WHITE PAPER

# LTE: The Future of Mobile Broadband Technology

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## CONTENT

# 1. Introduction

This paper provides an overview of Long Term Evolution (LTE) and Worldwide Interoperability for Microwave Access (WiMAX)—the leading technologies for next-generation mobile broadband. The information presented here will help readers understand how the two technologies differ, why Verizon Wireless chose LTE, and what advantages LTE offers customers. The following executive summary gives a quick overview of the paper's contents and its subject matter. The remaining sections go into greater technical detail about LTE and WiMAX wireless technologies.

## 1.1 Audience

This paper has been developed for independent customers, enterprise customers, IT administrators, decision makers, and other personnel. It is assumed that the reader has an understanding of earlier generations of wireless technology, as well as an understanding of computer and network concepts.

# 2. Executive Summary

Driving the evolution of wireless broadband technology is customers' increasing expectations for speed, bandwidth, and global access. Customers want more information, such as business and consumer applications, and entertainment available through their mobile devices, but with greater speeds. For wireless carriers to achieve greater speeds and pervasive connectedness, their networks need to start behaving more like landline IP-based networks. This line of thinking represents a fundamental shift in perspective—from mobile services to broadband connections—for customers and service providers alike. Enter the fourth-generation (4G) wireless network. Unlike earlier wireless standards, 4G technology is based on TCP/IP, the core protocol of the Internet. TCP/IP enables wireless networks to deliver higher-level services, such as video and multimedia, while supporting the devices and applications of the future.

Verizon Wireless chose LTE over WiMAX as the technological foundation for its 4G wireless broadband network. The company believes that LTE offers a number of significant technological and business advantages over WiMAX that make it a superior networking standard. Verizon Wireless customers want to be truly untethered with advanced communication devices that provide a similar immersive experience as found in today's wired networks—whether it's downloading or uploading large files, video, gaming, downloading music, or social networking. They want to be able to communicate in new and innovative ways whenever and wherever they choose around the globe. For these reasons, Verizon Wireless believes LTE is the best technology with the global scale needed to deliver such experiences.

# 3. The Benefits of LTE

- Provides a global ecosystem with inherent mobility
- Offers easier access and use with greater security and privacy
- Dramatically improves speed and latency
- Delivers enhanced real-time video and multimedia for a better overall experience
- Enables high-performance mobile computing
- Supports real-time applications due to its low latency
- Creates a platform upon which to build and deploy the products and services of today and those of tomorrow
- Reduces cost per bit through improved spectral efficiency

Within the Verizon Wireless network, LTE will operate in the 700 MHz spectrum, giving it vast potential for greater broadband speeds and access.

## 3.1 Verizon Wireless and LTE Mobile Broadband Technology

Wireless carriers are keenly interested in choosing the best technology for their customers—for both today and tomorrow. For Verizon Wireless, selecting the right technology is imperative. As a leader in the wireless industry, Verizon Wireless is committed to the potential technology advances offered by LTE. Verizon Wireless is currently conducting laboratory and field tests using LTE technology and plans to launch its 4G mobile network in 2010. This deployment will help the company realize its goal of delivering improved wireless Internet connectivity and mobility to its customers. For the mobile user, connectivity means an untethered experience and true mobility. Users can work and communicate almost whenever and wherever they want. LTE's improved speeds will allow wireless carriers to offer a number of business-specific applications and services, such as video conferencing, direct connectivity, and mobile applications that bring the desktop experience to mobile devices.

# 4. Wireless Technology Overview

Wireless technologies enable one or more devices to communicate without an actual wired connection. Radio frequency is used to transmit the data. Such technologies are rapidly evolving to meet a variety of communications needs, from simple to complex.

Wireless communications needs can all be classified in one of three ways, based on the distance they are meant to cover. These include: wireless personal area networks (WPAN), wireless local area networks (WLAN), and wireless wide area networks (WWAN).

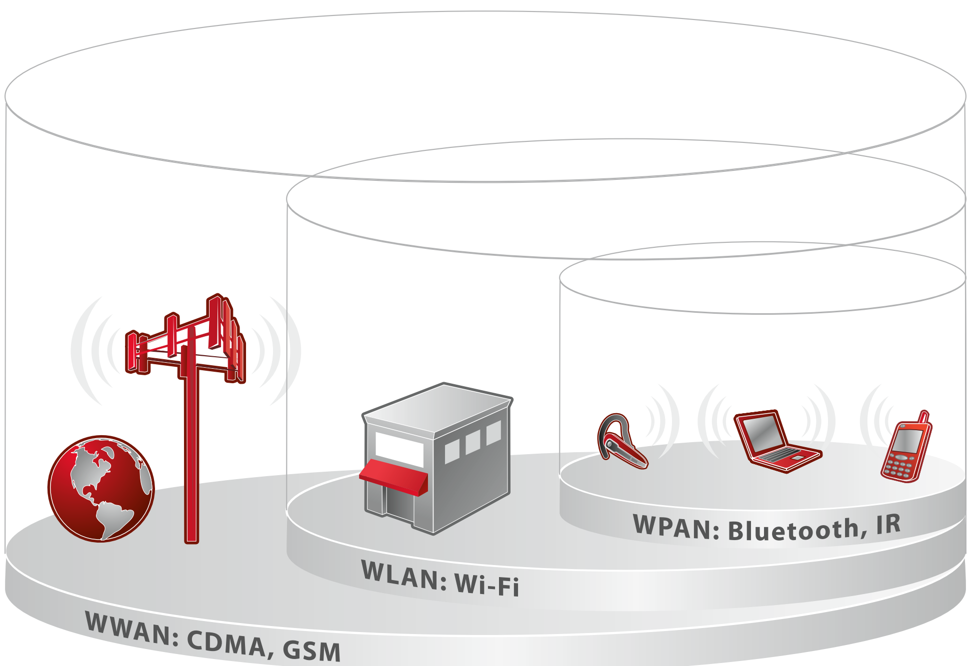


Figure 1: Wireless network technologies.

Wireless networks form the transport mechanism between devices and traditional wired networks. WPANs are limited to distances under about 10 meters and include technologies such as infrared (IR), Bluetooth® technology, and ultra-wideband (UWB). WLANs cover a local area with distances of individual access points reaching to about 100 meters, and include technologies such as Wi-Fi (802.11a/b/g/n). WWANs cover even larger areas, using cellular data networks. This section discusses some of the most popular and widely used wireless technologies to provide readers with a point of reference for the use of 3G technology.

## WPAN

WPANs typically provide *ad hoc* network connections designed to dynamically connect devices to other devices within close range of each other. These connections are termed *ad hoc* because they do not generally need to connect to any network infrastructure to operate. They can simply connect to each other and perform necessary communications without the need of any access network devices, such as access points or base stations.

### Bluetooth

Bluetooth has emerged as the most widely used WPAN network standard. The Bluetooth standard is an industry specification that describes how mobile phones, headsets, computers, handhelds, peripherals, and other computing devices should interconnect with each other. Bluetooth network applications include wireless headsets, hands-free operation, wireless synchronization, wireless printing, advanced stereo audio, dial-up networking, file transfer, and image exchange, to name a few.

## WLAN

WLANs provide connections designed to connect devices to wired networks. Unlike a wired LAN, a WLAN does not require cabling to connect the device to a switch or router. Devices connect wirelessly to nearby wireless access points that are attached to the local network using an Ethernet connection. A single access point communicates with nearby WLAN devices in a coverage area of about 100 meters. This coverage area allows users to move freely within range of an access point with their notebook computers, handhelds, or other network devices. Multiple access points can be coordinated together by a network WLAN switch to allow users to hand off between access points.

### Wi-Fi

Wi-Fi (or IEEE 802.11) is the set of standards established to define wireless LANs. A number of different protocols are defined in the 802.11 family of standards, addressing various operating frequencies and maximum throughputs. The 802.11g standard is currently the predominant protocol deployed in WLAN implementations.

## WWAN

WWANs provide broadband data networks with a far greater range, using cellular technologies such as GPRS, HSPA, UMTS, 1xRTT, 1xEV-DO, and LTE. Wireless data devices connect to a wireless broadband network through a commercial carrier's data network, allowing broadband performance without the need for a cabled connection to a network infrastructure (much like a WLAN), while providing end users with far greater mobility. These WWANs typically incorporate sophisticated user identification techniques to ensure that only authorized users are accessing the network. Multiple base stations are coordinated by base station controllers to allow users to hand off between base stations (cell sites).

### 1xEV-DO Rev. A

1xEV-DO is the broadband wireless network standard developed by the Third-Generation Partnership Project 2 (3GPP2) as part of the CDMA2000 family of standards. EV-DO networks were first launched based on release 0 of the standard. The standard is currently in revision A, which has been deployed nationally by Verizon Wireless, and provides average download speeds of 600 Kbps to 1.4 Mbps, and average upload speeds of 500 to 800 Kbps, with low latency, typically between 150 and 250 milliseconds.

# 5. WWAN Evolution: A Choice of Upgrade Paths

As the use and number of wireless devices increased, more and more demands were placed on the underlying technologies to deliver enhanced capabilities and services. This section discusses the evolution of WWAN technologies and their capabilities.


Figure 2: The Verizon Wireless upgrade path to LTE.

## 5.1 WWAN Evolution: CDMA to LTE

### 1G

First-generation (1G) radio networks were analog-based and limited to voice services and capabilities only. 1G technology was vastly inferior to today's technology. 1G devices were easily susceptible to cloning and one channel supported only one device at a time. Today's technology allows multiple devices to be supported by a single channel at the same time.

### cdmaOne

Second-generation (2G) CDMA-based wireless networks, known as cdmaOne, proved their effectiveness in delivering high-quality voice traffic to subscribers. 2G networks made the transition from analog signals to all-digital signals, expanding network capabilities to include both voice and data services. With cdmaOne technology, services such as email and text messaging became possible.

### CDMA2000

In response to subscriber growth and demand for data services that require high-speed access, 3G wireless network technology, known as CDMA2000, was implemented. CDMA2000 offered users increased voice and data services and supported a multitude of enhanced broadband data applications, such as broadband Internet access and multimedia downloads. This technology also doubled user capacity over cdmaOne, and with the advent of 1xRTT, packet data was available for the first time. In addition, CDMA2000 networks supported higher numbers of voice and data customers at higher data rates and at a lower cost, compared to 2G-based networks.

### CDMA2000 1xEV-DO

CDMA2000 1xEV-DO introduced high-speed, packet-switched techniques designed for high-speed data transmissions, enabling peak data rates beyond 2 Mbps. 1xEV-DO expanded the types of services and applications available to end users, enabling carriers to broadcast more media-rich content, while users could enjoy near-wireline speeds on mobile devices. CDMA2000 1xEV-DO was initially released as release 0 (Rel. 0) and has undergone one upgrade, known as 1xEV-DO Revision A (Rev. A).

### CDMA2000 1xEV-DO Rel. 0

Rel. 0 provides peak speeds of up to 2.4 Mbps with an average user throughput of between 400 and 700 Kbps. The average uplink data rate is between 60 and 80 Kbps. Rel. 0 makes use of existing Internet protocols, enabling it to support IP-based connectivity and software applications. In addition, Rel. 0 allows users to expand their mobile experience by enjoying broadband Internet access, music and video downloads, gaming, and television broadcasts.

### CDMA2000 1xEV-DO Rev. A

Rev. A supports the framework for future quality of service (QoS) applications, reduces latency, and features peak speeds of 3.1 Mbps for downloads, and 1.8 Mbps for uploads. Rev. A technology's increased bandwidth capabilities further improve a user's ability to send large files, email attachments, pictures, and video from mobile devices. Average speeds of Rev. A are 600 to 1,400 Kbps for downloads and 500 to 800 Kbps for uploads.

## LTE

As mentioned previously in this paper, LTE is a 4G wireless technology that Verizon Wireless and numerous leading wireless carriers have chosen as their upgrade path beyond 3G technologies. Verizon Wireless will operate LTE in the 700 MHz spectrum, which translates to unprecedented performance and data access.

| | 1xRTT | 1xEV-DO Rel. 0 | 1xEV-DO Rev. A | 3GPP LTE |
|---|---|---|---|---|
| Peak speeds | 153 Kbps (downlink)<br>153 Kbps (uplink) | 2.4 Mbps (downlink)<br>153 Kbps (uplink) | 3.1 Mbps (downlink)<br>1.8 Mbps (uplink) | 100 Mbps (downlink)<br>50 Mbps (uplink) |
| Average user throughput | 60–80 Kbps (downlink)*<br>60–80 Kbps (uplink)* | 400–700 Kbps (downlink)*<br>60–80 Kbps (uplink)* | 600–1,400 Kbps (downlink)*<br>500–800 Kbps (uplink)* | 5–12 Mbps (downlink)**<br>2–5 Mbps (uplink)** |

Figure 3: The evolution of CDMA to LTE.

## 5.2 WWAN Evolution: GSM to LTE

## 1G

Please see section 5.1, *WWAN Evolution: CDMA to LTE*, for a description of 1G WWAN technology.

## GSM

Global System for Mobile Communications (GSM) is 2G technology that offers both voice and data capabilities. GSM differs from 1G by using digital cellular technology and time division multiple access (TDMA) transmission methods, rather than CDMA. GSM offers data transmission rates of up to 9.6 Kbps, while enabling such services as short messaging service (SMS) or text messaging, as it is more commonly known, and international roaming.

## W-CDMA

Wideband Code Division Multiple Access (W-CDMA) brings GSM into 3G. W-CDMA is a type of 3G cellular network and is a high-speed transmission protocol used in Universal Mobile Telecommunications System (UMTS). UMTS offers packet-based transmission for text, digitized voice, video, and multimedia content.

* Based on advertised Verizon Wireless average user throughput.
** Based on preliminary analysis by multiple wireless vendors and Verizon Wireless.

## HSPA

High-Speed Packet Access (HSPA) is a mobile telephony protocol that helps improve the performance of UMTS. HSPA uses improved modulation schemes, while refining the protocols that mobile devices and base stations use to communicate. These processes improve radio bandwidth utilization provided by UMTS.

### HSDPA

High-Speed Downlink Packet Access (HSDPA) is a 3G mobile telecommunications protocol from the HSPA mobile protocol family. HSDPA enables higher data transfer speeds and capacity in UMTS-based networks. The standard currently supports peak downlink speeds of up to 14.4 Mbps in 5 MHz bandwidth.

### HSUPA

High-Speed Uplink Packet Access (HSUPA) is also a 3G mobile telecommunications protocol from the HSPA mobile protocol family. The HSUPA protocol enables peak uplink speeds of up to 5.76 Mbps.

## HSPA+

Evolved HSPA (HSPA+) is a wireless broadband standard that provides peak speeds of up to 42 Mbps on the downlink and 22 Mbps on the uplink, using multiple-input multiple-output (MIMO) technology and higher order modulation.

## LTE

Please see section 5.1, *WWAN Evolution: CDMA to LTE*, for a description of LTE.

| | W-CDMA | HSPA | HSPA + | 3GPP LTE |
|---|---|---|---|---|
| Peak speeds | 2 Mbps (downlink)* | 1.8 Mbps–14.4 Mbps (downlink)<br>384 Kbps–2 Mbps (uplink) | 42 Mbps (downlink)<br>22 Mbps (uplink) | 100 Mbps (downlink)<br>50 Mbps (uplink) |
| Average user throughput | 100 Kbps–320 Kbps (downlink)*<br>Less than 100 Kbps (uplink)* | Up to 2 Mbps (downlink only)*<br>Uplink speeds vary by device | 5 Mbps (downlink)*<br>3 Mbps (uplink)* | 5–12 Mbps (downlink)**<br>2–5 Mbps (uplink)** |

Figure 4: The evolution of GSM to LTE.

# 6. 4G Mobile Broadband Technologies

4G mobile broadband technologies will allow wireless carriers to take advantage of greater download and upload speeds to increase the amount and types of content made available through mobile devices.

## 6.1 Defining 4G Mobile Broadband Technology

4G networks are comprehensive IP solutions that deliver voice, data, and multimedia content to mobile users anytime and almost anywhere. 4G technology standards offer greatly improved data rates over previous generations of wireless technology. Faster wireless broadband connections enable wireless carriers to support higher-level data services, including business applications, streamed audio and video, video messaging, video telephony, mobile TV, and gaming.

* Based on *Data Capabilities: GPRS to HSDPA and Beyond* white paper; 3G Americas.org.
** Based on preliminary analysis by multiple wireless vendors and Verizon Wireless.

## 6.2 Trends Driving the Transition to 4G Technology

### Unified Technology

Today's global economy needs a "borderless" or unified wireless platform. The world is shrinking and mobile users conduct business all across the world, much like they used to do with people around the corner. Users need the ability to communicate, conduct business, and move around the globe as easily and seamlessly as they did with the "around the corner" set.

### Diverse Use

As capabilities advance and prices become more competitive, more people use wireless networks for heavier data and application access. As a result, bandwidth demand continues to rise. Also, people are becoming increasingly mobile, further changing the way they access and use the Internet.

### Increasing Expectations

Today, customers require the same broadband experience they get at the office or at home, regardless of their locations. They want easy access and use, high speed and low latency, better security and privacy, and seamless, global mobility.

### Rich Media

Music and video downloads, high-quality video conferencing, high-definition movie downloads, video on demand, and other trends are driving the need for 4G networks and their increased data capacity.

### Personal Expression

Mobile users today want to do more than simply consume information. They want to create things and share them. They also want to do it anytime, anywhere through blogs, social networks, and similar applications they use with fixed-line Internet connections.

# 7. LTE Overview and Development Background

Various technology standards bodies began to explore options for their 4G wireless technology offerings. Two groups, the Third Generation Partnership Project (3GPP), representing the family of networks generally referred to as GSM, and the Third Generation Partnership Project 2 (3GPP2), representing the family of networks generally referred to as CDMA, are working together to lay the foundation for LTE.

Established in 1998, 3GPP is a collaborative agreement that brought together multiple telecommunications standards bodies known as Organizational Partners. This group initiated the 3GPP LTE standards project to improve the UMTS mobile phone standard and to better meet future wireless technology needs. UMTS is one of the many 3G wireless technologies in use today. The most common form of UMTS uses W-CDMA as its underlying air interface and represents the European answer to the ITU IMT-2000 requirements for 3G cellular radio systems.

3GPP2 represents a collaboration between the numerous telecommunications associations that helped develop CDMA standards for 3G.

LTE is a global 4G standard, with researchers and development engineers throughout the world participating in the joint-LTE radio access standardization effort, involving more than 60 operators, vendors, and research institutes. This is the same standards body that researched and established the GSM, GPRS, W-CDMA, and HSPA wireless standards. The LTE standard is tightly integrated with GPRS/UMTS networks and represents an evolution of radio access technologies and networks for UMTS.

## 7.1 LTE Standards Evolution

The 3GPP body began its initial investigation of the LTE standard as a viable technology in 2004. In March 2005, 3GPP began a feasibility study whose key goals were to agree on network architecture and a multiple access method, in terms of the functional split between the radio access and the core network. The study concluded September 2006 when 3GPP finalized selection of the multiple access and basic radio access network architecture. 3GPP decided to use OFDMA in the downlink direction and use SC-FDMA in the uplink direction.

The specifications for the LTE standard were approved by 3GPP in January 2007. The specifications are now under change control, leading to their inclusion in 3GPP Release 8. While the LTE requirements are finalized, the standard is not fully completed. LTE Release 8 was completed by late 2008.

## 7.2 LTE Performance Estimates and Technical Attributes

Once fully deployed, LTE technology offers a number of distinct advantages over other wireless technologies. These advantages include increased performance attributes, such as high peak data rates and low latency, and greater efficiencies in using the wireless spectrum. Improved performance and increased spectral efficiency will allow wireless carriers using LTE as their 4G technology to offer higher quality services and products for their customers.

Benefits expected from LTE technology:

- High peak speeds:
  - 100 Mbps downlink (20 MHz, 2x2 MIMO)—both indoors and outdoors
  - 50 Mbps uplink (20 MHz, 1x2)
- At least 200 active voice users in every 5 MHz (i.e., can support up to 200 active phone calls)
- Low latency:
  - < 5 ms user plane latency for small IP packets (user equipment to radio access network [RAN] edge)
  - < 100 ms camped to active
  - < 50 ms dormant to active
- Scalable bandwidth:
  - The 4G channel offers four times more bandwidth than current 3G systems and is scalable. So, while 20 MHz channels may not be available everywhere, 4G systems will offer channel sizes down to 5 MHz, in increments of 1.5 MHz.
- Improved spectrum efficiency:
  - Spectrum efficiency refers to how limited bandwidth is used by the access layer of a wireless network. Improved spectrum efficiency allows more information to be transmitted in a given bandwidth, while increasing the number of users and services the network can support.
  - Two to four times more information can be transmitted versus the previous benchmark, HSPA Release 6.
- Improved cell edge data rates:
  - Not only does spectral efficiency improve near cell towers, it also improves at the coverage area or cell edge.
  - Data rates improve two to three times at the cell edge over the previous benchmark, HSPA Release 6.
- Packet domain only
- Enhanced support for end-to-end quality of service:
  - Reducing handover latency and packet loss is key to delivering a quality service. This reduction is considerably more challenging with mobile broadband than with fixed-line broadband. The time variability and unpredictability of the channel become more acute. Additional complications arise from the need to hand over sessions from one cell to another as users cross coverage boundaries. These handover sessions require seamless coordination of radio resources across multiple cells.

Figure 5 provides a quick glance at LTE's technical specifications and attributes.

| Peak performance downlink | Power-efficient uplink | Scalable and compatible with 3G networks | Flat all-IP architecture for performance and efficiency |
|---|---|---|---|
| • Efficiency OFDM/OFDMA in the downlink<br>– Spectral efficiency (2–5 times, Rel.6)<br>– Resistant to multi-path interference<br>• MIMO antennas<br>– Doubles the throughput<br>– Deployment simplicity | • SC-FDMA<br>– Lower peak-to-average ratio<br>– Longer mobile battery life<br>– Larger cell coverage<br>• Collaborative (multi-user or virtual) MIMO<br>– Simplifies mobile implementation<br>– Increases uplink capacity | • Scalable spectrum allocation (1.4, 3, 5, 10, 15, 20 MHz)<br>– Great for in-band deployment<br>• Mobility with 3GPP and non-3GPP access<br>– Smooth network migration to LTE and beyond<br>• Global roaming with other 3GPP networks | • High performance network<br>– Efficient IP routing reduces latency<br>– Increased throughput<br>– Fast state transition time (enhanced always-on)<br>– Less than 50 ms transition from dormant to active |

Figure 5: A summary of LTE capabilities.

## 7.3 Testing and Deployment

Many of the major global wireless carriers have lined up to support LTE as the foundation for their 4G network deployments. These global carriers include Verizon Wireless, as well as Vodafone, China Mobile, AT&T, China Telecom, KDDI, MetroPCS, NTT DoCoMo, and T-Mobile—plan to deploy LTE at some point in the future. Verizon Wireless and its European partner Vodafone have been among the most aggressive carriers in terms of LTE deployment timelines. Verizon Wireless has spent the past few years working with 3GPP standards in an effort to ensure interoperability between LTE and its current CDMA EV-DO Rev. A wireless broadband network.

LTE field demonstrations in realistic urban scenarios were conducted starting in December 2007. These field trials proved that future LTE-based wireless networks can operate using existing base station sites. Also in 2007, LTE test calls were completed between infrastructure and device vendors using mobile prototypes. These calls were the first test of multi-vendor, over-the-air LTE interoperability.

In April 2008, the first public announcements of LTE being demonstrated at high vehicular speeds were made with download speeds of 50 Mbps in a moving vehicle at 110 Kmph. Live 2x2 LTE solutions in 20 MHz were demonstrated at both Mobile World Congress 2008 and CTIA Wireless 2008. Among the new applications demonstrated on LTE networks (at various bands, including the new 1.7/2.1 GHz AWS band) were high-definition video blogging, high-definition video on demand and video streaming, multi-user video collaboration, video surveillance, and online mobile gaming. A handover between CDMA and LTE was also demonstrated, showcasing migration possibilities between the two generations of wireless technologies. Beginning third quarter 2008, UMTS/HSPA base stations were upgradable to LTE. Many bands are supported by these base stations, including the 1.7/2.1 GHz AWS band and the recently auctioned 700 MHz bands by the FCC in the United States.

Verizon Wireless, Vodafone, and China Mobile conducted laboratory and over-the-air tests of LTE in early 2008, followed by successful field tests in northern New Jersey; Columbus, Ohio; and Minneapolis, Minnesota. The final phase of LTE testing began in the second quarter of 2009, and 700 MHz tests commenced in June 2009 after the Digital Television (DTV) transition. Verizon Wireless will continue LTE testing throughout most of 2009, and will offer service in some 30 markets in 2010.

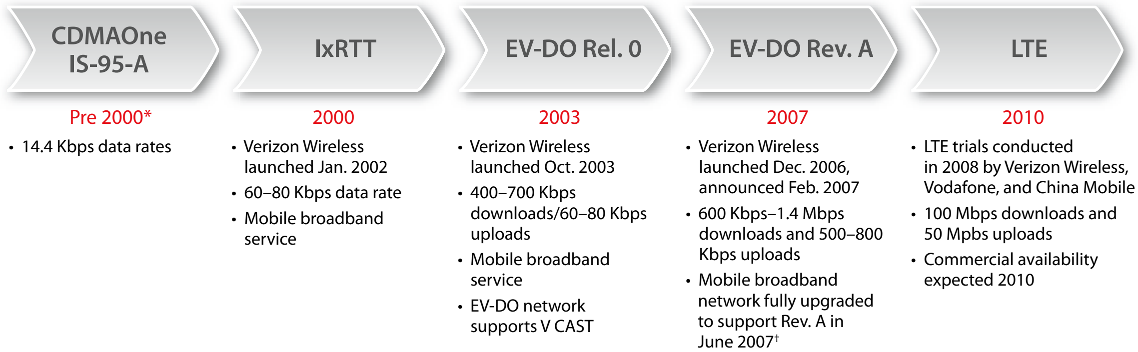


Figure 6: LTE evolution and roadmap.

## 7.4 LTE Supporting Technologies

The following information describes the various supporting technologies that make up LTE.

### MIMO

Multiple-input and multiple-output (MIMO) employs multiple transmit and receive antennas to substantially enhance the air interface. It uses space-time coding of the same data stream mapped onto multiple transmit antennas. This offers a substantial improvement over traditional reception diversity schemes where only a single transmit antenna is deployed to extend the coverage of the cell. MIMO processing also uses spatial multiplexing, allowing different data streams to be transmitted simultaneously from different transmitter antennae. Spatial multiplexing increases the end-user data rate and cell capacity. In addition, when knowledge of the radio channel is available at the transmitter, such as through feedback information from the receiver, MIMO can implement beam-forming to further increase available data rates and spectrum efficiency. Multiple antennas are also used to transmit the same data stream, thus providing redundancy and improved coverage, especially close to cell edge.

### OFDM

In the downlink, orthogonal frequency-division multiplexing (OFDM) was selected as the air interface for LTE. OFDM is a particular form of multicarrier modulation (MCM). In general, MCM is a parallel transmission method that divides a radio frequency channel into several, more narrow-bandwidth subcarriers and transmits data simultaneously on each subcarrier. OFDM is well suited for high data rate systems that operate in multipath environments because of its robustness to delay spread. The cyclic extension enables an OFDM system to operate in multipath channels without the need for a complex Decision Feedback Equalizer (DFE) or Maximum Likelihood Sequence Estimation (MLSE) equalizer. As such, it is straightforward to exploit frequency selectivity of the multipath channel with low-complexity receivers. This allows frequency-selective scheduling, as well as frequency-diverse scheduling and frequency reuse one-deployments. Furthermore, due to its frequency domain nature, OFDM enables flexible bandwidth operation with low complexity.

Smart antenna technologies are also easier to support with OFDM, because each subcarrier becomes flat faded and the antenna weights can be optimized on a per-subcarrier or block of subcarriers basis. In addition, OFDM enables broadcast services on a synchronized single frequency network (SFN) with appropriate cyclic prefix design. This allows broadcast signals from different cells to combine over the air, thus significantly increasing the received signal power and supportable data rates for broadcast services.

* All dates reflect commercial launch dates.
† Information reflects the state of the Verizon Wireless network prior to the acquisition of Alltel.

## SC-FDMA

Single-carrier FDMA (SC-FDMA) was chosen to reduce Peak to Average Ratio (PAR), which has been identified as a critical issue for use of OFDMA in the uplink where power-efficient amplifiers are required in mobile devices. Another important requirement was to maximize the coverage. For each time interval, the base station scheduler assigns a unique time-frequency interval to a terminal for the transmission of user data, thereby ensuring intracell orthogonality. Slow power control, for compensating path loss and shadow fading, is sufficient as no near-far problem is present due to the orthogonal uplink transmissions. Transmission parameters, coding, and modulation are similar to the downlink transmission.

The chosen SC-FDMA solution is based on using a cyclic prefix to allow high-performance and low-complexity receiver implementation in the eNodeB. As such, the receiver requirements are more complex than in the case of OFDMA for similar link performance, but this is not considered to be a problem in the base station. The terminal is only assigned with contiguous spectrum blocks in the frequency domain to maintain the single-carrier properties and thereby ensure power-efficient transmission. This approach is often referred to as blocked or localized SC-FDMA.

# 8. WiMAX Overview

WiMAX refers to the standards developed by the Institute of Electrical and Electronics Engineers Inc. (IEEE) for 802.16 wireless networks. IEEE is a developer and one of the governing bodies that determine international standards for many of today's telecommunications, information technology, and power generation products and services. IEEE developed the set of standards for WLAN, commonly known as "Wi-Fi" (IEEE 802.11). 802.16 is the set of IEEE standards for broadband WLAN and WMAN (wireless metro area networks). Although the 802.16 family of standards is officially called WirelessMAN, it has been dubbed "WiMAX" by an industry group called the WiMAX Forum.

WiMAX is available in two versions—fixed and mobile. Fixed WiMAX, which is based on the IEEE 802.16-2004 standard, is ideally suited for delivering wireless, last-mile access for fixed broadband services. It is similar to DSL or cable modem service. Mobile WiMAX, which is based on the IEEE 802.16-2005 standard, supports both fixed and mobile applications while offering users improved performance, capacity, and mobility.

## 8.1 WiMAX Standards Evolution

In 1998, the IEEE formed a group called 802.16, which was tasked to develop a standard for what would become known as WMAN. Over the past few years, the 802.16 standard has evolved as follows:

- IEEE Std 802.16–2001: Line-of-sight fixed operation in 10 to 66 GHz
- IEEE Std 802.16a–2003: Air interface support for 2 to 11 GHz
- IEEE Std 802.16d–2004: High-speed data rates for fixed wireless and nomadic access
- IEEE Std 802.16e–2005: Improved air interface and capability for limited mobility

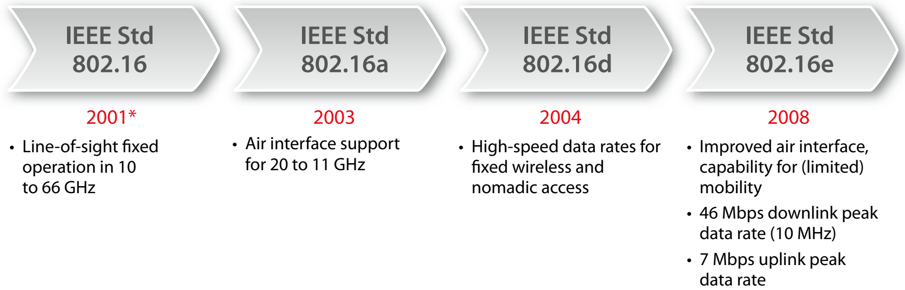


Figure 7: The evolution of WiMAX.

### 8.2 WiMAX (802.16e–2005) Performance Estimates and Technical Attributes

Benefits expected from WiMAX technology:

- 46 Mbps downlink peak data rate (within 10 MHz bandwidth)
- 7 Mbps uplink peak data rate (within 10 MHz bandwidth)
- Scalable bandwidth (1.25 to 20 MHz)
- Enhanced support for end-to-end quality of service

### 8.3 WiMAX Supporting Technologies

MIMO—Please see section 7.4, *LTE Supporting Technologies*, for a description of this technology.

OFDM—Please see section 7.4, *LTE Supporting Technologies*, for a description of this technology.

### 8.4 WiMAX Deployment

WiMAX's deployment began in September 2004 when Intel shipped the first WiMAX chipset, called Rosedale. In January 2006, the first WiMAX Forum-certified product was announced for fixed applications.

Sprint-Nextel and Clearwire have formed a partnership with the intention of deploying WiMAX services covering several major cities in North America. In addition, Intel continues to support the WiMAX standard by including WiMAX-based radios alongside 802.11n-based Wi-Fi radios in its Centrino Pro notebooks. Eventually, Intel plans to position WiMAX as part of its core Centrino platform offering.

## 9. A Technology Comparison between LTE and WiMAX

LTE and WiMAX have many features and functions in common; more so than one might think. Both are 4G wireless technologies designed to move data rather than voice. Both are all-IP technologies that strictly separate the wireless network from the applications that run on them. In terms of how they operate, both LTE and WiMAX have more in common with Wi-Fi and the Internet than with traditional cellular networks that exist today. Rather than being rival wireless technologies, such as GSM and CDMA, WiMAX and LTE are more like siblings.

* All dates reflect commercial launch dates.

Figure 8 provides a quick comparison of LTE and WiMAX and what each technology offers:

| | LTE* | WiMAX 802.16e |
|---|---|---|
| **Technology** | MIMO<br>Downlink: OFDM<br>Uplink: SC-FDMA | MIMO<br>Downlink: OFDM<br>Uplink: OFDM |
| **Peak speeds** | Downlink: 100 Mbps<br>(20 MHz, 2x2 MIMO)<br>Uplink: 50 Mbps (20 MHz, 1x2) | Downlink: 46 Mbps<br>Uplink: 7 Mbps |
| **Average user throughput** | 5 Mbps–12 Mbps (downlink)<br>2 Mbps–5 Mbps (uplink) | 2 Mbps–4 Mbps (downlink)<br>500 Kbps–1.5 Mbps (uplink) |
| **One-way airlink latency** | 15 ms | 50 ms |
| **Bandwidth** | 20 MHz, 15 MHz, 10 MHz, 5 MHz, and <5 MHz | 3.5 MHz, 5 MHz, 7 MHz, 8.75 MHz, 10 MHz |
| **Spectrum** | Verizon Wireless will use 700 MHz, but LTE can be deployed in various frequencies. Using the 700 MHz frequency helps increase in-building coverage for wireless signals.* | 2.3, 2.5, 3.5, 5.8 GHz |
| **Mobility** | Targeted mobility up to 350 kmph | Targeted mobility up to 120 kmph |

Figure 8: Technical differences between LTE and WiMAX.

## 10. The Advantages of LTE

Despite their similarities, Verizon Wireless has chosen to deploy LTE because it offers a number of distinct advantages over WiMAX. Higher data rates and lower latency make LTE connections more responsive, enabling real-time multicast applications, such as online gaming and video conferencing. Choosing the 700 MHz frequency as the basis of the Verizon Wireless network results in a longer range from the base station, compared with systems operating at 2.5 GHz or 3.5 GHz. In addition, using the 700 MHz frequency allows for better in-building penetration and coverage by wireless signals, helping to improve network conditions. LTE also offers mobile users better coverage as they travel by providing seamless handover and roaming for true mobility.

LTE is better suited for global adoption than WiMAX. Although 2.5 GHz, 3.5 GHz, and 5.8 GHz bands are allotted in many regions of the world, many growth markets require new allocations to service their populations. Given the diverse requirements and regulations of various governments, it will be a challenge for WiMAX to achieve global harmonization.

LTE has strong and widespread support from the mobile industry, including support from a majority of the industry's key players. Many vendors will enable operator transition to LTE in a progressive, scalable, and cost-effective way—protecting investments in existing technologies made by today's GSM and CDMA carriers. GSM is the most popular mobile communications standard currently in use. Carriers on the GSM standard predominate around the globe and will use LTE as their wireless network upgrade pathway. According to an April 2008 report from Gartner Inc., the GSM family will account for 89% of the global market in 2011. In addition, LTE figures to enjoy widespread device support as most major device vendors have publicly announced the development of products to take advantage of LTE.

* Based on preliminary analysis by multiple wireless vendors and Verizon Wireless. One distinction is that LTE uses Frequency Division Duplex (FDD), but WiMAX uses Time Division Duplex (TDD).

## 10.1 Business Considerations for Using LTE

As an industry leader, Verizon Wireless must carefully consider both the technical and business implications of adopting new technologies for network deployment. LTE will offer a number of technological advantages over WiMAX:

- LTE features higher peak rates and shorter/lower latency to support real-time applications, such as video conferencing and mobile gaming.
- WiMAX suffers from coverage challenges (especially indoors) due to high frequency bands.
- LTE provides better global coverage and roaming capabilities, while maintaining compatibility with existing 2G and 3G wireless networks.
- Numerous vendors worldwide have publicly announced the development of user equipment based on the LTE standard; having a plentiful supply of equipment and devices will help drive down the costs of using the technology.
- LTE enjoys strong, widespread support from the mobile industry, both from wireless carriers and vendors alike.
- Multiple vendors, operators, and research institutes are participating in standardizing LTE. This provides a good base for creating a healthy technological ecosystem.
- The Verizon Wireless IMS/AIMS core network is access-technology agnostic and supports LTE.

Figure 9 provides an overview of why businesses should consider adopting LTE:

| | LTE | WiMAX 802.16e |
|---|---|---|
| Interoperability | Global roaming | Limited international roaming |
| Backwards compatibility | Connects to legacy 3GPP networks | None; new build out |
| Market momentum | Examples include: Verizon Wireless, Vodafone, AT&T, T-Mobile, Nokia, Qualcomm, Alcatel-Lucent, Ericsson, MetroPCs, KDDI, China Mobile, DoCoMo | Examples include: Sprint-Nextel, Clearwire, Intel, Google |

Figure 9: Business considerations for using WiMAX or LTE.

# 11. Conclusion

LTE is the future of the Verizon Wireless wireless broadband network. This technology will allow Verizon Wireless to offer users more of what they want, which is untethered mobility. Plus, LTE will support more of the products and services in use today, because of its backward compatibility to 3GPP networks. Verizon Wireless is fully committed to LTE mobile technology and improving its wireless network. To that end, the company actively participates in the development of technology standards to ensure that future standards will greatly benefit its customers. Verizon Wireless believes in the viability of the LTE standard and its future potential, having spent countless hours researching and testing 4G technologies to determine the best fit for its network. For these reasons, Verizon Wireless chose LTE as the technology to deliver the next generation of mobile services and applications to its customers.

## 12. Additional Resources

Verizon Wireless offers resources, products, and technical support specifically for IT managers who plan to implement wireless solutions for their organizations. These resources include:

### IT Solutions Guides

A comprehensive overview of wireless services and solutions offered by Verizon Wireless and its partners.

### Technical White Papers

Technical overviews that help IT managers quickly grasp the fundamentals of wireless technology, including security, connectivity, and more.

### Case Studies

Real-world stories of customer experiences that illustrate success factors and practical results.

## 13. Glossary of Terms

1xRTT (*One times Radio Transmission Technology*)—The first version of CDMA2000 technology that has peak downlink speeds of 307 Kbps and uplink speeds of 144 Kbps.

1xEV-DO (*One times Evolution Data Optimized*)—The first phase of 1xEV technology that increases peak download speeds to 2.4 Mbps.

2G (*second generation*)—The second generation of mobile phone technology introduced during the 1990s. This generation added data capabilities to mobile phones, including Internet and email access.

3G (*third generation*)—Third-generation mobile phone technology appeared in the 2000s and forms the foundation of our current mobile phone capabilities. 3G technology offers even faster Internet access, plus enables worldwide roaming capabilities.

4G (*fourth generation*)—The next generation of wireless technology that goes beyond what is currently available. The various industry groups driving development expect 4G technology to offer increased voice, video, and multimedia capabilities; a higher network capacity; improved spectral efficiency; and high-speed data rates over current 3G benchmarks.

Access network—A network that grants end users access to the network core and network services.

AIMS (*Advances to IP Multimedia Subsystem*)—Advances proposed to the subsystem supporting multimedia sessions, standardized by 3GPP.

Air interface—The radio link between a user's mobile device and the wireless carrier's base station.

AWS (*Advanced Wireless Services*)—The wireless telecommunications spectrum band that's used for wireless voice, data, messaging services, and multimedia.

CDMA (*Code Division Multiple Access*)—A method for sending multiple voice and/or data signals simultaneously across the radio spectrum.

DFE (*Decision Feedback Equalizer*)—A channel equalization technology of MIMO to help deliver good performance and high data rates.

eNodeB (*Evolved Node B*)—An integrated LTE base station and radio network controller that manages radio resources, performs subscriber scheduling, and initiates connections to the air interface.

FDD (*Frequency Division Duplex*)—A duplexing scheme in wireless communications used in voice-only applications that supports two-way radio communications by using two distinct radio channels.

GPRS (*General Packet Radio Service*)—A packet-based wireless communications service that offers peak data rates of 56 Kbps to 114 Kbps, while maintaining a continuous Internet connection for mobile devices.

GSM (*Global System for Mobile Communications*)—A 2G digital wireless telephony system that uses a variation of TDMA (Time Division Multiple Access) for network access.

HSDPA (*High-Speed Downlink Packet Access*)—A 3G wireless telephony protocol derived from the HSPA protocols that enable UMTS-based networks to have higher data transfer speeds and capacity.

HSPA (*High-Speed Packet Access*)—A collection of wireless telephony protocols that improve upon the performance offered by UMTS. HSPA consists of two existing protocols: HSDPA and HSUPA.

HSUPA (*High-Speed Uplink Packet Access*)—A 3G wireless telephony protocol derived from the HSPA protocols that offer peak uplink speeds of up to 5.76 Mbps.

IMS (*IP Multimedia Subsystem*)—The network architectural framework for delivering multimedia to mobile devices.

LTE (*Long Term Evolution*)—A 4G technology proposed and developed by 3GPP to improve the UMTS wireless standard.

MIMO (*Multiple-Input and Multiple-Output*)—A smart antenna technology that uses multiple antennas at the transmitter and receiver to improve communications performance.

MLSE (*Maximum Likelihood Sequence Estimator*)—An algorithm that is one of a number of techniques developed for processing signals with intersymbol interference. MLSE is used to minimize the probability of error within the radio channel.

OFDM (*Orthogonal Frequency-Division Multiplexing*)—A frequency-division multiplexing scheme used as a digital multi-carrier modulation method primarily used to carry data across a number of subcarriers. OFDM helps negate severe channel conditions and offers greater spectral efficiency.

OFDMA (*Orthogonal Frequency-Division Multiple Access*)—A multi-user version of OFDM.

PAR (*Peak to Average Ratio*)—The ratio of the instantaneous peak value or maximum magnitude of a signal parameter to its time-averaged value.

RAN (Radio Access Network)—The part of the wireless network that is positioned between mobile devices and the wireless carrier's core network. The term RAN is often used to describe GSM, UMTS, and other wireless technology standards.

RTD (*Round Trip Delay*)—RTD is a measurement of the overall delay encountered on both the transmit and receive direction.

SC-FDMA (*Single Carrier Frequency-Division Multiple Access*)—Similar to OFDM, SC-FDMA is a frequency-division multiplexing scheme that can operate either as a linearly precoded OFDMA scheme or a single-carrier multiple access scheme. SC-FDMA is the uplink multiple access scheme in LTE.

SFN (*Single Frequency Network*)—A broadcast network where multiple transmitters send the same signal simultaneously over the same frequency channel.

TCP/IP (*Transmission Control Protocol/Internet Protocol*)—A collection of communications protocols used to connect hosts to each other on the Internet.

TDD (*Time Division Duplex*)—A duplexing scheme in wireless communications that uses a single radio frequency to transmit in both the downstream and upstream directions.

UMTS (*Universal Mobile Telecommunications System*)—A 3G broadband service that allows for the packet-based transmission of text, digitized voice, video, and multimedia content.

UWB (*Ultra-Wideband*)—A wireless technology that enables the transmission of data over a large bandwidth (greater than 500 MHz).

WiMAX (*Worldwide Interoperability for Microwave Access*)—A technology proposed by IEEE as a wireless standard for point-to-point communications and cellular access.

## 14. Contact Information

For more information about Verizon Wireless, speak to a Verizon Wireless business specialist, visit **www.verizonwireless.com**, or call **1.800.VZW.4BIZ**.



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