LTE and the Anticipation of 5G

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About this paper

A Pathfinder paper navigates decision-makers through the issues surrounding a specific technology or business case, explores the business value of adoption, and recommends the range of considerations and concrete next steps in the decision-making process.

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**Introduction**

Mobile broadband technology transformed society as high-performance smartphones and affordable data services put the world in a user’s palm. This success sprung from a rich tapestry of radio access technology and core network design produced in industry collaboration as part of an open standards development process in the Third Generation Partnership Project (3GPP). Early mobile broadband technology drew upon CDMA (Code Division Multiple Access) innovations to deliver limited broadband IP data network support in 5MHz of spectrum. These 3G networks, however, were essentially remnants of legacy hierarchical circuit-switched systems architecture.

Recognizing the need for higher performance and more flexibility, 3GPP tackled the challenge of crafting the next technology generation with an approach that could evolve for years to come. This new 4th generation (4G), Long Term Evolution (LTE), came to market with support for 20MHz-wide channels, OFDM modulation and an evolved flat-IP core network. Since its initial 2010 launch in 3GPP Release 8, LTE has undergone continued change that drives home the concept of long-term evolution. The latest version, Release 13, enters the market as the industry is looking toward future 5G technology.

3GPP Release 13 provides a dramatic expansion of bandwidth delivered to end-user devices along with features that enable massive Internet of Things (IoT) traffic as well as mission-critical communications for public safety. LTE Advanced Pro features coming in Release 13 enter the market at a time when the industry is developing the initial 5G specifications. Experience gained from Release 13 deployments provide important insight that helps anticipate the promise and power of the future 5G network.

This paper explores the contours of LTE Advanced Pro. We look at some of the key features that come with 3GPP Release 13 and its successor, Release 14. On the eve of 5G, these two releases deliver significant new functionality that boosts customer experience, reduces network costs and establishes valuable insight to guide coming 5G deployments.

**4G LTE's mobile broadband success and limitations**

With the arrival of mobile broadband technology based on 3GPP LTE, subscribers gained access to responsive high-speed user experiences that transformed the role of mobile devices in people’s lives at home, work and play. By moving subscribers away from performance-limited 3G systems based on WCDMA and CDMA technologies running over traditional hierarchical telecom architectures, operators delivered networks with higher throughput and lower latency.

From a spectrum efficiency standpoint, LTE delivered more data per Hertz thanks to adoption of a spectrally efficient OFDM waveform designed for larger channel widths. Where 3G networks were limited in terms of channel sizes, with CDMA EVDO networks capped at 1.5MHz and WCDMA networks operating in 5MHz channels, LTE enables 20MHz channels.

As with WCDMA technology evolution that resulted in a move to higher capacity by combining multiple 5MHz carriers for a larger aggregate data capacity, LTE embraced the evolutionary promise incorporated into its name and provided for carrier aggregation. With carrier aggregation, recent LTE network deployments can combine many carriers in different radio bands together for extraordinary bandwidth.

Radio performance is only one benefit delivered by LTE. The underlying system architecture shifted from a legacy hierarchical telecom structure designed for circuit-switched voice calling to a flat structure based on IP routed packet data. With network functionality consolidated to fewer network elements and optimal routing, LTE brought sharply improved data traffic throughput and lower latency. For network operators, the new architecture enabled important infrastructure cost reductions for the core network supporting the radio access network.

For end users, the superior experience offered by LTE made video consumption a part of everyday mobile life, while new mobile-based virtual reality experiences such as Pokémon Go became part of the modern lexicon. At 451 Research, we tracked the expanding take-up of LTE-based services around the globe. Our December 2016 Global Mobile Forecast showed sustained strong 44% annual growth for LTE mobile broadband adoption, with 26% of subscribers now using 4G around the globe.

Structural limits, however, constrain the evolutionary path of LTE. The maximum channel width of 20MHz and a rigid air interface frame structure with a limited numerology prevent evolution toward the lowest possible latency and greatest possible throughput. Breaking past these barriers requires new techniques proposed for the next generation of radio technology: 5G.
Beyond broadband: Building on LTE success

With the word ‘evolution’ as part of the name assigned to 3GPP’s 4G radio technology, it is no surprise that LTE continues to gain important new capabilities as it converges with, and ultimately becomes an integral foundation for, 5G.

Following 3GPP Release 8, the first release bringing LTE into commercial networks, 3GPP introduced important functional extensions with Release 10 and Release 13. With the addition of carrier aggregation, Release 10 ushered in the era of LTE Advanced networking by freeing operators from small slices of spectrum in a single band. In 2017, Release 13 enters operational networks to begin an era of LTE Advanced Pro networking that brings low-power, wide-area cellular network support for the Internet of Things, as well as essential features for mission-critical public-safety network operations.

LTE evolution continues with 3GPP Release 14 features that expand on the new functionality that came in Release 13. Taken together, these releases offer essential synergy with future 5G deployments. These new capabilities are worth considering individually.

ENHANCING THE MOBILE BROADBAND EXPERIENCE

The arrival of 3GPP Release 13 significantly boosts mobile broadband performance with additional carrier aggregation flexibility. When added to higher-order Multiple-In Multiple-Out (MIMO) and more sophisticated modulation that came with prior 3GPP releases, networks gain gigabit LTE traffic throughput that radically changes how end users perceive performance. This new technology offers vital synergy with 5G by supplying a high-performance umbrella of LTE-based network over hotspots of early 5G network regions. As subscribers move in and out of 5G coverage, the variation in performance becomes less noticeable when the foundational LTE network is operating at gigabit levels.

Since the arrival of 3GPP Release 10 features, mobile network operators have boosted the end-user experience by blending multiple physical chunks of spectrum together into a single logical channel. Carrier aggregation, a key advance of Release 10, incorporated mechanisms enabling the combination of constituent carriers across different bands, helping expand the total addressable bandwidth to match the operator’s actual holdings.

With Release 13, a framework is now in place enabling future carrier aggregation of up to 32 component carriers. This achievement is important for two reasons: First, many operators had ample spectrum, but it was not contiguous; carrier aggregation allowed the operators to combine the different chunks into a useful, high-performance asset. Second, LTE is bounded by 20MHz channel size. Even if the operator has more spectrum available, the most spectrum that could operate in LTE was 20MHz wide. With carrier aggregation, this limit can be escaped to offer multi-gigabit services to end users. While no operator has enough spectrum to aggregate a theoretical maximum 32 carriers, future 3GPP releases will define a variety of CA carrier combinations that constitute an important step toward broadband service continuity as users move from 5G to LTE.

Boosting user performance, however, is more than just adding bandwidth. Adding the number of antenna ports for MIMO processing helps boost receiver signal-capturing power by combining signals arriving from different paths and at different times. Higher-order MIMO LTE systems with support for 4x4 antennas are now beginning to arrive in networks around the globe. These MIMO features help extend high-quality coverage toward the cell edge while also contributing to higher throughput.

Massive MIMO (M-MIMO) is an important advancement enabled by 3GPP Release 13 support for full-dimension (3D) MIMO. A hallmark of coming 5G networks tapping spectrum above 6GHz, M-MIMO is also useful in sub-6GHz bands deployed with Release 13 LTE systems. At Mobile World Congress 2017, network equipment suppliers showed off a number of M-MIMO demos that help extend cell ranges in challenging 2.5GHz spectrum. By deploying an M-MIMO system with up to 64x64 antenna elements, an operator can better utilize this generous spectrum band by leveraging 3D beamforming to boost range and gain capacity.

Finally, modulation schemes have an impact on how much data is transmitted per Hertz of spectrum. LTE supports a variety of modulation schemes to accommodate varying radio conditions. At cell edge, for example, simpler schemes are required due to poor signal conditions. Release 12 introduced 256 Quadrature Amplitude Modulation (256QAM), an advance in signal modulation that encodes 8 bits in a single symbol. By contrast, 16QAM encodes 4 bits in each symbol. By increasing the efficiency of the modulation, more data can be transmitted with the available spectrum.
When carrier aggregation on the downlink, 4x4 MIMO and 256QAM are deployed, end users can experience received data throughput at rates above 1Gbps. As 5G networks enter the market, this umbrella of high-performance LTE networking will serve as the connective tissue for satisfying seamless mobile wireless networking.

**CLIPPING WIRES TO THE INTERNET OF THINGS - LPWA**

Effective and affordable machine-type communication is a vital foundation for the expected growth of IoT connectivity. With LTE Advanced Pro features in 3GPP Release 13, mobile network operators gain several important technologies for services supporting massive machine-type connectivity. The support coming with LTE Advanced Pro addresses near-term IoT scale requirements in advance of 5G entering the market.

Standing out in LTE Advanced Pro is new Narrowband IoT (NB-IoT) technology supporting low-power, wide-area (LPWA) machine connectivity. Addressing essential LPWA requirements for long battery life and wide coverage, NB-IoT is an important advance that provides network operators the opportunity to extend existing LTE networks with a new service offering. NB-IoT is an independent air interface that operates in a dedicated portion of an OFDM signal. Within the resource block set aside for NB-IoT, the LTE base station operates session signaling and data transmission procedures optimized for a large number of low-power, wide-area machine devices serviced in a cell sector. Data rates supported by the 180kHz of bandwidth supplied is limited to 200Kbps with half-duplex transmission. The lower transmission rate coupled with high repetitions helps deliver wide coverage benefits.

Reports from operators gaining early experience with this new technology suggest that a single cell sector can support up to 100,000 machines with these procedures. This achievement is important because massive machine-type connectivity supporting one million devices per cell sector is slated for the second phase of 5G development coming in Release 16. Support for 100,000 is a substantial leap from existing LTE capability and provides headroom for market growth in the lead-up to 5G.

Of course, not all machine communications have the constraints that drive ultra-low power requirements. In fact, some machine communication applications benefit from higher data rates. To address those applications, LTE Advanced Pro added Cat-M1, a new user equipment category supporting up to 1Mbps transmission rates. The benefit of Cat-M1 is that a user device only powers 1.4MHz of bandwidth, in contrast to the 20MHz of bandwidth powered by typical LTE devices. The reduction of power and a significant drop in modem complexity – as much as 80% of the complexity found in legacy Cat 1 modems – makes Cat-M1 an important solution for machine-type applications that require power efficiency without compromise on data rates.

Along with the new equipment categories aimed at machine communications, LTE Advanced Pro expands the tools available to operators for boosting device power efficiencies. The Power Saving Mode (PSM) introduced in Release 12 and extended Discontinuous Reception (eDRX) cycles that come in Release 13 enable long sleep periods for machine-type devices deployed in the field. The more a device sleeps, the longer the battery life.

**ADDING UNLICENSED SPECTRUM TO DRAMATICALLY EXTEND LTE TECHNOLOGY POWER**

The dramatic expansion of carrier aggregation capacity with support for 32 constituent carriers in 3GPP Release 13 is only one element of LTE’s growing prowess as broadband media. Also important are new innovations that leverage unlicensed spectrum to boost LTE user experience. Several approaches for combining licensed and unlicensed spectrum bands arrive with Release 13.

A major innovation introduced in Release 13 is a striking new capability that transmits an LTE waveform in unlicensed spectrum. Called Licensed Assisted Access (LAA), this air interface incorporates multiple features to coexist fairly with Wi-Fi devices sharing the unlicensed spectrum. These techniques include Listen-Before-Talk, Discontinuous Transmission, Dynamic Frequency Selection, Carrier Selection and Transmit Power Control. With LAA, operators gain access to readily available supplemental downlink carriers that can be aggregated with licensed carriers. With access to large spectrum blocks in the 5GHz band, mobile network operators can supplement limited spectrum holdings without the costs of a new spectrum license.

In addition to LAA, two other mechanisms introduced in Release 13 provide mobile network operators with an ability to divide packet traffic across an LTE air interface on licensed spectrum and a Wi-Fi air interface on unlicensed spectrum. The first approach is called LTE Wi-Fi Aggregation using IPSec Tunnel (LWIP). LWIP supplements licensed spectrum by adding a packet flow between eNodeB base stations and user equipment over an IPSec tunnel established across a Wi-Fi access point. The advantage of LWIP is that no changes are required in legacy Wi-Fi infrastructure to reap the benefits of using
licensed and unlicensed spectrum. User equipment, however, must support the dual connectivity mechanism to combine the data streams. For LWIP to work, the user equipment must support dual connectivity and Packet Data Convergence Protocol (PDCP) aggregation.

The other Wi-Fi mechanism described in Release 13 is LTE Wi-Fi Aggregation (LWA). As with LWIP, the LTE eNodeB can aggregate the bandwidths of the LTE and WLAN links by dividing packets flowing on the downlink so that some packets travel over the LTE link and others over Wi-Fi. The packets are then reassembled by the PDCP layer in the user equipment, so that the usage of licensed and unlicensed spectrum is transparent to the upper layers and the user. Implementations for LWA may combine Wi-Fi and LTE in the same base station (e.g., a small cell) or in different network elements (e.g., eNodeB and a Wi-Fi network). When different network elements are used, packets sent to the Wi-Fi network must travel over the Xw 3GPP defined interface between an eNodeB and a Wi-Fi access point or access controller. For LWA to work, the user equipment must support dual connectivity and PDCP aggregation.

SAVING LIVES WITH MISSION-CRITICAL COMMUNICATIONS

The arrival of high-performance fixed and mobile broadband has transformed corporate operations in the enterprise. As applications shift to the cloud and mobility extends application reach across geographies, corporations revolutionized business practices to produce efficiencies while accelerating innovation speed. While government operations typically move more slowly than nimble enterprises, public-safety agency leaders see the potential for an equivalent transformation as emergency services networks are modernized.

Several nations are already moving to embrace LTE as a key element of their public-safety communications architecture. The most ambitious move is in the UK, as the nation prepares to retire its legacy land mobile radio (LMR) network hosted by Airwave. In the US, the First Responder Network Authority (FirstNet) is in the process of creating a national public-safety network operating LTE in dedicated 700MHz spectrum. Korea is in the final stages of building its national public-safety network based on LTE in dedicated spectrum. With the exception of the UK, these networks focus on mobile broadband data support that complements existing legacy LMR networks providing mission-critical voice communications. Eventually, however, the convergence of mission-critical data and mission-critical voice will occur. Because the UK is moving rapidly toward this objective with its new Emergency Services Network (ESN), the nation’s progress is being closely watched by other agencies around the globe.

Replacing mission-critical voice networks based on TETRA and APCO Project 25 with LTE is a daunting challenge. These legacy LMR technologies were designed from the ground up to be hardened systems offering specialized voice communications capabilities that are difficult to achieve in a LTE network. Challenges include supporting direct communications from device to device in the absence of a supervising network, limited group communications functions, power limitations for device uplink transmissions and limited support for priority access. To address these limitations, 3GPP delivered new specifications in Release 12 and Release 13. Initial work in Release 12 brought enhanced quality-of-service capabilities for priority and preemption, as well as Proximity Services (ProSe) and Group Call System Enablers for LTE (GCSE_LTE). ProSe enables device-to-device communication, while GCSE_LTE enables group communication where one talks and many listen.

The LTE Advanced Pro mission-critical push-to-talk (MCPTT) features arriving with Release 13 build on the work in Release 12 to provide services for floor control to determine who gets access to speak, and for speaker identification, emergency signaling for a user’s ‘Mayday’ distress alert and location information. The group’s efforts included enhancements to the Evolved Multimedia Broadcast/Multicast Service (eMBMS), group calling and group management. With this work, emergency services operations gain responsive PTT functionality suitable for large groups of users. Additional public-safety communications functionality arrives in 3GPP Release 14 to extend the group communications support to include video.

5G expands on the concept of mission-critical communications by adding support for low latency and ultra-high reliability. These features enable a new class of performance-critical applications that have life-safety implications due to the use of drones or robotics. For Releases 13 and 14, however, the term ‘mission critical’ is used to describe public-safety communications in support of law enforcement, firefighting and emergency medical services voice and data needs.
CONNECTED VEHICLES TRANSFORMING TRANSPORTATION NETWORKS
The automotive industry is being transformed by communications technology. With dramatic innovations targeting vehicle safety, autonomous driving and passenger entertainment, communications networks delivering Vehicle-to-Everything (V2X) connectivity are fast becoming an essential part of the landscape. These links include Vehicle-to-Vehicle (V2V) for direct communication, Vehicle-to-Infrastructure (V2I) for links to roadway systems, Vehicle-to-Pedestrian (V2P) for pedestrian safety, and Vehicle-to-Network (V2N) for access to cloud-based transportation systems. For safety reasons, of course, V2V technology functions even when vehicles are beyond cellular coverage.

Early work on V2V and V2I systems embraced short-range Wi-Fi technology adapted for higher mobility. In the US, Dedicated Short Range Communication (DSRC) technology based on IEEE 802.11P and IEEE 1609 Wireless Access in Vehicular Environments (WAVE) is one option for addressing the challenge. ITS-G5, a similar specification produced by ETSI and also based on IEEE 802.11P, is proposed for the European region. More recently, however, LTE gained important new device-to-device functionality that promises superior performance for V2X applications. When coupled with ubiquitous geographic cellular coverage now in place across the world, LTE and 5G promise a high-quality uniform radio access enabling all V2X use cases.

To fully realize the promise of LTE-based direct mode communications, the 3GPP standards organization is introducing new cellular V2X (C-V2X) features in Release 14. Building on past work in Releases 12 and 13 that developed device-to-device communications with ProSe and quality-of-service enhancements, Release 14 addresses requirements enabling high-performance, low-latency V2X communications. Examples of these requirements include lower latency, support for periodic broadcast messages and communication ranges accommodating human response time. Adoption of LTE Advanced Pro – and ultimately 5G – means that the evolution of intelligent transportation systems will gain the benefit of 3GPP silicon scale along with the superior radio performance offered by LTE-based radio interfaces.

Architecturally, LTE Advanced Pro technology serves as a physical access layer in V2X communications. This sets the stage for other industry bodies to adapt higher-layer vehicle protocols such as IEEE 1609, as well as protocol specifications produced by the Society of Automotive Engineers (SAE), for use with V2X approaches. The automotive industry stands to benefit by leveraging years of V2X research and development with a flexible, high-performance radio technology. Aside from superior radio performance, this approach enables a flexible blend of direct and network-based functionality that delivers a superior end-user experience for drivers and passengers while also enhancing safety with longer-range, higher-rate transmissions.

Work on 3GPP Release 14 is in progress this year, while the first commercial networks will arrive in the 2018 to 2019 time frame. But LTE Advanced Pro features supporting V2X are just the start. 5G will bring aggressive latency and reliability enhancements that can enable new use cases such as vehicle platooning, remote driving, intersection safety and dynamic ride sharing.

The Virtualization of the Network and Mobile Edge Computing
Digital transformation is under way across the enterprise landscape. With this transformation, applications migrate into the cloud and, increasingly, end users access and control data from mobile devices. This work is going on in today’s 4G LTE networks with an aim of delivering improved network performance and more flexible service deployment.

In advance of 5G, many efforts are under way to make this flexibility possible. Deployment of network elements hosted in virtual environments is made possible by network functions virtualization (NFV), an architecture that allows migration from hardware-based networking appliances to software-based network functions consolidated onto virtualized, high-volume servers. The application of NFV yields near-term infrastructure flexibility that simplifies deployment of new services.

Along with NFV, software-defined networking (SDN) adds important flexibility by separating the data path (e.g., voice call, streaming video) from the control path (e.g., management). The impact of SDN-based networks is greater network flow control that aids load balancing and helps meet demanding quality-of-service needs.

In addition to the expanding options for virtualizing the network, new capabilities that bring compute power to the edge of the network are becoming reality. Support for compute power at the edge of an access network, close to user equipment and with limited storage and compute options, helps enable some applications that require very low latency between a device and a cloud-based application. Emerging use cases for machine-to-machine applications, for example, may need a tight loop to send sensor data to a cloud instance and obtain an immediate response for a control action. To enable these new use cases in LTE and 5G networks, specification efforts are in progress outside of the mobile-focused 3GPP organization.
Reducing latency becomes possible when cloud instances can materialize at the edge of the mobile network. Mobile Edge Computing (MEC) is a network innovation that makes this possible by putting computing capability at the edge of the radio access network, close to the end user. Not surprisingly, MEC is an advance that plays a large role in future 5G networks that aim to deliver low-latency support for performance-critical applications. But availability of robust performance at the edge of the network is also a useful addition to today’s LTE networks. Fortunately, MEC specification work began in 2014 as a European Telecommunications Standards Institute (ETSI) initiative aimed at 4G networks. As a result, early MEC deployments are becoming possible in advance of 5G standardization efforts.

The benefits of MEC can be illustrated by the stadium use case, where applications run in cloud-based instances at large sporting events. Leveraging low-latency access to sensors supplying real-time player data and video, the applications can deliver a rich spectator experience through responsive live video feeds and augmented reality. Even better, this is possible in advance of 5G with high-performance LTE Advanced Pro and ETSI-standardized MEC systems.

MEC becomes even more important with 5G. The low latencies called for with 5G-enabled critical communications use cases – tactile Internet, autonomous driving and factory automation – cannot be realized with legacy LTE network architecture. MEC is a vital enabler for transformative use cases. While MEC is being specified to coexist with today’s 4G networks, 5G will take the potential of MEC to the next level of performance.

5G opening up avenues to innovation

Looking to the future, 3GPP designed 4G LTE technology with an eye to continuous enhancements bringing new features and performance over a span of many years. To be sure, 3GPP delivered on its promise and LTE Advanced Pro exemplifies the extent of innovation possible within the LTE framework. But LTE radio access network and systems architectures do have limits. LTE’s limited 20MHz channel width and a focus on spectrum below 6GHz means that a new generation of radio access technology is required. Likewise, the evolved systems architecture that took the industry from legacy telco hierarchical network design to a flat, IP-based approach holds limitations that stymie new innovations calling for ultra-low latency, ultra-high reliability and massive device scale. Addressing these new limits requires the next generation of mobile radio technology: 5G.

Industry players are now working at full throttle to develop the essential 5G capabilities needed for increasing devices, new use cases and higher performance. At time of this writing, 3GPP has set plans for two phases of 5G specifications: Phase One in Release 15 and Phase Two for Release 16. The first phase will hew closely to the existing LTE path, with OFDM serving as the dominant radio aspect but gaining wider channel sizes and increased frame flexibility. The Release 15 systems architecture may be the bigger story, with ingrained support coming for network slicing mechanisms that make cloud-based virtualization techniques useful in designing and deploying mobile services. Just as vital, MEC becomes an integral element in the system architecture as a means to drive end-to-end latency down for performance-critical applications. Release 15 will serve as the start of a revolutionary period that transforms what mobile radio access offers to enterprises and consumers. Release 16 will go further, but its breadth remains under investigation as study items during development of Release 15.

To be sure, an early embrace of 5G technology will come from tech-savvy markets such as China, Japan, South Korea and the US. Some of the first deployments – using pre-standard approaches – will serve as wireline replacement technologies in the US and demonstrations of technology prowess at the 2018 Winter Olympic Games in South Korea. We expect broad adoption of 5G to occur during the period between 2020 and 2025 as Release 15 systems enter the market at large scale.

As 5G emerges, however, LTE will continue to play a significant role. A prime benefit of the new 5G radio is its capability for unlocking broad spans of high-frequency spectrum below and above 6GHz. But lower ranges of the radio spectrum do not have large available chunks of spectrum. This means that LTE Advanced Pro operating in lower bands will be vital for filling in gaps between 5G coverage zones. LTE in lower bands also serves as a valuable and reliable signaling layer for coordinating access across LTE, LTE Advanced Pro and 5G regions. Clearly, LTE will continue its evolutionary journey even as 5G spreads across the globe.
Conclusion

Future 5G systems hold the promise of transformational technology that reshapes industry and society. This pioneering technology will integrate devices, radio access technology, core network and cloud to achieve a fertile end-to-end foundation for innovation. To be sure, the 5G mandate is different from 4G. New use cases envisioned for 5G networks call for greater radio flexibility and forward-looking future-proofing.

LTE remains a foundational radio access technology and, in fact, continues its evolutionary path by building upon the original value delivered by wideband OFDM signals and flat IP networking. LTE Advanced Pro, the latest incarnation, brings notable advancements that bridge the gap between LTE and 5G. New LTE Advanced Pro features for the Internet of Things and Vehicle-to-Everything communications, as well as ETSI efforts advancing Mobile Edge Computing, show the benefits of a long-term evolutionary architecture.

Beyond 3GPP-based standards, the IEEE continues to expand wireless communications capabilities for Wi-Fi systems. One important example is WiGig, a wireless local area network (WLAN) protocol that operates using large channels operating at 60GHz. Enhancements to WiGig are in progress as well, with 802.11ay efforts expanding on the number of channels that can be bonded for greater throughput. This standard (so-called WiGig2) supports use cases that include large indoor area access as well as outdoor environments (hotspots) with coverage range up to 150 meters. Beyond typical WLAN applications, IEEE 802.11ay systems may also address ‘last mile’ transport links with ranges up to 500 meters. Finally, spectral efficiency can be improved with new approaches for WLAN air interfaces. IEEE 802.11ax borrows some of the air interface mechanisms used in LTE to deliver more bits per Hertz. With improvements in spectrum efficiency, 802.11ax can boost WLAN effectiveness in dense networks.

5G, however, remains a critical new foundation for future communications innovation. With a flexible and future-proof radio air interface, new 5G-enabled systems will eliminate performance limitations while boosting reliability. Along with system architecture changes that build upon SDN/NFV innovations to introduce service delivery flexibility with network slicing, 5G promises much more than simple changes to radio technology. It promises a shift from personal communications platforms to network-enabled computing environments that deliver low-latency, high-speed access to cloud-oriented applications. The transformative reach of 5G sets the stage for innovations that are, simply put, not possible today.

Our communications landscape changes rapidly. Thanks to the efforts of industry, academia and government, enterprises and consumers enjoy potent mobile service offerings that transform our lives. LTE Advanced Pro stands at the threshold to a new 5G era that promises to continue this transformational journey.