LTE Benefits v 3.3

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CONTENTS
Executive Summary........................................................................................................................................................................... 2
LTE Benefits for the Consumer.......................................................................................................................................................... 2
  1. Higher Data Rates............................................................................................................................................................................. 3
  2. Coverage............................................................................................................................................................................................ 3
  3. Better Multipath, Mobility, and Power Performance..................................................................................................................... 4
    3.1. OFDMA Downlink Transmission................................................................................................................................................ 4
    3.2. SC-FDMA Uplink Transmission................................................................................................................................................ 5
  4. Lower Latency................................................................................................................................................................................... 5
  5. Greater Simultaneous Use Support.................................................................................................................................................. 5
  6. Security............................................................................................................................................................................................. 6
  7. Simplified Worldwide Roaming......................................................................................................................................................... 6
  8. Mass M2M Deployment................................................................................................................................................................. 6
Conclusion...................................................................................................................................................................................... 7
References......................................................................................................................................................................................... 7
Appendix B: Acronyms................................................................................................................................................................. 7
Executive Summary

Verizon Wireless has selected 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) as its technology for Fourth Generation (4G) wireless services. LTE represents the next big step in the evolution to an all-IP wireless network that not only provides advanced mobile broadband capabilities, but also enables the enhancement of existing services and the introduction of new rich multimedia services. The Verizon Wireless LTE network will co-exist and integrate with its current Evolution Data Optimized (EV-DO) Rev. A network. It will also support handover to existing mobile networks, thereby providing seamless coverage to Verizon Wireless subscribers from the time of its deployment.

LTE Benefits for the Consumer

LTE will be providing Verizon Wireless consumers with significant benefits that extend beyond traditional day to day wireless communications. Consumers will benefit from access to a wide gamut of new and rich innovative multimedia applications. LTE opens the doors for innovative applications, products, services, and solutions targeted not only to today’s handheld mobile devices, but also to other non-traditional devices. LTE will facilitate the introduction of new services in areas that have not yet been fully explored for wireless services interaction; these include consumer electronics and appliances, health care, public utilities, and telematics.

What makes the Verizon Wireless LTE network best suited to support the needs of these new, rich, and exciting solutions is a multitude of factors—significantly increased data rates, much lower latency, and better coverage. LTE’s more efficient use of bandwidth, as compared to existing 3G wireless technologies, makes high bit rate applications more viable for consumer use.

The following section summarizes the technical advantages that the Verizon Wireless implementation of LTE will provide:

1. **Higher data rates**: With the Verizon Wireless 10 + 10 MHz implementation, LTE will be supporting average data rates per user of 5 to 12 Mbps in the forward link, and 2 to 5 Mbps in the reverse link. The maximum and average LTE data rates are significantly greater in magnitude in the reverse and forward link correspondingly, than those supported by existing 3G technology. In addition, LTE has much better edge-of-cell data rates—over two to three times better than the previous benchmark, HSPA Release 6. LTE will truly enable video application on the downlink as well as uplink—including, but not limited, to video-sharing, surveillance, conferencing, and streaming in higher definition than is possible with existing 3G technology today.

2. **Coverage**: Verizon Wireless’ deployment of LTE in the beachfront 700 MHz spectrum provides coverage and in-building penetration advantages over existing 3G technologies (and other 4G competitive implementations) deployed at higher frequency bands. This enhanced in-building coverage/penetration will make indoor applications even more powerful.

3. **Better multipath, mobility, and power performance**: The advanced radio characteristics of LTE address several issues that have traditionally crippled cellular wireless, including multipath and multiuser interference. LTE’s use of orthogonal frequency division multiple access (OFDMA) and multiple-input and multiple-output (MIMO) in the downlink transmission effectively eliminates intra-cell multiuser interference and minimizes inter-cell multiuser interference, thereby maximizing performance. Similarly, the single-carrier frequency division multiple access (SC-FDMA) uplink transmission allows for user equipment to transmit low power signals without the need for expensive power amplifiers. Improvement in battery power consumption in end-user devices (UEs) is a side-benefit of the coverage and multipath/power performance advantages offered by LTE.

4. **Latency**: The user plane latency achieved in LTE is approximately one-fourth of the corresponding latency in existing 3G technologies. This provides a direct service advantage for highly immersive and interactive application environments, such as multiplayer gaming and rich multimedia communications.

5. **Simultaneous user support**: LTE provides the ability to perform two-dimensional resource scheduling (in time and frequency), allowing support of multiple users in a time slot; in contrast, existing 3G technology performs one-dimensional scheduling, which limits service to one user for each timeslot. This capability of LTE results in a much better always-on experience, and also enables the proliferation of embedded wireless applications/systems.
6. **Security**: LTE provides enhanced security through the implementation of UICC Subscriber Identity Module (SIM) and the associated robust and non-invasive key storage and symmetric key authentication using 128-bit private keys. LTE additionally incorporates strong mutual authentication, user identity confidentiality, integrity protection of all signaling messages between UE and Mobility Management Entity (MME), and optional multi-level bearer data encryption.

7. **Simplified worldwide roaming**: The Verizon Wireless chosen migration path to LTE, the widely adopted next-generation 3GPP standard, will provide greater opportunities for seamless international roaming and for global device economies of scale as well.

8. **Mass deployment**: LTE’s inherent support for Internet Protocol version 6 (IPV6) addressing and IMSI-based identifiers makes mass deployments of machine-to-machine (M2M) applications over LTE possible.

1. **Higher data rates**

The channel bandwidth supported by LTE has a significant impact on the advantages it provides. LTE is flexible and scalable, and can accommodate multiple channel bandwidths—1.4, 3, 5, 10, 15, or 20 MHz. However, the performance of LTE in terms of user data rates, sector data rates, and higher spectral efficiency (bps/Hz) is significantly better as the channel bandwidth goes over 5 MHz. In addition, LTE supports and takes advantage of MIMO (multiple antennas at transmitter and receiver) to allow transmission of two or more parallel streams of data simultaneously. This also has a multiplicative effect on throughput. Verizon Wireless is implementing the 10 + 10 MHz (downlink and uplink separated by FDD) channel bandwidth for the deployment of LTE services.

The expected characteristics of the Verizon Wireless LTE network are:

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Expected LTE Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Data Rates</td>
<td>Peak Rates over 2x10 MHz</td>
</tr>
<tr>
<td></td>
<td>DL (2x2): 86 Mbps</td>
</tr>
<tr>
<td></td>
<td>UL (1x2): 28 Mbps</td>
</tr>
<tr>
<td>Average User Throughputs</td>
<td>DL: 5 to 12 Mbps</td>
</tr>
<tr>
<td></td>
<td>UL: 2 to 5 Mbps</td>
</tr>
<tr>
<td>(Average) Sector Throughput</td>
<td>DL 2x2: 15 Mbps</td>
</tr>
<tr>
<td></td>
<td>UL 1x2: 5 to 6 Mbps</td>
</tr>
<tr>
<td>Latency (one-way)</td>
<td>15 ms</td>
</tr>
</tbody>
</table>

There is over a 50% improvement in spectral efficiency with LTE versus EV-DO Rev. A.

In addition, use of standardized compression (ROHC—Robust Header compression) for overhead reduction supplements the end-user throughput experience.

The data rate benefits of LTE are amplified in marginal and cell-edge coverage. LTE has much better cell-edge data rates—over two to three times better than the previous benchmark, HSPA Release 6.

As a result of its support of high peak and average data rates in uplink and downlink, LTE enables a host of high-quality video uplink and downlink applications, including but not limited to, surveillance, streaming, sharing, and conferencing.

2. **Coverage**

Due to the use of the upper C-band (700 MHz range) for LTE, and the acquisition of a coast-to-coast spectrum license in this band, the Verizon Wireless LTE Network will have better coverage than existing 3G technologies (and other 4G competitive implementations) deployed at higher frequency bands—specifically the PCS (1900 MHz) and AWS (2100 MHz) bands. The use of 700 MHz provides increased penetration and better attenuation characteristics, resulting in an in-building performance advantage. The coast-to-coast license will ensure seamless coverage and minimize hard-handoff scenarios attributed to channel frequency changes.
Verizon Wireless uses a combination of 850 MHz and 1900 MHz spectrum in the current EV-DO Rev. A deployment, and the 700 MHz range has about 1db better propagation characteristics than 850 MHz. The propagation/penetration advantage is significantly higher when comparing 700 MHz with 1900 MHz (PCS) and/or 2100 MHz (AWS) or higher bands (such as 2500 MHz)—because the received power is inversely proportional to the square of frequency.

Note that network design (including factors such as: cell sector placement/spacing, antenna center line selection, antenna downtilt, and azimuth optimization, among others) will also influence coverage/penetration. Verizon Wireless is designing LTE to be a “performance-optimized” network (including, but not limited to, implementing the best-of-breed designs in antennas/coax/fiber/etc)—this will further the native advantage provided by the Verizon Wireless use of the 700 MHz spectrum for LTE.

The enhanced coverage and penetration afforded by the Verizon Wireless implementation of LTE in the 700 MHz spectrum will make indoor and in-car applications more powerful.

**3. Better multipath, mobility, and power performance**

Careful consideration was given to the selection of the RF downlink and uplink transmission for LTE. Multipath delay spread and user equipment power consumption were two important areas of focus, in addition to speed improvement and latency reduction. LTE implements OFDMA for downlink transmission and SC-FDMA for uplink transmission. Due to multiple lower-bandwidth subcarriers, the symbol time is larger, and hence multipath spread (Inter-Symbol Interference) is not nearly as much an issue as in CDMA. This leads to better performance (lower bit error rate and therefore lower retransmissions) in high delay-spread environments (dense urban scenarios). LTE is also optimized to yield better performance at the cell sector edge.

The combination of better coverage, the 700 MHz advantage, better cell-edge performance, and reduced adverse impact of multipath will reduce battery drain on the end-user device, making it more power-efficient.

**3.1. OFDMA downlink transmission**

LTE uses multicarrier OFDMA technology rather than single carrier modulation schemes used in traditional cellular systems. The selection of OFDMA provides an efficient method for addressing the issue of multipath delay spread, which can account for several microseconds. The delay spread is the amount of time delay at the user equipment side from a signal traveling from the transmitter via different paths. The delay spread can cause a symbol received along a delayed path to bleed into a subsequent symbol arriving at the user equipment via a more direct path, leading to a condition called Inter Symbol Interference (ISI). At high data rates, it is feasible for ISI to exceed a symbol period and even spill into subsequent symbols. OFDM does not depend on increased symbol rates to deliver high data rates, but instead divides the available bandwidth into narrow sub-carriers and transmits data in parallel streams. Each OFDM symbol is therefore a linear combination of the instantaneous signals on each of the subcarriers in the channel.

In addition to the lower bandwidth subcarriers, each OFDMA symbol is preceded by a cyclic prefix (a guard interval used to separate symbols), thus reducing/eliminating the ISI.

LTE also incorporates Inter-channel Interference (ICI) resistance, which keeps its performance near consistent even in high-mobility scenarios.

FDMA has subcarriers very tightly spaced (overlapping yet not interfering because of orthogonality) to make efficient use of available bandwidth; subcarrier spacing is 15 KHz with a maximum number of 600 carriers in 10 MHz bandwidth. The carriers carry symbols for multiple users. The relatively high number of low bandwidth subcarriers enhances OFDM’s multi-path capabilities, which strengthens its resistance to interference, and improves spectral efficiency. By contrast, single-carrier systems do not scale well with bandwidth and are impractical at much above 5 MHz in real-world path delay environments.
3.2. SC-FDMA uplink transmission

A variation of the OFDMA, the SC-FDMA was selected for the uplink transmission in LTE. SC-FDMA was selected to compensate for a drawback with normal OFDM, which has a very high Peak to Average Power Ratio (PAPR). A high PAPR requires expensive and inefficient power amplifiers, increasing the cost of the terminal, and draining the end user’s battery more quickly.

SC-FDMA addresses the issue by grouping together the resource blocks in a way that reduces the need for linearity, and power consumption. A low PAPR also improves coverage.

4. Lower latency

Lower latency in LTE contributes to a better user experience. In the control plane, LTE supports a transition time of less than 100 ms from a camped state (idle mode) to an active state, such that a user plane is established. LTE also supports a transition time of less than 50 ms between dormant state and active state.

In the user plane, the delay is defined as the one-way transit time between a packet being available at the IP layer in the UE/evolved Node B (eNB) and the availability of the packet at IP layer in the eNB/UE. LTE enables a user plane latency of about 15 ms.

A significant improvement has been achieved in LTE for latency; EV-DO Rev. A supports a user plane latency of approximately 60 to 80 ms.

Additional factors that contribute to lower latency are:

a. Flat network model in bearer path—fewer network elements need to be traversed from device to Internet/application. Specifically, there is no separate Radio Network Controller (RNC) element in the bearer path. This separation of control and bearer plane also enables separate optimization of the control plane network (for signaling Busy Hour Call Attempt [BHCA] handling) versus the data plane network (for throughput and high-speed switching).

b. All-IP network—fewer expensive protocol translations and packet segmentations/reassembly operations need to occur due to the use of the all-IP network over Multiprotocol Level Switching (MPLS) backbone. In addition, the core network switching operation is closer to line-speed.

The lower latency provides a direct service advantage for highly immersive or interactive application environments, such as multiplayer gaming or rich multimedia communications.

5. Greater simultaneous use support

In EV-DO Rev. A (pure TDM-based scheduling), there is only one user being actively serviced on the downlink in any given timeslot (one-dimensional resource scheduling on the time axis). As a result, in order to engineer to a given latency budget (especially for real-time services), there is limited scheduling flexibility.

In LTE, in addition to higher data rates, the ability to perform two-dimensional resource scheduling (on the time and frequency axes) enhances the ability to support multiple simultaneous users (up to 50 users can be scheduled in the same timeslot). This lends support to always-on applications with need for session persistence with minimal latency and enables the “enhanced idle mode” concept as well as more granular/real-time multi-user support.

With EV-DO Rev. A, there is an upper-limit of 114 on the simultaneously active users (MAC-indices) per cell-sector. These are users actively assigned to the scheduler and a traffic channel—although not receiving transmissions in the same timeslot. In LTE, this equivalent number (engineered for 10 ms bearer latency) is 1,000.

In addition to the better simultaneous access for multiple users afforded at the RAN/RF layer, LTE also provides “simultaneous multiple network access” benefits to a single user at the IP-network layer.

For a single UE, LTE provides the ability to have multiple simultaneous Packet Data Network (PDN) connections—this means a single end-user can be assigned multiple IP-addresses for simultaneous IP connectivity to multiple public and/or private and/or enterprise networks. LTE does this while maintaining complete logical separation of data across these
multiple networks, to ensure differential treatment can be provided as required. This adds another dimension to single user functionality. EV-DO Rev. A does not have this ability to maintain multiple simultaneous PDN connections. Additionally, LTE will have full support IPv6 addressing from day one.

The increased simultaneous user support is a significant advantage over existing 3G implementations. This is key to enabling the proliferation of embedded wireless applications/systems.

6. Security

LTE incorporates multiple elements of security—including, but not limited to:

a. Symmetric key mutual authentication using 128-bit private keys and the EAP-AKA scheme.

b. Subscriber Identity Module (SIM) well-known methods of robust and non-invasive key storage.

c. RAN encryption of bearer data using derived keys post-full-authentication to prevent eavesdropping.

d. Integrity protection of all messages between UE and MME using covering codes to prevent alteration/snooping of sensitive subscriber ID (IMSI/IMEI) information in the signaling messages.

e. Additional identity protection/confidentiality to prevent snooping/tracking of specific users (by use of aliases and minimal unencrypted use of real user/device identifiers).

f. Replay protection using encrypted counter values and nonces.

g. Internet Protocol Multimedia Subsystem (IMS) granular authentication/authorization per service.

h. Use of Internet Protocol Security (IPSec) (mandatory in IPv6) for secure tunneled mode between the IP communication endpoints.

7. Simplified worldwide roaming

Because LTE will be the unified 4G standard for most 3GPP and 3GPP2 carriers worldwide, LTE devices will be fundamentally easier to set up for worldwide roaming. The caveat is that the actual frequency band used by different carriers will be different (thereby retaining the need for multiband devices).

As a result, the Verizon Wireless migration path to LTE will provide greater opportunities for seamless international roaming and for global device economies of scale as well.

8. Mass M2M deployment

LTE’s inherent support for IPv6 addressing and IMSI-based identifiers makes mass deployments of machine-to-machine applications over LTE possible.

This is in contrast to EV-DO Rev. A’s current use of IPv4 addressing and MIN/MDN identifiers (which have smaller addressing length, thereby limiting the total number of devices that can be simultaneously addressed).

IPV6’s increased addressing space advantage over IPv4 (128 versus 32 bits) is clear. IPv4 addresses are a scarce resource. Although the use of private-addressing and NAT (Network Address Translation) have extended the IPv4’s lifetime, the complexity and error conditions introduced by such IPv4 public-address-conservation techniques make them undesirable.

LTE’s use of the 15-digit IMSI as the primary identifier of the subscriber allows a much larger subscriber penetration. This is especially important for M2M/embedded wireless applications that will need a much larger numbering space, which is currently limited by technologies that require primarily-MDN-based-identification (10-digits). Although several LTE device implementations will use both IMSI and MDN/MSISDN identifiers, LTE opens up the possibility of MDN/MSISDN-less identification for M2M devices, thereby alleviating any issues due to scarcity of these “telephone number” identifiers.
Conclusion

LTE will provide Verizon Wireless subscribers with significant advantages in traditional and non-traditional wireless communication, over those currently provided via existing 3G technologies. LTE will also enable Verizon Wireless business opportunities in new areas, due to its advanced mobile broadband capabilities.

We expect that LTE will allow the development and deployment of a new generation of innovative applications, products, and solutions for Verizon Wireless consumers extending beyond the handset model, into the areas of consumer electronics, appliances, health care, telematics, cloud-computing, entertainment, utilities, security, education, and the M2M world.

All of the aforementioned benefits of the Verizon Wireless LTE implementation, including high uplink and downlink data rates, lower latency, better coverage and in-building performance, greater simultaneous access, security, and simplified worldwide roaming, will play an important role in the new services that will be supported by 4G.

The Verizon Wireless deployment of LTE is poised to change the landscape of today’s consumer and enterprise wireless communications experience and expectations.

References

Appendix B: Acronyms

3GPP—3rd Generation Partnership Project
3GPP2—3rd Generation Partnership Project 2
4G—Fourth Generation
APN—Access Point Name
AWS—Advanced Wireless Services
BHCA—Busy Hour Call Attempt
EAP–AKA—Extensible Authentication Protocol Method for 3rd Generation Authentication and Key Agreement
eNB—Evolved Node B
EV-DO—Evolution Data Optimized
FDD—Frequency Division Duplexing
ICI—Inter-channel Interference
IMS—Internet Protocol Multimedia Subsystem
IMSI—International Mobile Subscriber Identity
IP — Internet Protocol
IP-CAN — Internet Protocol-Connectivity Access Network
IPSEC — Internet Protocol Security
IPv6 — Internet Protocol Version 6
ISI — Inter Symbol Interference
LTE — Long Term Evolution
MAC — Media Access Control
MDN — Mobile Directory Number
MIMO — Multiple-Input and Multiple-Output
MME — Mobility Management Entity
MPLS — Multiprotocol Label Switching
MSISDN — Mobile Subscriber Integrated Services Digital Network Number
OFDM — Orthogonal Frequency Division Multiple
OFDMA — Orthogonal Frequency Division Multiple Access
PAPR — Peak to Average Power Ratio
PCEF — Policy Charging and Enforcement Function
PCS — Personal Communication Services
PERL — Packet Error Loss Rate
RF — Radio Frequency
RNC — Radio Network Controller
SC-FDMA — Single-Carrier Orthogonal Frequency Division Multiple Access
SIM — Subscriber Identity Module
TDM — Time Division Multiplexing
UE — User Equipment