now combined WiMAX and Wi-Fi capabilities on their Echo Peak chip set that is available in dozens of PC models. With their ongoing commitment to WiMAX, Intel has indicated their intention to incorporate multiband WiMAX (2.3 GHz, 2.5 GHz, and 3.5 GHz) along with Wi-Fi on their next generation Kilmer Peak chip set, and to eventually integrate WiMAX with their CPUs. These chip sets could be used in a variety of integrated WiMAX interfaces for laptops, netbooks, smartphones, router cards and even consumer electronics devices.

• **Wi-Fi/WiMAX Routers:** Sprint is also working with Cradlepoint and others to deliver Wi-Fi routers with a WiMAX backhaul connection. With a Wi-Fi/WiMAX router a number of users with Wi-Fi equipped laptops, smartphones or other devices can share one high-speed WiMAX network connection.

Sprint 4G Applications

While the WiMAX technology is impressive, the real impact is in what WiMAX will allow users to do and how it will perform. The basic idea of Sprint 4G is to extend the desktop experience to mobile devices and open the door to a whole new range of capabilities. While Sprint 4G can improve both consumer and enterprise applications, we will focus on the latter.

Corporate Networking

In a corporate network environment, Sprint 4G can play a role both in user access and data center connectivity. The most typical application at the outset would be wireless laptop access delivering performance equivalent to a wired DSL or cable modem connection. That means the user could access high-capacity data services along with VoIP softphone and real-time video wherever they are located. As Sprint 4G uses mobile WiMAX technology, users could access those services either while stationary or while traveling. Rather than simply having email and basic applications access, with Sprint 4G the user could do large file uploads and downloads, participate in audio or video conferences, and make use of all of the functionality being provided by Unified Communications (UC) solutions. Sprint 4G could also provide secure, high-capacity access from home without depending on the user's home Internet connection.

With a Wi-Fi/WiMAX router that access could also be shared by a number of users. WiMAX could provide a highly secure, portable office capability to use at meetings, conferences or temporary offices. With the ability to use WiMAX at customer locations, sales presentations could include video link-ups with technical experts or company executives without the hassle of connecting to the customer's network. With a Wi-Fi/WiMAX router, users could set up a temporary office or disaster recovery site instantly with a "network-in-a-box."

At the data center, WiMAX can serve as a primary or back-up connection. As a primary connection, WiMAX would allow users to install or add capacity instantly without waiting weeks for a wireline carrier to turn up a new circuit. As a back-up connection, WiMAX will continue to operate even if all cable links to the central office have been damaged or cut. While many associate WiMAX solely with user access, with static IP addressing capability for firewall traversal, it can also play a role in providing reliable, high-capacity network access at the data center.

Vertical Applications

Along with generic networking capability, Sprint 4G can also add new capabilities to a variety of vertical markets.

• **Medical and Medical Telemetry:** Wireless is finding countless applications in healthcare—from bedside data entry to x-ray/CAT scan viewing and medical device telemetry. WiMAX can support these applications more reliably than Wi-Fi and provide coverage both inside and outside the facility. Further, medical telemetry can be used both when the patient is in the hospital and after he/she returns home. Hospitals can clear beds sooner, and clinicians can still keep a close watch on their patients' progress.

• **Municipal Government:** Local government agencies have been implementing Wi-Fi mesh networks for a variety of applications ranging from traffic and security cameras to parking meter systems, gunfire detection and first-responder communications. The problem is that the limited range of a Wi-Fi transmission requires hundreds of access points to be deployed and maintained, and the failure of a few of them could wipe out communications to an entire section of the city. A single WiMAX base station can provide coverage equivalent to dozens of Wi-Fi mesh access points, and because it operates in the licensed BRS band, it will not interfere with (or be disrupted by) home Wi-Fi networks. Finally, the redundant hybrid microwave-fiber backhaul network can ensure reliable implementation.

• **Security Monitoring:** The range and capacity of Sprint 4G along with its support for Static IP addressing will allow it to support video cameras and other remote devices without the cost and complexity of installing cable connections.

• **Customized Applications:** With WiMAX chip sets, it's now possible to embed a secure, reliable, high-capacity wireless connection in any number of different devices from handsets to laptops, mobile computers, bar code scanners and any number of other devices for machine-to-machine (M2M) applications. WiMAX provides a transmission capacity that borders on Wi-Fi without the range and reliability issues. Whereas Wi-Fi can provide high-speed wireless networking over a few hundred feet, WiMAX can extend that capability to an entire city.

Conclusion
The move to 4G represents a major step forward in wireless communications. With state-of-the art radio technology, Sprint 4G moves wireless performance to a new level while offering speed, reliability and security on par with wired network connections. Extending this type of network service to mobile users is equivalent to moving from dial-up to broadband Internet access. As Sprint 4G is built on an all-IP core network, it brings the mobile network into step with the overall directions in enterprise networking. Most importantly, WiMAX uses IEEE-developed open standards, allowing the entire industry to design, build and integrate WiMAX-compatible products and services.

For enterprise users, Sprint 4G powered by WiMAX means that you don't have to wait to take advantage of 4G.

The revolution has begun.

Glossary of Acronyms

1xRTT 1-Carrier Radio Transmission Technique

1G/2G/3G/4G 1st, 2nd, 3rd, 4th Generation

AAA Authentication, Authorization, and Accounting servers

AES Advanced Encryption Standard

AMPS Advanced Mobile Phone Service

ASN-GW Access Service Node Gateway

ARQ Automatic Retransmission reQuest

B2B Business-to-Business

B2C Business-to-Consumer

BE Best Effort

BPSK Binary Phase Shift Keying

BRS Broadband Radio Service

BS Base Station

CCK Complementary Coded Keying

CDMA Code Division Multiple Access

DES Digital Encryption Standard

DSL Digital Subscriber Line

DSSS Direct Sequence Spread Spectrum

EDGE Enhanced Data Rates for GSM Evolution

ertPS Extended Real Time Polling Service

EVDO Enhanced Version-Data Optimized/Data Only

FCC Federal Communications Commission

FDD Frequency Division Duplex

FEC Forward Error Correction

FTP File Transfer Protocol

GPRS Generalized Packet Radio Service

GSM Global System for Mobile Communications

HSDPA High-Speed Downlink Packet Access

HSPA High-Speed Packet Access

HSS Home Subscriber Server

HSUPA High-Speed Uplink Packet Access

Hz Hertz (Prefixes: Kilo = Thousands, Mega = Millions, Giga = Billions)

IEEE Institute of Electrical and Electronics Engineers

IP Internet Protocol

IPsec IP Security

L2TP Layer 2 Tunneling Protocol

LTE Long Term Evolution

M2M Machine-to-Machine

MAN Metropolitan Area Network

MIMO Multiple Input-Multiple Output

MGW/MGC Media Gateway/Media Gateway Controller

MPLS Multi Protocol Label Switching

MSC Mobile Switching Center

nrtPS Non-Real Time Polling Service

OAM&P Operations, Administration, Maintenance and Provisioning

OFDM Orthogonal Frequency Division Multiplexing

OFDMA Orthogonal Frequency Division Multiple Access

PCS Personal Communications Service

PDA Personal Digital Assistant

PPTP Point-to-Point Tunneling Protocol

x-QAM x-level Quadrature Amplitude Modulation

QoS Quality of Service

QPSK Quadrature Phase Shift Keying

rtPS Real Time Polling Service

SCFDMA Single Carrier Frequency Division Multiple Access

SOFDMA Scalable Orthogonal Frequency Division Multiple Access

SSL Secure Socket Layer

TCP/IP Transmission Control Protocol/Internet Protocol

TDD Time Division Duplex

TDMA Time Division Multiple Access

UGS Unsolicited Grant Service

UMTS Universal Mobile Telecommunications System

USB Universal Serial Bus

VoIP Voice over IP

VPN Virtual Private Network

WCDMA Wideband CDMA

Wi-Fi Trademark for products built to the IEEE 802.11 Standard and certified by the Wi-Fi Alliance

WiMAX Worldwide Interoperability for Microwave Access

WLAN Wireless LAN

WNC WiMAX National Center

WRC WiMAX Regional Center

WSC WiMAX Service Center

Sprint

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