



4G LTE WHITE PAPER

# The Verizon Wireless 4G LTE Network: Transforming Business with Next-Generation Technology

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## 1. Introduction

This paper provides an overview of Long Term Evolution (LTE), the wireless technology standard that serves as the basis for the Verizon Wireless fourth-generation (4G) wireless broadband network. The information presented here will help the reader understand the innovation and promise offered by LTE, why it was chosen and the power it has to transform mobility.

The following executive summary gives a quick overview of the paper's contents and its subject matter. The remaining sections discuss the technological specifications of LTE, its technical and business drivers and future developments.

### 1.1 Audience

This paper has been developed for individual customers, enterprise customers, IT administrators, business and technical 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 today are connected 24/7 via their wireless devices and want immediate access to the applications and content they use most: business productivity tools, streaming video, social networking and more. The desire for instant access creates a need for greater bandwidth, improved responsiveness and faster upload and download speeds than was offered by previous generations of wireless technologies. Wireless carriers' networks need to function more like landline IP-based networks to achieve the speeds and connectedness customers have come to expect.

This line of thinking represents a fundamental shift in perspective—from wireless services to broadband connections—for customers and service providers alike.

Enter the 4G wireless network. Unlike earlier wireless standards, most 4G technologies are based on IP, the core protocol of the Internet. IP enables wireless networks to deliver more advanced services, such as high-definition video and multimedia, while supporting the devices and applications of the future. The Verizon Wireless 4G network is built upon LTE, the "gold" standard for wireless. For Verizon Wireless and other carriers that have chosen LTE as their migration path, LTE offers a number of distinct advantages over other wireless technologies, such as increased data rates, lower latency, greater security and more efficient use of the wireless spectrum. These improved capabilities help Verizon Wireless deliver higher quality services and solutions its customers require.

## 3. LTE Overview

LTE's technology advances help the company deliver improved wireless Internet connectivity and true mobility to its customers. LTE's improved speed, greater bandwidth and lower latency help redefine the traditional office with enhanced productivity for mobile workers by offering in-office business applications and services. LTE allows improved communication features such as real-time videoconferencing, powerful wireless applications and direct-connect access to files and customer-specific applications workers need, when they need them most.

LTE represents the culmination of decades of technological evolution and development, with each new generation building upon the previous to improve users' overall wireless experiences and meet users' wireless connectivity needs for years to come.

## 4. The History and Evolution of Wireless Technologies

Wireless technologies enable one or more devices to communicate without an actual wired connection. Radio frequency (RF) is used to transmit the data. Such technologies are rapidly evolving to meet even the most complex communications needs.

Wireless communications technologies 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).

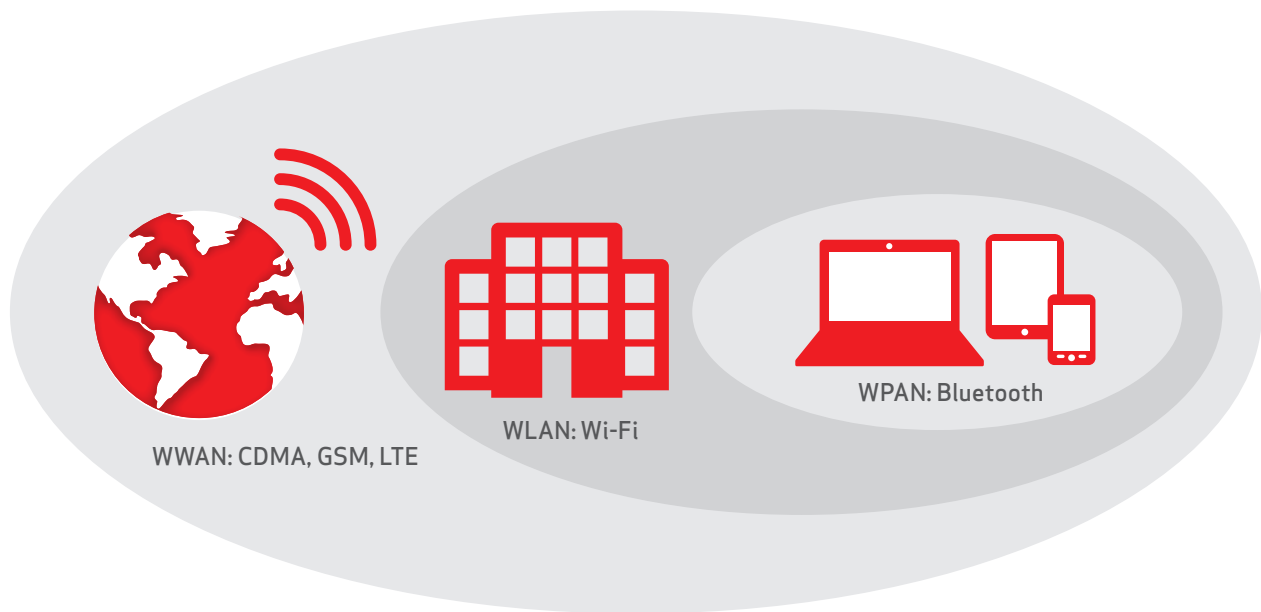


Figure 1: Wireless network technologies.

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 connect with each other. Bluetooth network applications include wireless audio, 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 by the Institute of Electrical and Electronics Engineers Standards Association 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 802.11n 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 (cell sites) are coordinated by base station controllers to allow users to hand off between base stations.

### **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 round trip.

## 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 devices were easily susceptible to cloning and one channel supported only one device at a time. Today's technology far surpasses 1G capabilities, in part by allowing 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 wireless 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 400 to 700 Kbps. The average uplink data rate is 60 to 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 wireless experience by enjoying broadband Internet access, music and video downloads, gaming and television broadcasts.

### CDMA2000 1xEV-DO Rev. A

Rev. A introduced a reduction in latency and featured 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 wireless devices. Average speeds of Rev. A are 600 to 1,400 Kbps for downloads and 500 to 800 Kbps for uploads.

### LTE

LTE is the 4G wireless technology chosen by Verizon Wireless and numerous leading wireless carriers as their upgrade paths beyond 3G technologies. Under nominal network conditions<sup>1</sup> across a user population in a given wireless sector, the average user throughput speeds on the Verizon Wireless 4G LTE network will fall between 5 Mbps to 12 Mbps from network to device and 2 Mbps to 5 Mbps from device to network, comparable to landline broadband speeds. LTE features reduced network-to-device (one-way) latency, down from 120 ms in 1xEV-DO Rev. A to below 50 ms on the Verizon Wireless network.

| The evolution of the Verizon Wireless network |                                          |                                            |                                                |                                       |
|-----------------------------------------------|------------------------------------------|--------------------------------------------|------------------------------------------------|---------------------------------------|
|                                               | 1xRTT                                    | 1xEV-DO Rel. 0                             | 1xEV-DO Rev. A                                 | 4G LTE                                |
| Average user throughput                       | 60-80 Kbps download<br>60-80 Kbps upload | 400-700 Kbps download<br>60-80 Kbps upload | 600-1,400 Kbps download<br>500-800 Kbps upload | 5-12 Mbps download<br>2-5 Mbps upload |
| Latency                                       | Approximately 120 ms                     | 150-250 ms                                 |                                                | Below 50 ms                           |

Figure 3: The evolution of CDMA to LTE.

## 5.2 WWAN Evolution: GSM to LTE

### 1G

Please see section 6.1, *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 text messaging and international roaming.

<sup>1</sup> A nominal network condition is defined as the conditions under which the network resource utilization is at a moderate to high level but with no persistent contention. Intuitively, the lower part of the expected throughput range would correspond to the higher resource utilization.

## 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 and international roaming.

## 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 wireless 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 6.1, *WWAN Evolution: CDMA to LTE*, for a description of LTE.

|                                | W-CDMA                                                    | HSPA                                                           | HSPA +                                    | 3GPP LTE†                                     |
|--------------------------------|-----------------------------------------------------------|----------------------------------------------------------------|-------------------------------------------|-----------------------------------------------|
| <b>Peak speeds*</b>            | 2 Mbps (downlink)**                                       | 1.8–14.4 Mbps (downlink)<br>384 Kbps–5 Mbps (uplink)           | 28–43 Mbps (downlink)<br>11 Mbps (uplink) | 100 Mbps (downlink)<br>50 Mbps (uplink)       |
| <b>Average user throughput</b> | 100–320 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.

\* Verizon Wireless 4G LTE target peak speeds are based on the 3GPP LTE release 8 standard. Actual peak speeds will vary depending on real-world network conditions.

\*\*Based on *Data Capabilities: GPRS to HSDPA and Beyond* white paper; [3G Americas.org](http://3G Americas.org).

† Based on preliminary analysis by multiple wireless vendors and Verizon Wireless.

## 6. The Potential and Promise of LTE

### 6.1 Why Verizon Chose LTE for Its 4G Network

Verizon Wireless chose LTE 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 competing wireless technologies 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.

4G LTE sets the standard for other wireless technologies to follow and creates a number of significant improvements in an already great wireless network, the Verizon EV-DO Rev. A network. The following chart illustrates the improvements 4G LTE offers over EV-DO Rev. A:

| Network Performance | EV-DO Rev. A                                                                                                                                                                                                                                                                                                                                   | 4G LTE                                                                                                                                                                                                                                                                                                                                                            |
|---------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Packet Latency      | <b>Latency</b> is a function of RF conditions and traffic load. The worse RF conditions are the more Forward Error Correction (FEC) coding is applied and the greater the processing time.<br><b>Traffic Scheduling</b> targets fair-share resource allocation (the more active users are in a sector, the lesser the traffic share per user). | <b>Latency:</b> With OFDMA (DL), SC-OFDM (UL) and MIMO less FEC and deeper modulation are possible due to the multi-subcarrier nature of the OFDM and MIMO transmitter and receiver diversity.<br><b>Traffic Scheduling:</b> LTE eNB allows for multi-user traffic in one DL/UL frame. With QoS in the future some users' traffic may be prioritized over others. |
| Transmission Rate   | <b>Bandwidth:</b> CDMA uses 1.25 MHz per sector.<br><b>Modulation:</b> top modulation levels (under good RF conditions) of 16QAM (4 bits per modulation symbol).                                                                                                                                                                               | <b>Bandwidth:</b> 10x10 MHz FDD bands per sector.<br><b>Modulation:</b> 16QAM on both uplink and downlink are supported (6 bits per modulation symbol).<br><b>Spatial Multiplexing:</b> MIMO—2x2 antenna arrays significantly increase DL/UL transmission rates.                                                                                                  |
| Packet Loss         | <b>Link Layer</b> has built-in mechanisms for reliable traffic delivery.<br><b>Receiver Diversity</b> (using the diversity antenna). In general the packet loss rates are low but may fluctuate.                                                                                                                                               | <b>Link Layer</b> has enhanced HARQ protocols.<br><b>Receiver Diversity</b> uses Maximum Ratio Combining and MIMO for fast and reliable delivery with minimal packet loss.                                                                                                                                                                                        |

Figure 6: 4G LTE's improvements over 3G EV-DO Rev. A.

### 6.2 The Consistent Wireless Experience of LTE

Deploying Verizon Wireless 4G LTE in the 700 MHz frequency band results in a longer range from the base station, compared with systems operating at 2.5 GHz or 3.5 GHz. LTE also offers mobile users better coverage as they travel by providing seamless handover and roaming for true mobility.

Verizon Wireless has invested more than \$9 billion total, including \$4 billion<sup>2</sup> in securing the C-Block (3GPP Band 13) 700 MHz frequency. The C-Block frequency provides significant advantages over other frequencies in the spectrum, such as the ability to resist attenuation as the signal goes through foliage and common building materials.

<sup>2</sup> [www.verizon.com/investor](http://www.verizon.com/investor)

### 6.3 The Global Adoption of LTE

LTE enjoys strong and widespread support from the wireless industry, including backing from a majority of the industry's key players. LTE has been selected by more than 297 mobile technology mobile operators worldwide as their global technology for 4G services. These global carriers, including industry leaders Vodafone, China Mobile and Verizon Wireless, along with AT&T, China Telecom, KDDI, MetroPCS, NTT DoCoMo, Sprint and T-Mobile—have all deployed or plan to deploy LTE at some point in the future.

### 6.4 The Verizon Wireless 4G LTE Network

The Verizon Wireless 4G LTE network offers a number of benefits, including:

- + High peak speeds:
  - ~86 Mbps downlink (10 MHz, 2x2 MIMO).
  - ~28 Mbps uplink (10 MHz, 1x2).
  - Carrier aggregation will further improve the users' speed.
- + Low latency:
  - Below 50 ms round trip over the airlink within the Verizon Wireless radio access network.
- + Scalable bandwidths:
  - Bandwidth allocation of 1.4, 3, 5, 10, 15, 20 MHz.
  - Scalable bandwidth provides the flexibility for deployment and capacities.
- + 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.
  - The only contiguous spectrum in the United States. Other LTE providers will have to rely on partners for contiguous spectrum deployment.
  - 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 of LTE improve near cell towers, it also improves at the coverage area or cell edge, which makes more bandwidth available at the cell edge.
  - Data rates improve two to three times at the cell edge over the previous benchmark, HSPA Release 6.

- + Seamless performance:
  - 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 where the time variability and unpredictability of the channel become more acute, creating the issue. Additional complications arise from the need to hand over sessions from one cell to another as users cross coverage and frequency boundaries. These handover sessions require seamless coordination of radio resources across multiple cells. In the past, 3G networks split both voice and data signals. 4G LTE uses an Evolved Packet Core that is 100% IP based, facilitating simultaneous voice and data communications.

| 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 <ul style="list-style-type: none"> <li>• Spectral efficiency (2–5 times, Rel.6)</li> <li>• Resistant to multi-path interference</li> </ul> + MIMO antennas <ul style="list-style-type: none"> <li>• Doubles the throughput</li> <li>• Deployment simplicity</li> </ul> | + SC-FDMA <ul style="list-style-type: none"> <li>• Lower peak-to-average ratio</li> <li>• Longer wireless battery life</li> <li>• Larger cell coverage</li> </ul> + Collaborative (multi-user or virtual) MIMO <ul style="list-style-type: none"> <li>• Simplifies wireless implementation</li> </ul> + Increases uplink capacity | + Scalable spectrum allocation (1.4, 3, 5, 10, 15, 20 MHz) <ul style="list-style-type: none"> <li>• Great for in-band deployment</li> </ul> + Mobility with 3GPP and non-3GPP access <ul style="list-style-type: none"> <li>• Smooth network migration to LTE and beyond</li> <li>• Global roaming with other 3GPP networks</li> </ul> | + High performance network <ul style="list-style-type: none"> <li>• Efficient IP routing reduces latency</li> <li>• Increased throughput</li> <li>• Fast state transition time (enhanced always-on)</li> <li>• Less than 100 ms transition from dormant to active</li> </ul> |

Figure 7: A summary of Verizon Wireless 4G LTE capabilities.

## 7. Technical Drivers for LTE

### 7.1 IPv4 and the Introduction of IPv6

IPv4 and IPv6 make it possible for users to connect their devices to the Internet. In order for devices to communicate across the Web, data packets must be delivered to the IP addresses of both devices. However, available IP addresses for IPv4 have all been allocated, which prompted the development of IPv6 to accommodate new addresses.

IPv6 is designed to handle the explosive growth of Internet-capable devices and is supported by more advanced wireless technologies, such as LTE. IPv6 makes a significantly larger amount of IP addresses available for assignment and uses 128 bits so it can support  $2^{128}$  addresses. Combined with LTE, it offers additional security benefits over previous wireless technologies, such as encryption, authentication and longer key lengths. IPv6 also features improvements to the Authentication Header (AH) and Encrypted Security Payload (ESP) and includes enhancements to Internet Protocol Security (IPsec) to combat packet sniffing, IP spoofing and connection hijacking.

IPv4 and IPv6 will coexist for many years during this transition. As more and more solutions migrate toward IPv6, Verizon Wireless networks will continue to support IPv4 with IPv6-over-IPv4 encapsulation or tunneling, including providing support for customers with their own network infrastructure.

## 7.2 The Verizon Wireless Foundational IMS Core

The IP Multimedia Subsystem (IMS) network core serves as the foundation for the Verizon Wireless 4G LTE network and provides the platform for the development and deployment of new features and services that take advantage of LTE's capabilities. IMS supports multiple types of access, including wireline, wireless, fiber and private networks, and uses IPv6 for transport. The Verizon Wireless IMS network launched with Voice over IP (VoIP) service over the Evolved High Rate Packet Data (eHRPD) protocol as its access technology, which allows users to compete wireless voice calls via IP technology with a new packet network, rather than using the existing circuit-switched network. This service is based on the Verizon Converged Network Architecture, which provides a common user experience across both mobile and fixed devices. With it, users can transparently access all existing Verizon Wireless services, as well as access voice and data services simultaneously, including multimedia services like video telephony and streaming video. In addition, location-based and presence capabilities that are inherent within the IMS architecture enable enhanced services for mobile users, such as identifying location-based food vendors available in a user's immediate area, physical destination arrival-notification applications, mobile retail loyalty rewards programs and social media check-in/arrival-notification applications.

## 7.3 eHRPD

eHRPD provides a phased migration path from EV-DO Rev. A to LTE by allowing network operators to reuse elements within the existing 3G packet core network. Reusing these elements makes internetworking between eHRPD and LTE networks possible, which helps create a seamless service experience for mobile users. Initially, LTE will rely on eHRPD and the IMS core network to deliver ubiquitous services throughout the Verizon Wireless network. Operating a single-packet core infrastructure helps simplify network deployment and management, and ultimately helps improve network performance by:

- + Reducing dropped data sessions.
- + Minimizing handover latency between LTE and eHRPD.
- + Maintaining the same IP address from LTE to EV-DO.

eHRPD also offers consistent data connection integrity that provides users a seamless experiences for multimedia messaging, push-to-talk services, video and gaming, as well as for enterprise applications like virtual private networks. Location-based services also benefit from eHRPD as these types of applications require seamless service mobility to maintain viability in the marketplace.

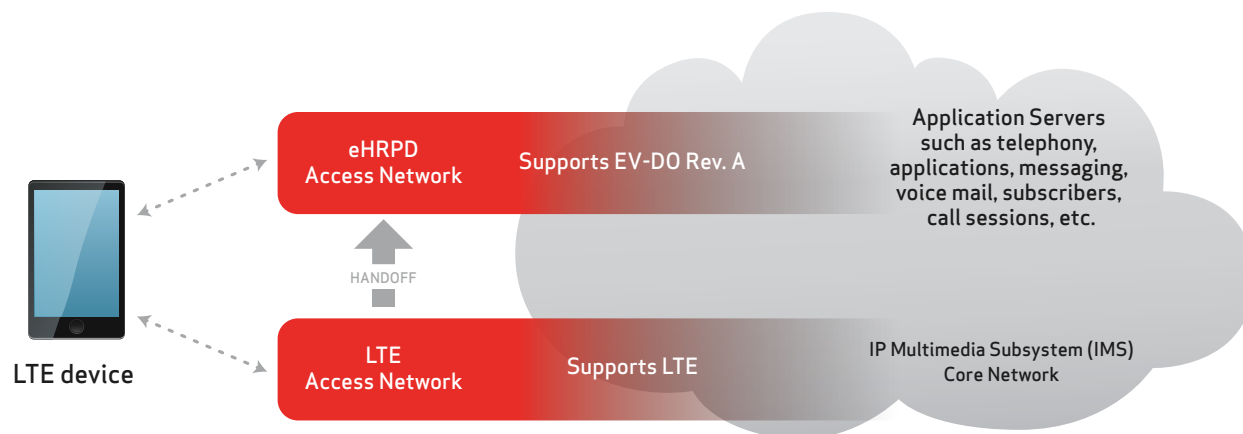


Figure 8: Coupling with Evolved High Rate Packet Data, LTE enables ubiquitous coverage for next-generation services.

## 8. Verizon Wireless 4G LTE Security Enhancements

Verizon Wireless 4G LTE includes a number of security enhancements that make it even more secure than previous 3G technologies. And as policies and procedures become more stringent within businesses, the combined security advancements listed here will provide better overall protection of corporate and personal data. The following chart describes many of the new security enhancements available in Verizon Wireless 4G LTE.

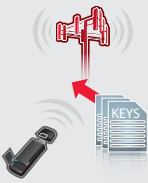
| SECURE STORAGE                                                                      | MUTUAL AUTHENTICATION                                                               | ROOT KEY LENGTH                                                | SECURITY CONTEXT                                                                    | INTEGRITY PROTECTION                                                                 | ENCRYPTION                                                                            |
|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|----------------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
|  |  | <b>128</b><br>vs.<br><b>64</b>                                 |  |  |  |
| Device with credentials and secret data for secure access of the network            | In LTE, both the device and the network authenticate each other                     | Key length better secures user plane and signaling information | Keys to encrypt signaling and subscriber data created for each session              | Additional algorithm to check the integrity of data translated                       | Signaling and subscriber data encryption                                              |

Figure 9: Security enhancements found in LTE.

## 8.1 Secure Storage

Subscriber Identity Module (SIM) cards are the most secure, tamper-resistant devices for storing and using credentials and secret data. These cards securely store subscription information and device settings for portability, allowing users to carry their entire user environment from one device to another.

The Verizon Wireless 4G SIM card provides the option to limit access to data or applications only after the user has entered the correct personal identification number (PIN). If the user opts to enable the PIN, after three incorrect entries, the Universal Subscriber Identity Module (USIM), which is the logical identity of the 4G SIM card, will be blocked. If blocked, the user will be required to enter the appropriate PIN unblocking key (PUK). If the correct PUK is entered, the 4G SIM card will be unblocked. The PUK can be used 10 times to unlock the PIN. After 10 incorrect entries, the 4G SIM card will be permanently blocked.

## 8.2 Mutual Authentication

In an LTE network, the network authenticates 4G SIM, and the 4G SIM authenticates the network credentials as shown in figure 10. Mutual authentication protects against attacks, including those from rogue base stations. The Verizon Wireless 4G SIM card contains the necessary authentication security credentials for accessing multiple network types, including LTE, GSM and CDMA. It contains secret keys known only to the 4G SIM and home subscriber server (HSS)/home location register (HLR)/authentication center (AuC), so a secure authentication procedure is supported and all communications on the air interface are encrypted. The authentication procedure will always take place within the home network while roaming.

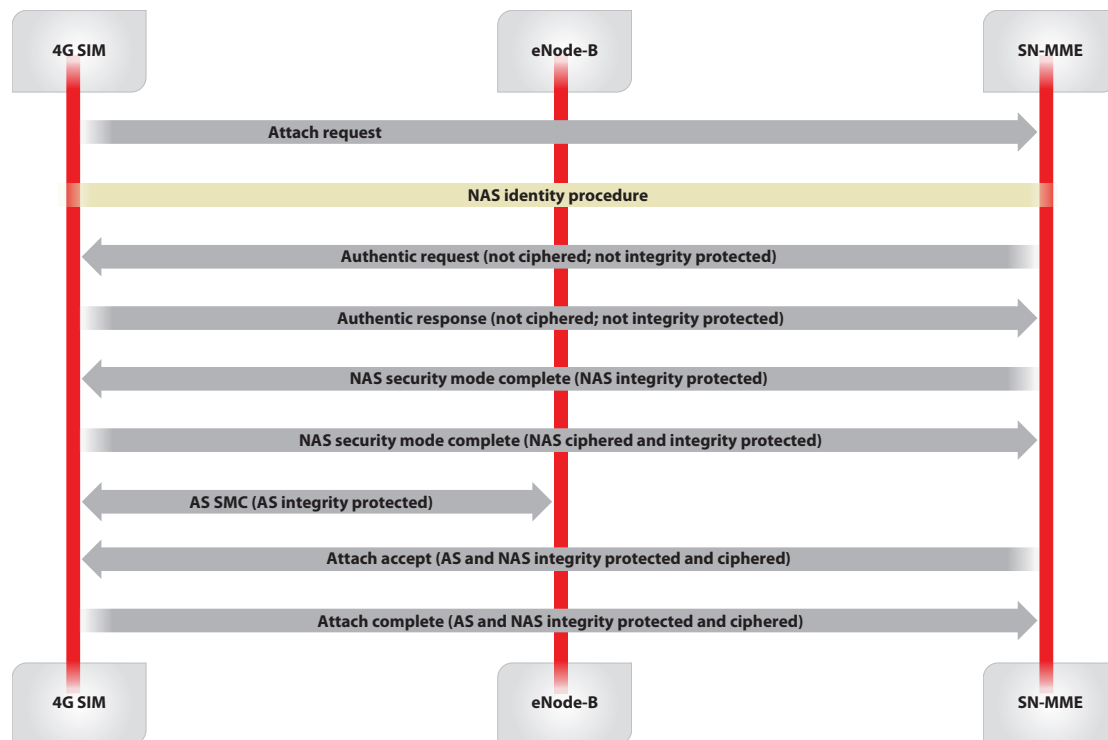


Figure 10: The establishment of NAS and AS security contexts during initial attach.

The 4G SIM stores authentication algorithms and certificates that make it extremely difficult for an external third party to access a user's communications. The primary algorithm for accessing the LTE network services is the 3GPP-defined algorithm, MILENAGE. MILENAGE provides efficiency of the smart-card implementation, security of the smart-card implementation, fixed input length, secret key input and the use of block ciphers. USIM requires verifying an additional sequence number that must be within a range and using a window mechanism to avoid replay attacks, and is in charge of generating the session keys to be used in the confidentiality and integrity algorithms.

### 8.3 Root Key Length

The LTE-3GPP Rel. 8 technical specification defines a comprehensive key management hierarchy (see figure 10), scope and lifetime. The security keys in the Verizon Wireless 4G LTE network are derived from a key derivation function (KDF). While the inputs are different, each key used for crypto-algorithms is 128 bits in length, effectively providing a common format. The CDMA CAVE key (A-key) is 64 bits in length. This longer key length translates to requiring a significantly greater level of effort in attacking the algorithm. Since the LTE and Evolved Packet Core (EPC) keys are cryptographically separated, each key is independent of the other, i.e., it is not possible to figure out one of the keys from the other. The result is that the Verizon Wireless 4G LTE network has two layers of security instead of one, which minimizes the effects of a compromised LTE security layer.

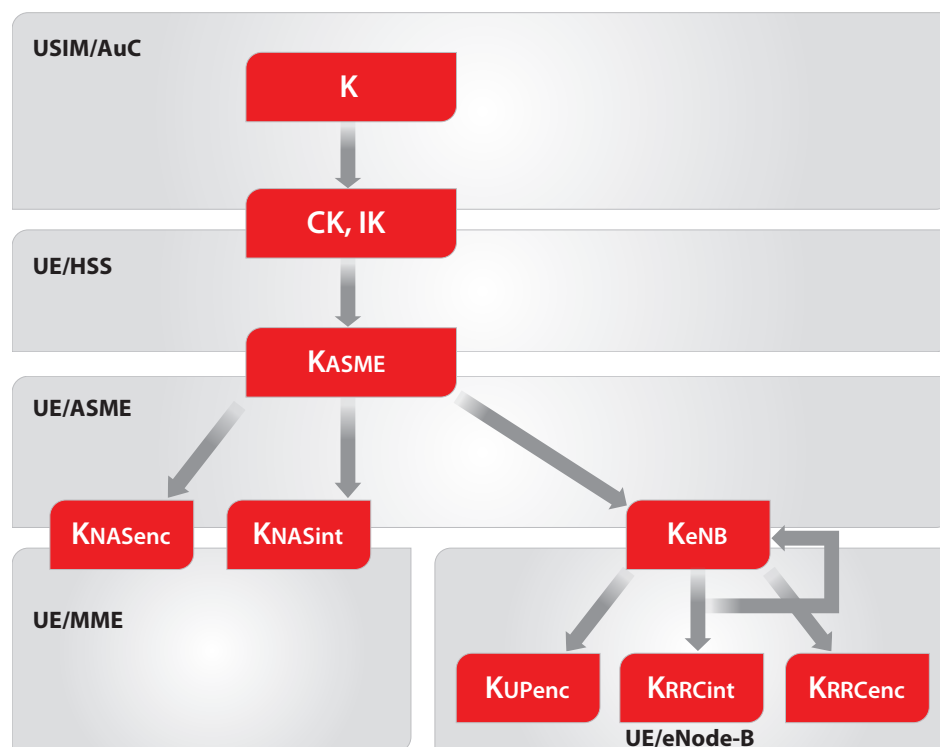


Figure 11: Key hierarchy in LTE.

## 8.4 Security Context

Keys to encrypt signaling and user-plane (UP) data are created for each data session on the Verizon Wireless 4G LTE network. The master key KASME is shared between the user equipment (UE) and EPC and all subsequent keys are derived using the master key. The keys KeNB, KUPenc, KRRCint and KRRCenc are used to protect the user traffic and radio resource control (RRC) signaling between the UE and eNode-B. The key for UP traffic is retained for the period the UE is in a valid connected session, and the keys are deleted upon transition to idle mode or upon handover to another eNode-B (i.e., cell site). Handover between eNode-Bs can only be performed after security is activated, and it is also only during handovers that ciphering and integrity algorithm can be negotiated.

## 8.5 Integrity Protection

The Verizon Wireless 4G LTE network goes beyond CAVE (used in 1xRTT0) with its integrity-protection capabilities. Evolved Packet System-Authentication and Key Agreement (EPS-AKA), which is used in LTE, provides the keys used for integrity protection for the signaling channels (Radio Resource Control [RRC] )and non-access stratum [NAS] signaling; the UP packets are not integrity-protected. Each signaling message is appended with an integrity tag and only upon verification of the integrity by the receiving end is the message accepted. In the Verizon Wireless 4G LTE network, the UEs and the eNode-Bs will use 128-bit Advanced Encryption Standard (AES) and SNOW3G algorithms for integrity protection.

## 8.6 Encryption

Airlink encryption (ciphering) and integrity protection are independent security features found in LTE. While the integrity protection mechanism is used to protect signaling (RRC and NAS), the airlink encryption is used to provide protection for the UP data or signaling so that they are not compromised over the radio access interface. In the Verizon Wireless 4G LTE network, UEs and eNode-Bs support three options for encryption: AES, SNOW3G and NULL. One of the three options is negotiated between the UE and eNode-B before communications take place (the UE's capabilities will dictate the encryption options). The 128-bit AES algorithm is the preferred option in the Verizon Wireless 4G LTE network, followed by SNOW3G and, if the UE is not capable of either option, no encryption (NULL) is used. AES is preferred because it has undergone more public scrutiny than other encryption options.

## 8.7 Verizon Wireless Private Network Solution

In addition to the inherent security found in 4G LTE, Verizon Wireless builds upon that secure foundation with its Private Network solution, which is available on both its 3G and 4G LTE networks. The Verizon Wireless Private Network solution offers many features that help enterprise customers manage their wireless devices more efficiently. The solution segregates enterprise traffic from public network elements of the Internet and assigns them to enterprise-specific home agents (gateways), effectively helping to reduce security risks that result from unprotected public networks and access through public gateways. Traffic segregation also helps improve overall enterprise network performance by bypassing poor network conditions and unpredictable performance behavior of public network elements of the Internet.

Verizon Wireless offers a variety of IP addressing options that provide differing levels of accessibility, protection and manageability. Its Private Network solution supports enterprise-owned, private IP address assignment to the devices, essentially making the device a virtual extension of the wired enterprise network. This allows enterprise IT administrators to manage mobile stations and LAN devices using the same tools and techniques. For example, the same firewall and routing schemes can be used and the IT administrators define which users get Internet access. This makes it easier for enterprise IT administrators to manage and monitor network usage and enforce company IT policies.

The Verizon Wireless Private Network solution also supports IPsec for securing IP communications by authenticating and encrypting each IP packet of the data stream. The solution supports IPsec to enhance security measures and is compatible

with most virtual private network (VPN) technologies, as well as the Verizon Business MultiProtocol Label Switching (MPLS) network.

Also, when it becomes available on 4G LTE, enabling the Dynamic Mobile Network Routing (DMNR) option on a private network will advertise users' LAN subnet addresses behind a wireless router. Doing so will simplify the connection of LAN subnets, such as notebooks, desktop computers or other devices located on those routers, to applications connected to enterprise users' data centers. This option protects sensitive data from traversing the public Internet and further enhances an IT administrator's ability to manage individual subnets behind a wireless router by communicating directly to those nodes.

## **9. Verizon Wireless 4G LTE Support Programs**

Verizon Wireless has introduced a number of support programs designed to take advantage of what LTE has to offer and bring new, innovative devices and applications to market. These programs are intended to attract premium partners and make Verizon Wireless the first place developers and consumers come for LTE services.

### **9.1 Verizon Wireless Open Development Program**

The Verizon Wireless Open Development program is designed to stimulate the creation of new and nontraditional wireless devices, applications and services that will operate on our network. Our streamlined certification process helps manufacturers get devices to market quickly and cost-effectively. Once a device is certified, manufacturers can choose either the Open Development Direct Solution, which allows them to focus on selling devices while Verizon Wireless manages customer billing, activation and collections, or the Open Development Wholesale Solution, which means manufacturers manage all aspects of the customer relationship.

### **9.2 Wholesale Applications Community**

The Wholesale Applications Community (WAC) was formed by many of the world's leading telecommunications companies to create open standards for telecom applications development. The WAC's mission is to grow and expand the market for wireless applications by:

- + Simplifying the applications process by helping developers create applications for multiple devices that are deployable across multiple platforms.
- + Spurring the creation of more compelling applications that take advantage of next-generation device and network capabilities.
- + Providing additional choices for mobile users by enabling the portability of applications across multiple devices, operating systems and network operators.

### **9.3 LTE Innovation Center**

The LTE Innovation Center is a collaborative environment for Verizon Wireless technology partners and participant companies to quickly develop and bring to market innovative products, solutions and applications that will run on the Verizon Wireless 4G LTE network. The LTE Innovation Center offers a state-of-the-art LTE lab environment and a range of premier services and support from Verizon Wireless, including product design, user experience testing and business development resources. Highlights of the design space include:

- + LTE networks with both RF and wired access for evaluating a wide range of user equipment and usage scenarios. Nearly every conceivable LTE scenario can be explored and evaluated.
- + Flexible design workspace that is private, secure and capable of hosting small design and engineering teams.

- + A complete user-testing facility for simulating environments that people encounter in the real world. Various simulated (and configurable) environments are available, such as a replica home, a travel environment and a business office, where product usage can be tested.

#### **9.4 Verizon Wireless Machine to Machine Services/Machine to Machine Management Center**

For businesses looking to manage remote assets, wireless machine-to-machine communications represents potentially significant cost savings, new sources of revenue and new business models. Verizon Wireless Machine to Machine Services enables businesses to manage connected machines, people and information in real time. Verizon Wireless works with other industry leaders to provide solutions for remote monitoring, asset tracking and management, monitoring and control, entertainment and more—all managed by the Verizon Wireless Machine to Machine Management Center.

The Verizon Wireless Machine to Machine Management Center simplifies the management of Verizon Wireless-certified devices, network connections and other elements of machine-to-machine connectivity. This solution enables enterprises to self-manage all their devices and services from a single portal as needed.

#### **9.5 Verizon Developer Community**

Verizon Developer Community (VDC) provides application developers and Business Solution Alliance providers with the platforms, tools and resources needed to build wireless applications such as software development kits (SDKs) and application programming interfaces (APIs). VDC also offers testing, certification and a streamlined go-to-market process for placement in the Verizon Wireless V CAST apps store.

#### **9.6 The Verizon Wireless/Motorola Alliance for Public Safety**

Verizon Wireless and Motorola Solutions have formed a technology alliance designed to enhance public safety agencies' communications and collaboration abilities across the country. The alliance enhances agency interoperability by allowing them to connect via a Motorola® private Public Safety 4G LTE (PS 4G LTE) network and the Verizon Wireless 4G LTE and 3G commercial networks. This connectivity permits public safety personnel to travel outside agency jurisdiction, yet still maintain access to their agency's data and information. Plus, the combined Verizon Wireless/Motorola solution enables public safety agencies to take advantage of LTE's capabilities to share images, large data files and real-time video to enhance their situational awareness, increase safety and improve emergency preparedness.

## 10. LTE's Impact on Business

In a 4G LTE network, connectivity means an untethered experience and true mobility. Mobile workers can work and communicate almost whenever and wherever they want. LTE's improved speeds allow wireless carriers to offer a number of business-specific applications and services, such as videoconferencing, in-office connectivity and wireless applications that bring the desktop experience to users' wireless devices. Specifically, 4G LTE:

- + Provides a global ecosystem with inherent mobility.
- + Offers greater security and privacy.
- + Dramatically improves speed and overall network latency.
- + Delivers enhanced real-time video and multimedia for a better overall user 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.

Businesses are looking for new ways to become more efficient and to do more with the resources they have. That is why Verizon Wireless continues to invest in network technologies that will improve the user experience and pushes the technological boundaries to generate positive business outcomes.

### Unified Technology

The arising global economy needs a "borderless" or unified wireless platform. Today's 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 do with the "around-the-corner" set.

### Diverse Use

As capabilities advance and operational costs continue to rise, companies 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 ease of access and use; high speed and low latency; better security and privacy; and seamless, global mobility. Users live and work in a content-driven world, which means they want engaging content and they want it now—they are unwilling to wait for something to download. As users' expectations rise, so must their wireless network, as they increasingly rely on using their wireless devices as a single point of connectivity. Capabilities such as unlimited texting, rich multimedia gaming, powerful business applications and streaming, real-time, high-definition video further drive the need for networks to evolve and innovate to deliver a wireless network technology that can meet these demands.

## 10.1 Improving Business Functions and Processes with LTE

LTE greatly improves the mobile office experience through its increased speeds, enhanced security and lower latency. Business applications that once relied on a wireline network are now capable of running on a variety of wireless devices. As wireless devices become more sophisticated, consumers expect their network to keep pace by providing a reliable connection that offers the flexibility their businesses require. LTE gives workers the connectivity they need to enhance productivity and accomplish more, faster. Faster speeds, lower latency and improved security lead to an overall better wireless experience. And with the projected explosion of machine-to-machine implementations, LTE delivers the scalable, secure and consistent wireless experience required by businesses of all types and sizes.

As new business models materialize every day, Verizon Wireless continues to support this expansion with innovative networking technology. A variety of industries are realizing improved business benefits from the advancements of LTE. The following examples show how 4G LTE can help transform business processes for select vertical industries.

### **Health Care: Remote Care**

For health care, 4G LTE can enhance physicians and caregivers' ability in providing remote care to patients. Caregivers can establish a home-monitoring and management program for patients with chronic diseases, such as diabetes, congestive heart failure or similar conditions, and use 4G LTE-enabled tablets and smartphones to monitor patient conditions remotely. Caregivers can take advantage of 4G LTE's capabilities to quickly download large data files, such as medical records and digital x-rays from multiple sources, to help doctors treat patients. In addition, 4G LTE's built-in security features allow caregivers to securely monitor patient status and protect patients' privacy.

### **Distribution: Fleet Management**

For distribution companies, 4G LTE can help increase the efficiency of fleet operations and management. Fleet managers equipped with 4G LTE-capable ruggedized tablets can quickly download and access large data files, such as fleet usage and operational reports, driver schedules, vehicle and fuel consumption data, operational metrics and more. Plus, this data can be accessed in real time, enabling fleet managers to make changes and updates on the fly. Drivers carry 4G LTE-enabled smartphones that allow them to receive updated schedules and delivery assignments as needed, access multimedia maps and driving directions, monitor cargo status and more, which helps improve operational efficiency and reduce fuel costs.

### **Financial Services: ATMs and Vending Machines**

For financial services companies, deploying machine-to-machine-enabled ATMs in high-traffic locations or temporary locations, such as concerts, farmers' markets or sporting events, can help create new revenue opportunities and improve customer satisfaction by making banking services readily available to those that need them while on the go.

Vending-machine operators can use machine-to-machine services powered by 4G LTE to facilitate secure, cashless transactions and to remotely monitor machine inventory levels and potential malfunctions. 4G LTE has the capability to handle large-scale mass deployments of thousands of devices. Combining this deployment capability with machine-to-machine services allow operators add more and more vending machines to their operations, which can help increase revenues. In addition, operators can control costs by eliminating unnecessary travel to restock or service machines.

### Public Safety: Increased Situational Awareness

For public safety agencies, 4G LTE provides the ability to help improve responders' situational awareness when dealing with emergencies. In emergency situations, responders need access to reliable information about the affected area. 4G LTE's capabilities allow responders to pull and transmit live video feeds from multiple sources to and from the scene. Responders can share location information and collaborate through 4G LTE-capable wireless data terminals, smartphones or tablets, helping to improve how they deal with emergency situations. 4G LTE's increased network bandwidth supports geospatial situational awareness and collaboration applications to deliver critical information almost immediately, making such information easily accessible to command, analysis and field operator personnel. Plus, responders can take advantage of 4G LTE's large data-file capabilities to download building schematics and satellite/aerial images, and its ability to access and share high-definition thermal images for a more informed response.

## 11. Conclusion

LTE represents the future of the Verizon Wireless network. Its increased speeds, improved latency and greater bandwidth give users what they want, which is faster access to the content and applications they consume. For businesses, this means increased collaboration and communications among mobile workers and greater sharing of data and information. For consumers, it means true, untethered mobility that can enhance their 24/7 connected lives. Going forward, LTE establishes a base from which Verizon Wireless will develop new business models, products and services. Applications such as rich multimedia content, "on-demand anything," real-time video collaboration, streaming media, "everything as a service" and more are now made possible through the power of LTE.

## 12. 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 wireless 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.

**eHRPD**—eHRPD provides a phased migration path from EV-DO Rev. A to LTE by allowing network operators to reuse elements within the existing 3G packet core network.

**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 wireless 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 wireless 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 wireless 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 500MHz).

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

## 13. Contact Information

For more information about Verizon Wireless and its 4G LTE network, speak to your Verizon Wireless business specialist or visit <http://network4g.verizonwireless.com/>.

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