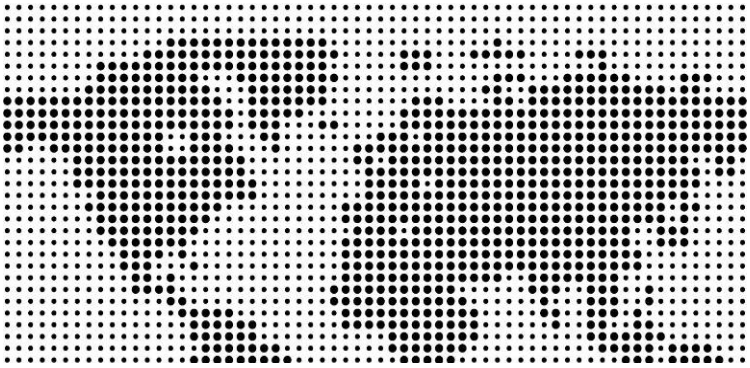
LTE—A Well-Designed Mobile OFDMA IP Solution



Qualcomm Incorporated
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[1] Executive Summary

UMTS operators around the world are experiencing tremendous success with High-Speed Packet Access (HSPA), and are rapidly launching services to capitalize on HSPA's mobile-broadband capabilities and increased data capacity. 3GPP is currently defining Long Term Evolution (LTE), which allows UMTS operators to build on HSPA's success and complement HSPA with even higher peak rates and lower latency, thus supporting an enhanced broadband experience in high-demand areas, while leveraging new and wider spectrum.

The industry is rapidly moving toward the convergence of communication, computing and consumer platforms, as well as converged services across fixed and wireless networks. Users desire services like voice, music, picture and video sharing, and social networking—anytime and anywhere, with a similar experience regardless of location. Mobile broadband is in the center of convergence, enabling consumer and corporate users to enjoy higher data rates and a broadband experience in all environments, using converged devices. As already happening with 3G, LTE will support a variety of devices, including desktop modems, mobile phones, laptops and ultra-mobile PCs (UMPCs), and will effectively meet the demand for connectivity from a new generation of consumer electronics devices with embedded modems. LTE allows operators to economically and effectively address all market segments and offer innovative services.

LTE is a leading OFDMA-based, mobile broadband technology, supported by a new core network being developed by 3GPP. LTE has been designed to provide interoperability and service continuity with existing UMTS networks, allowing UMTS operators to capitalize on existing UMTS/HSPA and future HSPA+ investments. It offers high spectral efficiency, low latency and high peak data rates (150 Mbps downlink, 75 Mbps uplink in 20 MHz) and leverages HSPA/LTE multimode devices. LTE incorporates the most advanced techniques of OFDMA and antenna techniques such as MIMO (Multiple-Input Multiple-Output), SDMA (Spatial Division Multiple Access) and beamforming, among others.

[2] Converging Markets

As the trend toward convergence accelerates, individuals increasingly expect to have access to services anywhere and anytime—access to voice, broadband Internet, email, portable music, picture sharing and live video sharing. In addition, user-generated content and social networking open an array of possibilities in a mobile world. Many of these services have already been made available through today's 3G networks, and demand for these services will continue to grow. LTE's flexible air interface with integrated Quality of Service (QoS) and low latency will support the entire range of IP services, including delay-sensitive services such as telco-quality VoIP.

LTE will benefit users by enriching mobile communications and enhancing broadband applications through higher peak and average data rates. For fixed and nomadic applications, users will experience wireline-like speed and performance, similar to DSL and cable connections, over a wireless connection. For operators, QoS support enables service tiering, which allows the network to assign users different levels of priority based on subscription levels tailored to each user's needs.

2.1 LTE Addresses a Wide Range of Market Segments

Consumers will enjoy LTE's broadband functionality in a variety of consumer electronic devices as well as phones, PDAs, UMPCs and laptops with embedded LTE modems or PC cards. As has already occurred in many HSPA markets, consumers may consider LTE as a replacement for their primary residential fixed broadband connection, thanks to its higher bandwidths and lower delays.

A variety of devices, from gaming and portable entertainment players to pocket computers and beyond, can leverage the broadband-communication capabilities of LTE. The fast response times satisfy the needs of the most demanding users, such as gamers who require low-latency networks for interactive, real-time gaming.

Ubiquitous mobile broadband connectivity via LTE and HSPA+ will also act as a catalyst for future innovation in devices. Consumers will increasingly demand that devices and services enabled today by Wi-Fi provide wide-area broadband coverage, through HSPA today and LTE tomorrow.

Corporate users will be able to obtain Ethernet-class performance through LTE, and mobile operators can configure their networks to satisfy the more stringent requirements of corporate users, such as higher-priority performance and response time. Corporate users will enjoy LTE services by using PC cards or embedded modems in devices such as PDAs, UMPCs or laptops, in addition to mobile phones. Multimode LTE and HSPA+ devices will ensure a similar user experience and ubiquitous coverage, regardless of the user's location.

As with consumer users, corporate users will increasingly consider LTE as a primary broadband replacement for their business landlines, thanks to the higher bandwidths, lower delays and high capacity provided by LTE.

2.2 LTE Leverages Multimode Devices

One important factor driving the cost of a wireless technology is the ecosystem of infrastructure and device vendors. LTE leverages multimode devices that are backward compatible with existing 3G technologies. It relies on a proven industry business model for faster time to market with innovative services and robust mobile-broadband systems. Multimode devices allow operators to deploy LTE networks in phases, thus minimizing initial investments and focusing LTE on high-demand areas. Users can fall back on existing 3G networks in areas outside the LTE coverage.

[3] LTE Leverages New and Wider Spectrum

LTE leverages new and wider spectrum, complementing HSPA and HSPA+ deployments by providing a capacity boost in high-demand areas. LTE's OFDMA technology provides increasingly higher capacity at wider bandwidths. From a performance perspective, LTE is therefore best suited for bandwidths of 10 to 20 MHz, leveraging the benefits of OFDMA. Similarly, LTE is less suited for bandwidths below 5 MHz; HSPA+ provides similar capacity and peak rates as LTE in the 5 MHz block, for the same number of antennas.

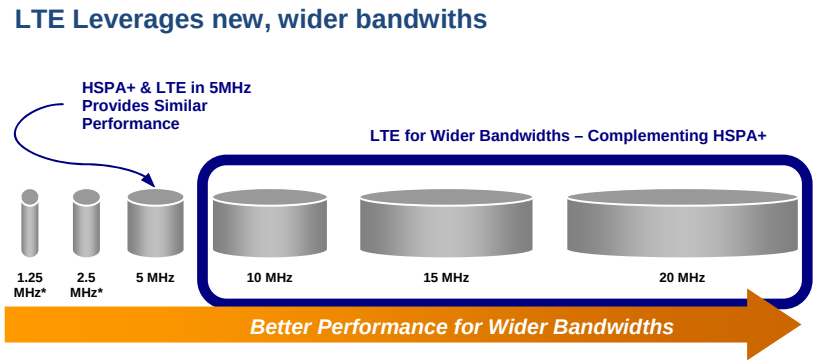

Figure 1: LTE Leverages Wider Bandwidths

LTE flexibly supports a range of bandwidths up to 20 MHz, as depicted in *Figure 1*. The available peak rate and average user rate per individual user scales directly with the bandwidth. LTE supports both frequency division duplex (FDD) and time division duplex (TDD) modes, allowing operators to address all available spectrum types.

[4] LTE Complements HSPA

UMTS operators around the world are experiencing a tremendous success with HSPA and are rapidly launching services to capitalize on HSPA's mobile broadband capabilities and increased data capacity. HSPA+ further enhances the performance capabilities through incremental investments and backward-compatible devices. HSPA+ will ensure a consistent user experience across the entire network, and it allows the operator to roll out LTE in phases, such that LTE

is first deployed in dense urban areas and then gradually expanded. The common IMS network enables users to experience the same services across the entire network, regardless of airlink technology.

HSPA+ offers similar capacity and peak rates as LTE in the 5 MHz block, and provides a similar user experience and service continuity outside the LTE coverage. LTE enables even higher peak rates and average rates through 4x4 MIMO, using four receive and transmit antennas at both the Node B and user device. Furthermore, HSPA+ supports high-capacity VoIP, allowing voice-service continuity for LTE systems that rely on VoIP.

LTE uses a new core network called Enhanced Packet Core (EPC), which allows for a more flat and IP-based architecture. Throughout the design of LTE and EPC, emphasis is placed on ensuring interoperability with existing 3GPP technologies like UMTS and GSM. This will ensure that HSPA+ and LTE coexist. The emphasis on EPC is also to reduce network latency and simplify network operation and maintenance.

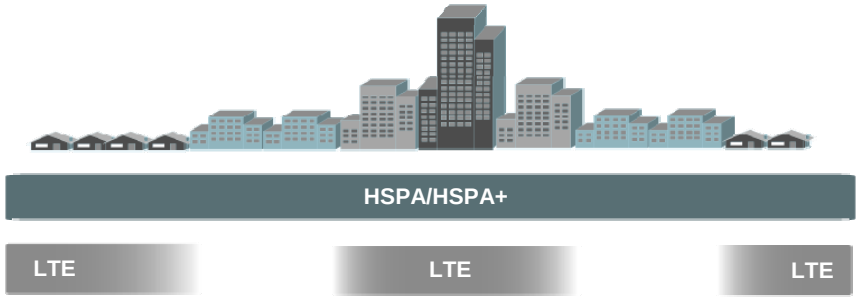

Figure 2: LTE Overlay on a 3G Network

As shown in *Figure 2*, an operator can initially focus on high-demand areas, falling back to HSPA/HSPA+ outside the LTE coverage, and then continue the network build-out in phases, as data demand increases. Multimode devices supporting both LTE and the existing 3GPP technologies will enable backward compatibility outside the LTE coverage. The LTE network supports seamless handoffs to UMTS/HSPA networks, providing seamless service continuity throughout the complete UMTS network.

[5] LTE Performance and Key Features

LTE was designed from the ground up for mobility and high capacity, as well as for efficient delivery of real-time applications such as voice through VoIP. Supporting any mix of voice with data services on the same carrier allows the operator to meet all possible service needs and market segments. However, the initial commercial focus is on data services and voice is expected to be implemented in future LTE phases.

LTE leverages advanced antenna techniques such as MIMO, SDMA and beamforming, which provide benefits to users in both high and low signal-strength areas. Compared to HSPA+, LTE introduces higher-order downlink MIMO (up to 4x4 MIMO, but 2x2 is initially commercialized) and MIMO in the uplink, to further increase the peak rates and performance. All of these techniques aimto increase the data rates experienced by the user, as well as the capacity of the system.

LTE Peak Data Rates	10 MHz (2x2 MIMO)	20 MHz (2x2 MIMO)
Downlink	73 Mbps	150 Mbps
Uplink	36 Mbps	75 Mbps

Table 1: LTE Data Rate for 10 MHz and 20 MHz FDD

As shown in *Table 1*, the LTE peak data rates increases with the available bandwidths, and can be as high as 150 Mbps in the downlink, for a single user in ideal radio conditions using 2x2 MIMO in 20 MHz.

MIMO can increase the system capacity and the user data rates without using additional power or bandwidth, by transmitting multiple streams through multiple antennas at the receiver and transmitter. MIMO allows very high data rates, especially for users close to the base station,

whenever it is possible to transmit multiple orthogonal streams. A rich scattering environment is required to ensure that the multiple data streams remain orthogonal. The MIMO benefit is therefore maximized in a dense urban (city) environment, as there is enough scattering, and for users close to the eNode B.

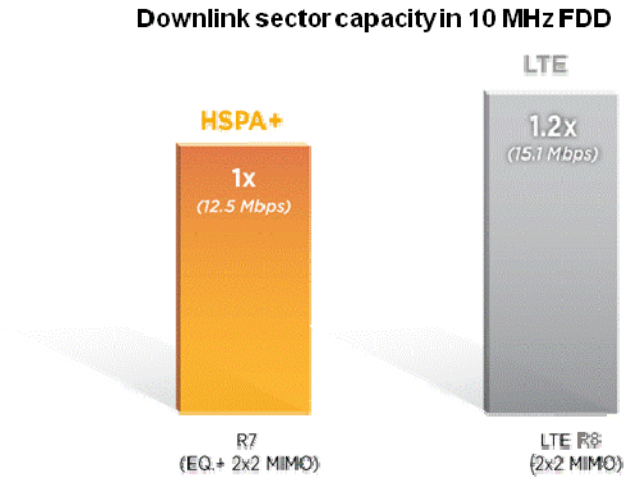

Figure 3: HSPA+ and LTE downlink capacity in 10MHz FDD[1]

Beamforming increases the user data rates by focusing the transmit power in the direction of the user, effectively increasing the signal at the user. Beamforming provides the most benefits to the users in areas with weaker signal strength, like the edge of the cell coverage. SDMA is another advanced technique, which increases sector capacity by allowing simultaneous transmissions of the same physical resources to different users, who are spatially separated. This technique can be combined with MIMO to offer higher data rates simultaneously.

Figure 3 presents the LTE downlink data capacity for 10 MHz FDD and a smaller cell, illustrating the benefit of advanced antenna techniques. Using the same number of antennas and MIMO, both HSPA+ and LTE provide similar performance.

[1]*Source: Qualcomm simulations, D1: 500m ISD, HSPA+ scaled up from 5 MHz, details in 3GPP R1-070674.*

[6] Conclusion

LTE is a highly optimized, spectrally efficient, mobile OFDMA solution built from the ground up for mobility, and it allows operators to offer advanced services and higher performance for new and wider bandwidths. LTE builds on HSPA's success and will complement existing HSPA and HSPA+ networks with a capacity boost in high-demand areas. LTE's high performance, integrated QoS support and low latency allow operators to efficiently target the entire range of IP services, from delay-sensitive services such as telco-quality VoIP to HD-quality video streaming.

LTE will support the full range of devices including desktop modems, mobile phones, laptops, and ultra-mobile PCs, and will effectively meet the demand for connectivity from a new generation of consumer electronics devices. LTE allows operators to economically address all market segments and many types of innovative services, including the stringent needs of corporate clients with high-bandwidth demands.

LTE is based on a flattened IP-based network architecture that improves network latency, and is designed to interoperate on and ensure service continuity with existing 3GPP networks. LTE leverages the benefits of existing 3G technologies and enhances them further with additional antenna techniques such as higher-order MIMO. The 3G ecosystem of device manufacturers will leverage 3G knowledge and experience to ensure availability of multimode devices to suit a variety of applications and end-user preferences in the years ahead.