LTE-Advanced Pro

Pushing LTE capabilities towards 5G

NOKIA

Table of Contents

Introduction

LTE and LTE-Advanced are practical and popular technologies, with more than 700 million subscribers, more than 420 commercial networks and a peak data rate of 450 Mbps. This highly capable technology is set to get even better with the latest enhancements.

Improved radio capabilities will make mobile broadband services more efficient, providing higher quality and enabling new sets of services on top of LTE networks. These features, shown in Figure 1, are defined in 3GPP Releases 13/14 and are collectively known as 'LTE-Advanced Pro'. The developments will enable the Programmable World for billions of connected Internet of Things (IoT) devices, vehicular communication for Intelligent Traffic Systems (ITS) and public safety/critical communications. LTE-Advanced Pro raises user data rates to several Gbps, cuts latency to just a few milliseconds, gives access to unlicensed 5 GHz spectrum and increases network efficiency.

It also maintains backwards compatibility with existing LTE networks and devices. LTE-Advanced Pro and 5G can use similar technology components to enhance radio capabilities. 5G is a new non-backwards compatible radio technology that can operate both below and above 6 GHz frequencies and provide even higher data rates and lower latency. LTE-Advanced Pro operates below 6 GHz and evolves in parallel to development work on 5G. The evolutionary paths of LTE-Advanced Pro and 5G are shown in Figure 2.

This white paper focuses on the key technical solutions in LTE-Advanced Pro, as well as on the features needed to optimize LTE networks to deliver new 5G services.

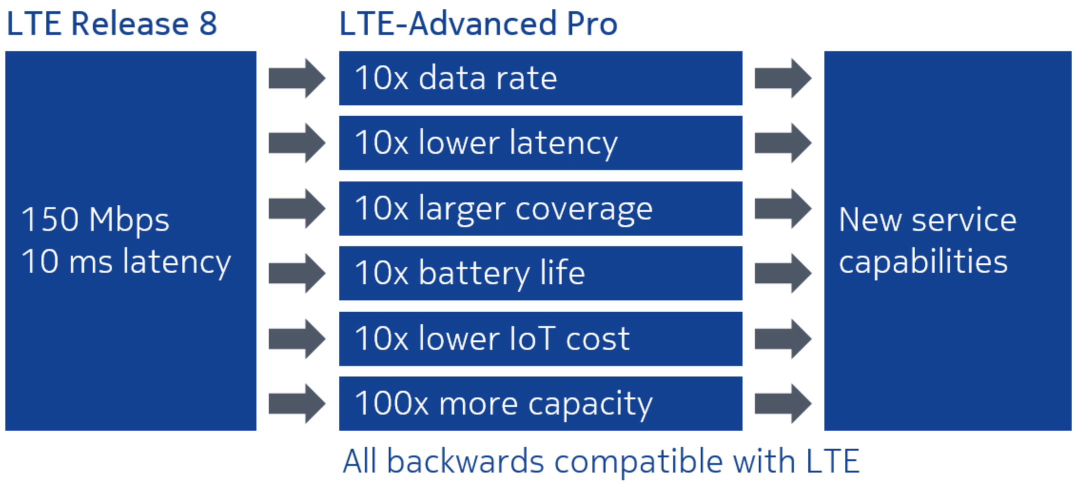

Figure 1. LTE-Advanced Pro pushes LTE capabilities towards 5G

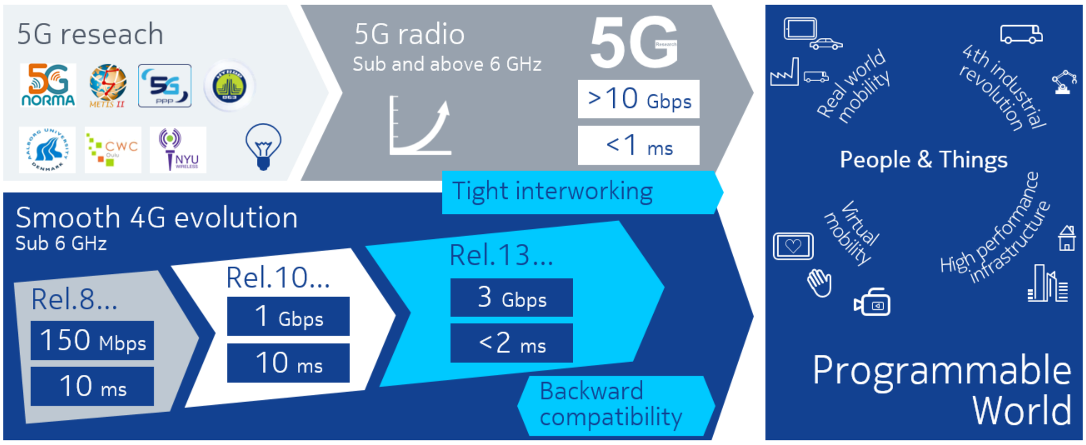

Figure 2. LTE-Advanced Pro evolves in parallel to 5G towards the programmable world

Multi-Gbps data rates with carrier aggregation evolution

LTE started with 150 Mbps peak rate and 20 MHz bandwidth. In Release 10, the peak data rates were upgraded by carrier aggregation. Mainstream carrier aggregation in 2015 delivers up to 300 Mbps on 2x20 MHz and the first networks with 3x20 MHz are about to go into commercial operation. Figure 3 shows live network measurements with three-carrier aggregation using 20 + 20 + 10 MHz, with peak data rates exceeding 370 Mbps. 3GPP Release 10 defines a maximum capability up to 5x20 MHz, which gives 1,000 Mbps (1 Gbps) with 2x2 MIMO and 64QAM, and even 3.9 Gbps with 8x8 MIMO.

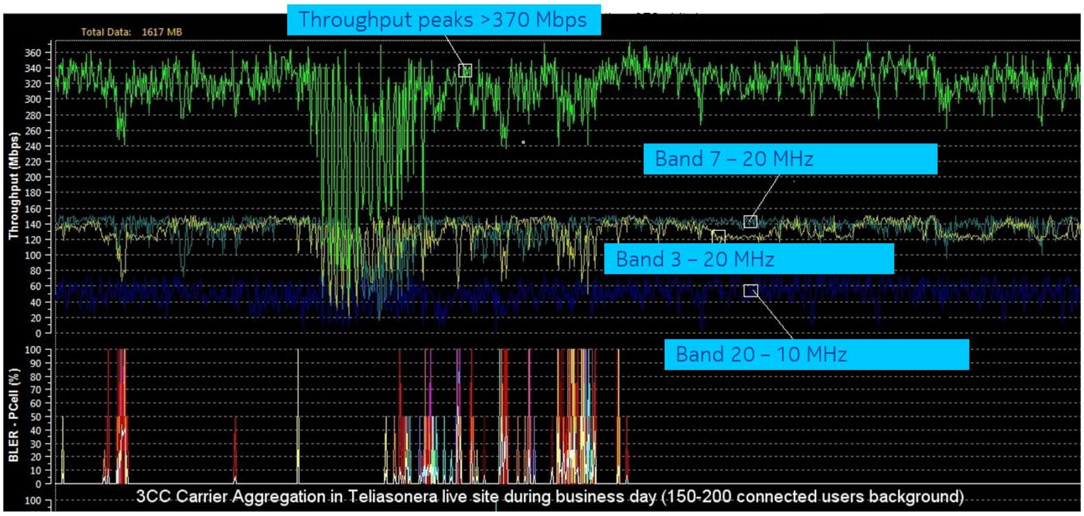

Figure 3. Three carrier aggregation measurements in a live network showing peak rates above 370 Mbps

The data rate can be increased still further with more spectrum and more antennas. A higher number of antenna elements is feasible when using comparatively large base station antennas, however, it is more of a challenge to integrate further antennas into small devices. For these, data rates are more easily increased by using more spectrum. Release 13 makes this possible by enhancing carrier aggregation to enable up to 32 component carriers. In practice, the use of unlicensed spectrum enables LTE to benefit from even further carrier aggregation capabilities. Figure 4 illustrates carrier aggregation evolution and Figure 5 shows the evolution of peak data rates.

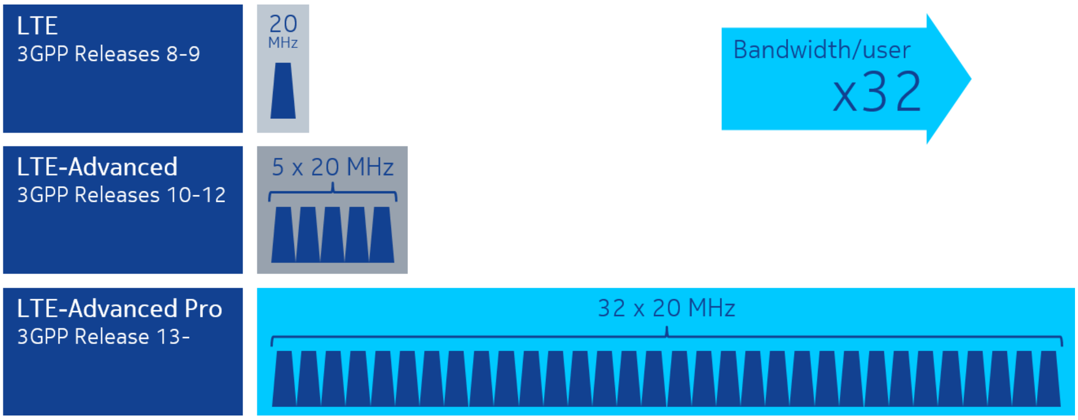

Figure 4. Aggregation of up to 32 component carriers

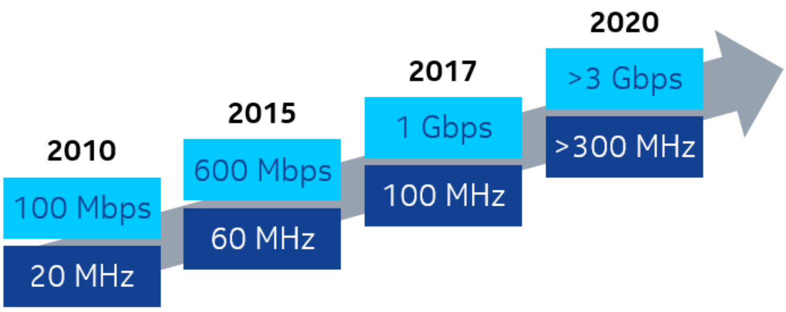

Figure 5. LTE-Advanced Pro data rate and bandwidth

Nokia has already demonstrated the very high data rates possible with carrier aggregation. A throughput of 4.1 Gbps was achieved by aggregating ten LTE carriers, each of 20 MHz, including both FDD and TDD carriers. The total bandwidth used was 200 MHz. For more details see the related press release.

Using the 5 GHz band

So far, LTE networks have been deployed using licensed spectrum between 450 and 3600 MHz. With ever increasing amounts of traffic, being able to use unlicensed as well as licensed bands will allow improvements in capacity and peak data rates for LTE-Advanced Pro. The unlicensed 5 GHz band has plenty of available spectrum, suitable in particular for small cell deployments. This large pool of spectrum allows mobile broadband operators to benefit from the carrier aggregation evolution provided by LTE-Advanced Pro. The evolution of LTE spectrum usage is shown in Figure 6, while the spectrum resources available in the unlicensed 5 GHz band are illustrated in Figure 7.

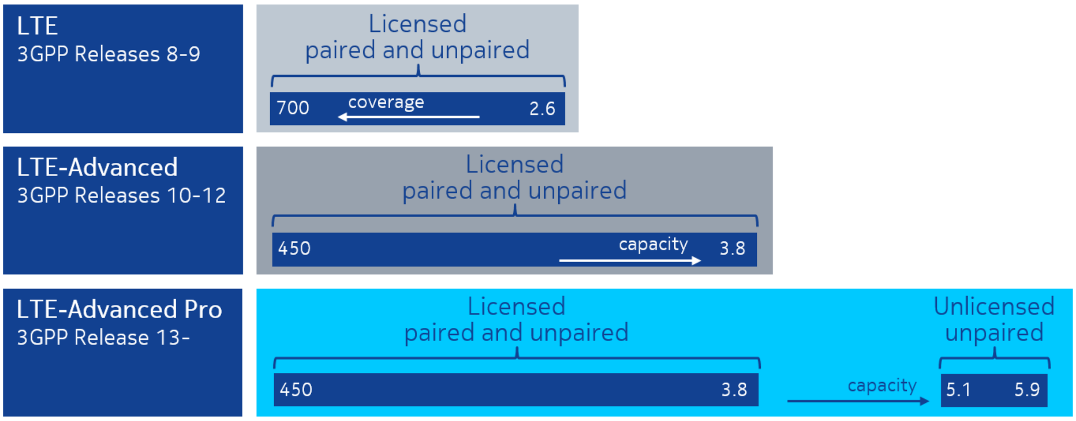

Figure 6. LTE spectrum utilization

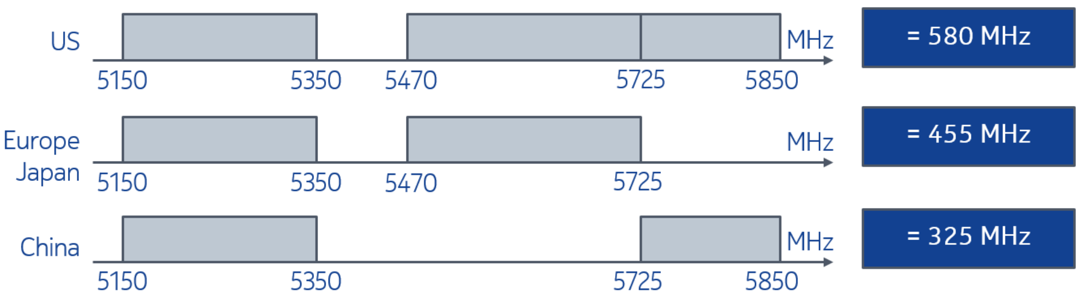

Figure 7. Spectrum availability in the 5 GHz band

LTE-Advanced Pro can use unlicensed band spectrum either through Licensed Assisted Access (LAA), or by integrating Wi-Fi more closely to the cellular network via LTE-Wi-Fi aggregation (LWA). The two solutions are shown in Figure 8.

LAA combines the use of licensed and unlicensed spectrum for LTE using carrier aggregation technology. It is a highly efficient method of offloading traffic, since the data traffic can be split, with millisecond resolution, between licensed and unlicensed frequencies. Licensed bands can provide reliable connectivity, mobility, signaling and guaranteed data rate services, while the unlicensed band can give a significant boost in data rates. The technical solution for combining licensed and unlicensed spectrum is based on dual connectivity and carrier aggregation – the same solutions that have already been defined in LTE-Advanced and which can be reused for the 5 GHz band.

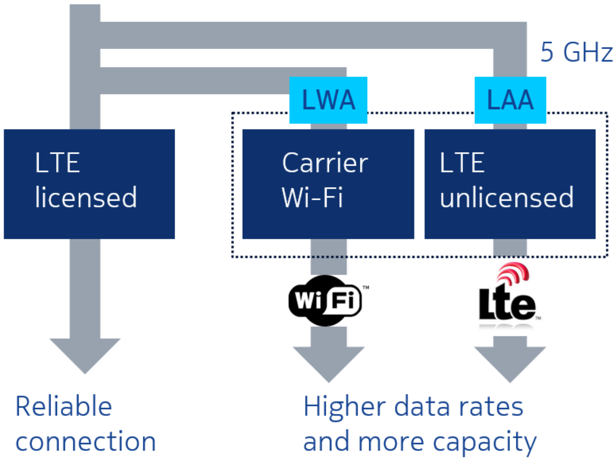

Figure 8. Combined usage of licensed and unlicensed bands

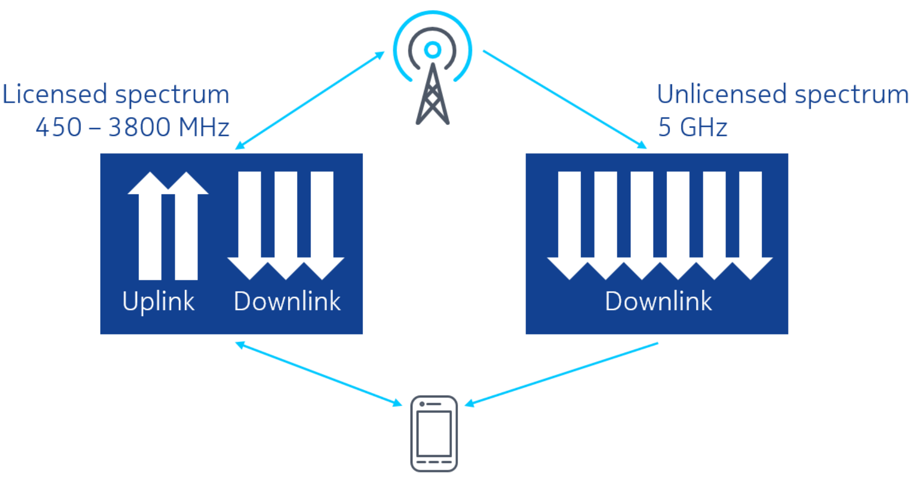

Figure 9. License Assisted Access (LAA) combines licensed and unlicensed spectrum

Refer to the Nokia press release about LAA for T-Mobile USA.

LTE-Advanced Pro also allows the aggregation of LTE and Wi-Fi transmissions, offering a further way to make use of unlicensed bands. So far, LTE and Wi-Fi interworking has been implemented on the application layer. Under 3GPP Release 13, the data traffic can be split between LTE and Wi-Fi transmissions, allowing the user device to receive data simultaneously via both paths. This allows full use of Wi-Fi capacity while maintaining the LTE connection for reliable mobility and connectivity.

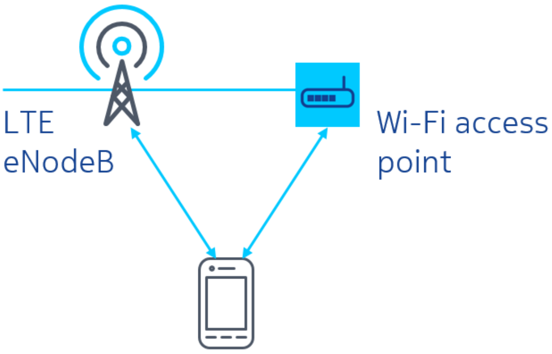

Figure 10. LTE – Wi-Fi aggregation (LWA)

Enhanced spectral efficiency with beamforming (3D MIMO)

LTE has also provided high spectral efficiency since its introduction. The downlink efficiency of LTE has been boosted further using Multiple Input Multiple Output (MIMO) technology, including 4x2 MIMO, 8x2 MIMO and 4x4 MIMO, a technique made more efficient with interference cancellation and the algorithms of the Nokia Smart Scheduler. LTE-Advanced Pro introduces the next step in spectral efficiency with 3-dimensional (3D) beamforming, also known as Full Dimensional MIMO (FD-MIMO). Increasing the number of transceivers at the base station is the key to unlocking higher spectral efficiencies.

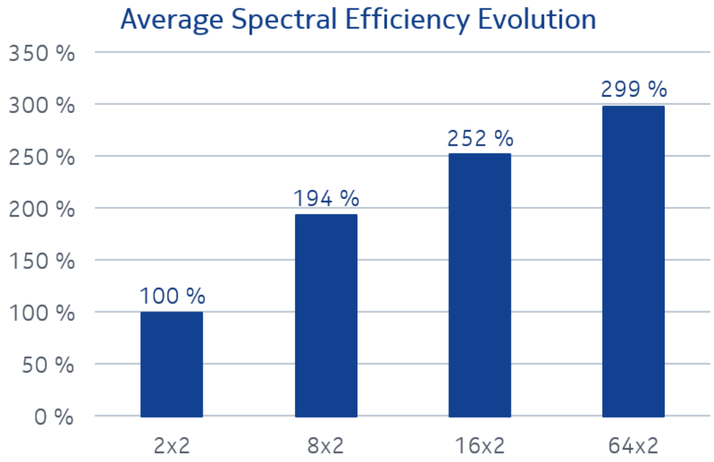

Figure 11. Downlink capacity gain from 3D MIMO

Release 13 specifies MIMO modes for up to 16 transceivers at the base station, while Release 14 may allow as many 64. These will bring efficiency gains for downlink transmissions as shown in Figure 11: 16x2 provides a 2.5-fold gain in spectral efficiency compared to 2x2, while 64x2 shows a 3-fold gain. The gain available from 64x2 compared to 8x2 is 50 percent. Note that the 8x2, 16x2 and 64x2 transceiver configurations each have four columns of cross-polarized antenna elements of approximately the same physical dimensions, while the 2x2 transceiver configuration has only one column of cross-polarized antenna elements. The total transmission power is the same in all cases.

The efficiency of the uplink can be improved by using a number of receiving antennas. This method has been widely deployed in the field by aggregating the signals received from 4, 8 or even more transceivers in the form of Centralized RAN (CRAN). These uplink improvements are mostly transparent to user devices supporting Release 8 and require no support for LTE-Advanced features.

The introduction of a large number of transceivers is made possible with active antenna arrays. In addition to passive radiating elements, these also have RF amplifiers, filters, or digital processing integrated into the array. Using such active arrays effectively moves the radio closer to the radiating elements, reducing feeder loss as well as the footprint of the tower-top structure. Several distant antenna locations can be connected to a single baseband processing unit using optical fiber or, potentially, within a cloud RAN solution.

Nokia has a long track record in the development of active antennas and has been driving related standardization activities in 3GPP RAN1 since 2013. Nokia has trialed active antennas in 3G and LTE networks with vertical beamforming. Related field results have shown up to a 60 percent capacity gain in loaded urban macro cells, illustrating the great potential of 3D MIMO technology.

Nokia white papers on active antenna and multi-antenna can be found here:

Refer to the white paper: Nokia Active Antenna Systems

And white paper: Nokia Multi Antenna Optimization in LTE

Extreme local capacity with Ultra-dense network

LTE-Advanced radio has shown it can provide high efficiency in the macro cellular layer but even this is not enough to satisfy the needs of the most extreme traffic hot spots. Small cells are the next step in providing increased local capacity. Such high traffic hot spots typically appear in dense urban areas, at sports venues or music festivals. An example of such a high traffic scenario (from a major car racing event) is illustrated in Figure 12. The car race attracted more than 70,000 spectators, generating a high volume of traffic that was successfully served by 20 small cells in addition to the macro layer. The highest-loaded small cell served more than 500 active users.

Figure 12. High capacity hotspot in a major car racing event

3GPP has defined a number of enhancements that bring greater efficiency to small cell deployment in coordination with the existing macro layer. Further Enhanced Inter-Cell Interference Coordination (FeICIC) was added in Release 11 and Dual connectivity in Release 12. Dual connectivity with inter-site carrier aggregation allows the user device to receive data simultaneously from two different sites served by non-ideal backhaul and has also been enhanced in Release 13 to support uplink transmission to two sites. The technique will be increasingly important for HetNets consisting of macro cells and many small cells. It also brings a number of benefits for small cell deployments by combining reliable mobility in the macro layer with the high capacity and enhanced data rates available from the small cells. This dual connectivity solution also provides the basis for integrating LTE + 5G and LTE + Wi-Fi.

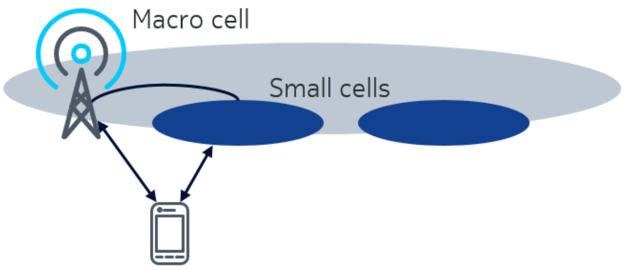

Figure 13. Dual connectivity between macro and small cells

Millisecond latency with flexible frame and Mobile Edge Computing

Work is continuing to reduce latency and increase bit-rates. As well as improving the throughput performance of Transmission Control Protocol (TCP), low latency is also important in, for example, reducing buffer requirements at high data rates in the radio equipment. Even more importantly, low access latency determines the user experience in interactive applications and will drive new delay-sensitive use cases. LTE-Advanced Pro tackles the latency problem by reducing the frame length and optimizing the physical layer control of the air interface resources. Figure 14 illustrates the evolution of the LTE frame structure and Transmission Time Interval (TTI). A shorter TTI is directly proportional to the air interface delay. Shortening the TTI by reducing the number of symbols is the most promising approach when seeking to maintain backwards compatibility and usability in existing LTE bands. The current 1 ms TTI produces in practice a 10-20 ms round trip time, while an LTE-Advanced Pro solution should provide even less than 2 ms round trip time and a less than 1 ms one-way delay. The evolution of round trip time from HSPA to LTE, LTE-Advanced Pro and 5G is illustrated in Figure 15.

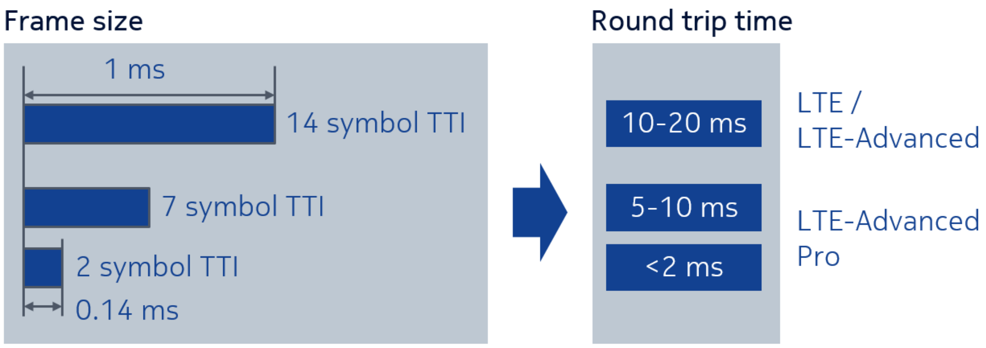

Figure 14. Shorter TTI reduces latency

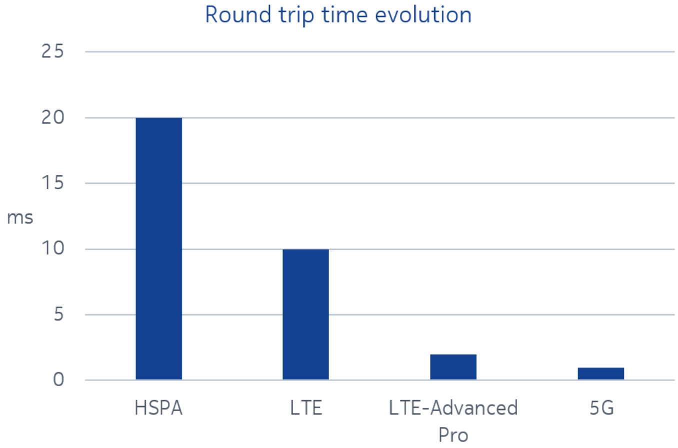

Figure 15. Evolution of end-to-end round trip time

A large part of the latency in the physical layer is caused by the time taken to provide a transmission grant to the device and acknowledge received data. Optimizing this time provides another avenue to shortening latency.

A number of promising solutions for improving uplink grant procedures are under discussion. For instance, pre-allocating uplink grants will eliminate a large part of the fixed delay. This kind of technique is known from semi-persistent scheduling for voice services, but can also be applied to other services where a small amount of data is transmitted in a more random fashion. Alternative or complementary techniques will help use resources efficiently. As an example, several devices may be given grants and channel access can be performed using contention techniques.

The fixed latency incurred by the current synchronous ACK is also reconsidered. As an alternative, along with potentially restricted data sizes, the asynchronous ACK used in the downlink may be employed. The improvements for uplink data procedures are illustrated in Figure 16.

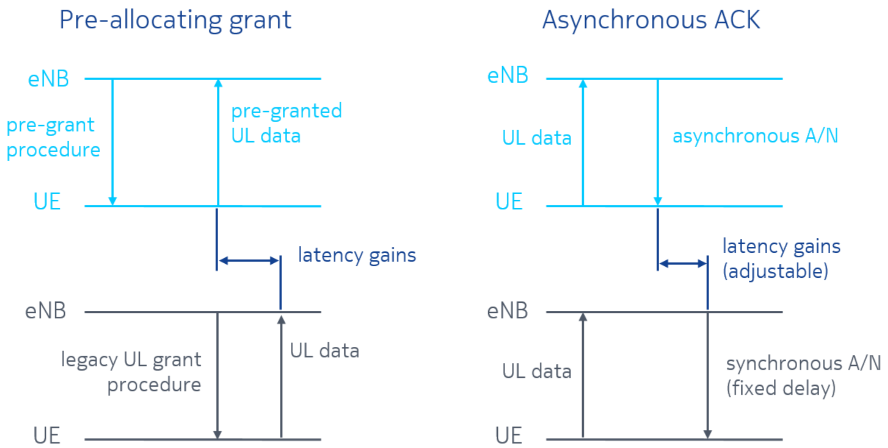

Figure 16. LTE uplink transmission latency

Nokia's implementation approach offers further reduction in end-to-end delay in content delivery, through deployment of Mobile Edge Computing (MEC). Nokia's MEC solution is called Liquid Applications. This allows the delivery of large amounts of localized data to the user with an extremely low delay, all without burdening the core network. Low-latency LTE-Advanced Pro will provide an even better radio interface to complement the benefits of Liquid Applications. The MEC concept is being standardized in ETSI, work that was initiated by Nokia. In addition to low latency, MEC allows authorized third-parties to gain access to the RAN edge, enabling them to deploy innovative applications and services for mobile subscribers, enterprises and vertical segments. Liquid Applications is also expected to be a key component in future 5G deployments.

Refer to the Nokia Liquid Applications white paper and ETSI MEC white paper.

Internet of Things optimization for the Programmable World

Internet of Things (IoT) refers to the interconnection and the autonomous exchange of data between devices which are machines or parts of machines, often involving sensors and actuators. The future connected world will have tens of billions of IoT devices. LTE evolution will enhance LTE's ability to serve the IoT by improving coverage, device power consumption, cost and connectivity.

IoT optimization in Release 13 extends coverage for power-limited devices via repetition and power spectral density, boosting to 164 dB path loss, allowing the use of power-limited devices to operate in cellars or closed indoor places. Release 13 also improves battery consumption by introducing longer Discontinuous Reception (DRX) cycles, allowing up to 10-year battery life with 2 AA batteries. Narrowing the operating bandwidth to 1.4 MHz and further to 200 kHz, together with reduced modem complexity enables LTE to support low cost device use. Moreover, signaling and network optimizations improve the capacity of networks, so that tens of billions of devices can be served by a single network. The IoT enhancements in LTE Release 13 are shown in Figure 17.

	LTE-Advanced	NB-IoT
Coverage	140-145 dB	164 dB
Operation time with with two AA batteries	1 year	10 years
Device cost	Reference	-85%

Figure 17. IoT enhancements in LTE-Advanced Pro

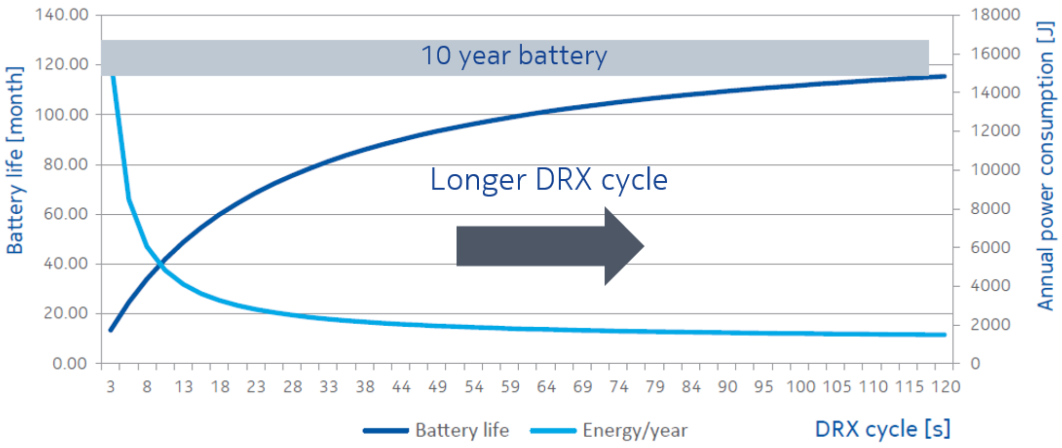

Figure 18. IoT device battery life

Operators can start supporting IoT devices with LTE networks from Release 8 using Category 1 devices that are available today. Device cost and power consumption is reduced in Release 12 with Category 0 devices using a simple software upgrade in the network. Even further cost reductions are possible with a narrow-band 200 kHz IoT solution developed in 3GPP Release 13. This will enable a further cut in the implementation costs of IoT modems, making mass market deployment feasible. This narrowband IoT solution can be multiplexed within an LTE carrier, outside an LTE carrier or deployed as a standalone carrier. The preferred solution is the in-band options which is a software upgrade to the LTE network and allows to multiplex NB-IoT within the existing LTE carrier.

Table 1. Lower cost IoT chip sets with LTE-M

	Release 8	Release 8	Release 12	Release 13	Release 13
	Category 4	Category 1	Category 0	Cat-M	NB-IoT 200 kHz
Downlink peak rate	150 Mbps	10 Mbps	1 Mbps	**1 Mbps**	**200 kbps**
Uplink peak rate	50 Mbps	5 Mbps	1 Mbps	**1 Mbps**	**100 kbps**
Number of antennas	2	2	1	**1**	**1**
Duplex mode	Full duplex	Full duplex	Half duplex	**Half duplex**	**Half duplex**
UE receive bandwidth	20 MHz	20 MHz	20 MHz	**1.4 MHz**	**0.2 MHz**
Modem complexity	**100%**	**80%**	**40%**	**20%**	**15%**

Quality of Service (QoS) differentiation is commonly used for Voice over LTE (VoLTE) prioritization and for the subscriber differentiation in data services. QoS can also be applied to IoT connectivity to provide higher priority for the critical IoT communication while the transmission of the lower priority packets can be delayed.

Related information on Nokia's IoT activities:

Press release: Nokia makes LTE networks IoT ready

Press release: Nokia, Ericsson and Intel Working Together on Next-Generation Wireless Connectivity for Internet of Things Market Segment

White paper: Nokia LTE-M – Optimizing LTE for the Internet of Things

Device-to-Device communications

3GPP has defined direct communication between two devices under the category of Device-to-Device (D2D) communications. D2D functionality can be used in several ways: for Vehicle-to-Vehicle (V2V) communication, for public safety, for social media and for advertisements. Looking at vehicular communications, present day communication equipment installed in cars is used for remote car diagnostics, providing in-car entertainment or fleet tracking. More integrated networking for vehicles will allow a fundamental transformation of the automotive environment. The aim is to introduce public safety systems as, for example, specified in ETSI ITS (Intelligent Traffic Systems). This will provide the environment for self-driving cars, perform real-time management of traffic in cities and provide car and traffic related services to users.

LTE-Advanced Pro is uniquely suited to support vehicular communications, as it provides network coverage for vehicle-to-infrastructure or vehicle–to-pedestrian communication, enables D2D communications and will support low latencies as specified in ITS.

The main application for V2V communication is enabling public safety applications such as collision avoidance. Nokia is currently studying extensions to D2D, also taking into account coexistence with current systems such as 802.11p. V2V will typically rely on some support from road side units, either for synchronization or to aid V2V communication.

V2i (infrastructure), V2n (network), V2p (pedestrian) are other facets of this topic currently being studied. A network for vehicular communication may be accomplished by routing V2V communication via a base station, or by base stations broadcasting or group-casting traffic information to cars. LTE MEC solutions are very well suited to vehicular communications applications, for example, dynamic map retrieval or localized car traffic management. Together with partners Nokia has demonstrated real-time low latency communication between vehicles via an LTE network, in the digital A9 motorway test bed in Germany. Refer to the Press release.

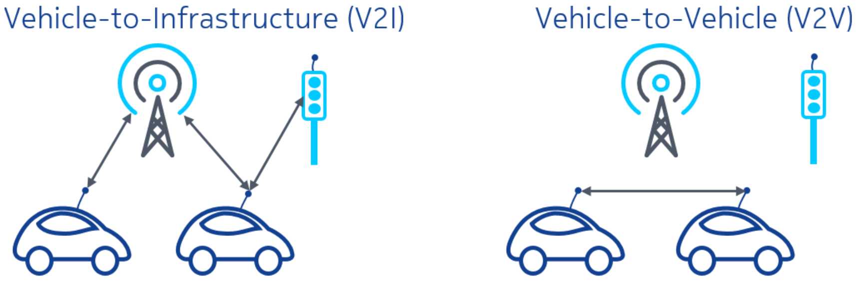

Figure 19. Vehicle communication for smart traffic will use LTE radio

Cloud radio architecture for network scalability

The introduction of new functionalities through LTE-Advanced Pro coincides with the trend to move network functionalities to the cloud, extending from the core network to the RAN. The cloud approach enables faster introduction of services as well as savings in operating expenditure. The radio cloud is more challenging than the core cloud because radio processing requires very low latency and because layer 1 processing requires dedicated hardware for high efficiency. Nokia’s cloud radio solution integrates low-latency layer 1 with the RF, while layers 2/3 are located in the cloud. Layer 1 processing is closely related to the RF bandwidth and the number of antennas, while layer 2/3 processing is more typically related to the number of connected users and to the signaling requirements. A cloud-based layer 2/3 offers greater flexibility to increase the network capacity as the number of IoT objects rises. Nokia’s cloud radio proof-of-concept is shown in Figure 20.

LTE-Advanced Pro makes radio cloud deployment more flexible by introducing asynchronous Hybrid Automatic Repeat Request (ARQ) retransmissions. The initial version of LTE supports only synchronous ARQ where the transmission delay is fixed, limiting the flexibility of radio cloud deployment. Asynchronous ARQ allows more flexibility for latency.

Radio cloud is supported by the Nokia AirFrame Data Center. The first cloud infrastructure solution tailored for telco, AirFrame combines IT best practice with the needs of the telco domain. It does this by evolving cloud architecture to incorporate centralized and distributed capabilities that will be vital to future telco networking and service delivery.

Refer to Nokia AirFrame launch.

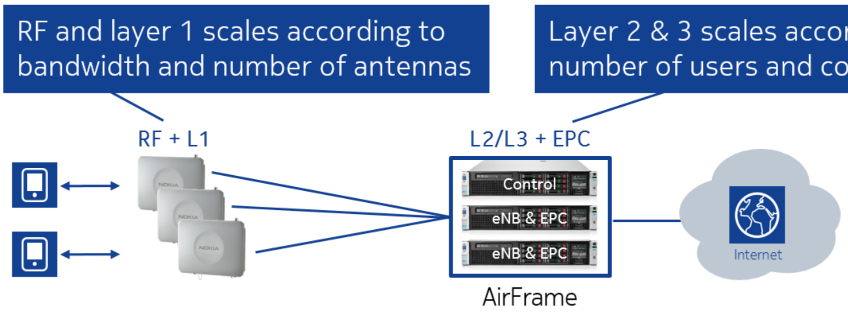

Figure 20. Nokia cloud RAN proof-of-concept

Evolution to 5G

LTE-Advanced Pro is a key technology for the immediate future of mobile network development. LTE-Advanced Pro will be backwards compatible on the same frequencies as current LTE networks and devices and will be available from 2017. In contrast, 5G will be a non-backwards compatible radio technology, starting trials around 2018 and commercially available on a wide scale in 2020. LTE will evolve to constitute part of the 5G system, complemented by new non-backwards compatible radio interfaces designed to better serve new use cases and scenarios. 3GPP is expected to define close interworking between LTE-Advanced Pro and 5G, in fact a tighter interworking than with any earlier technologies. One example is the dual connectivity between LTE and 5G. 5G phase 1 will be based on LTE networks from the control plane point of view – devices will have simultaneous connection to LTE and 5G radios, based on the LTE Dual Connectivity functionality. Future 5G networks will need excellent LTE. High performance 5G will only come with an excellent LTE network.

A comparison between LTE-Advanced Pro and 5G is shown in Table 2 and LTE-5G dual connectivity is illustrated in Figure 21.

Table 2. Roles of LTE-Advanced Pro and 5G

	LTE-Advanced Pro	5G Phase 1
Backwards compatible with current LTE	Yes	No
Control plane	LTE	LTE
Spectrum	450 MHz – 6 GHz	3 – 6 GHz

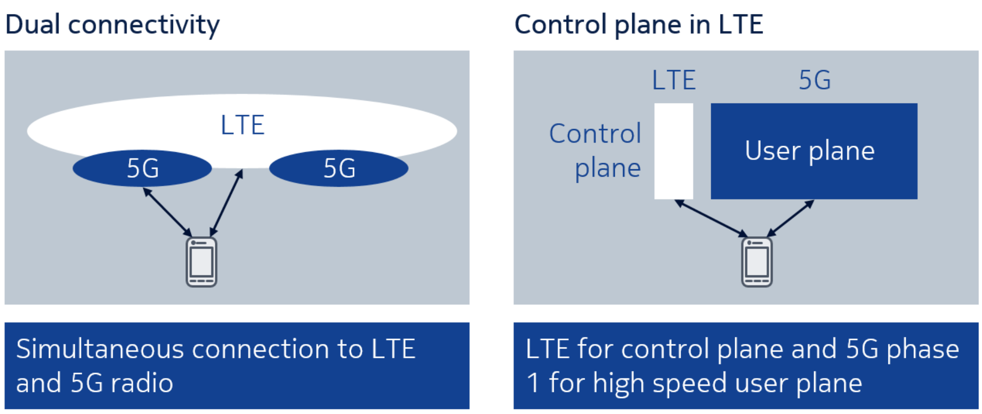

Figure 21. Dual connectivity between LTE-Advanced and 5G radios

Summary

LTE-Advanced Pro brings great enhancements in radio performance on top of LTE-Advanced - multi-Gbps data rates, higher spectral efficiency and one-way latency below 1 ms. LTE-Advanced Pro also enables a number of new application scenarios, including IoT optimization for the Programmable World, vehicular connectivity and public safety. LTE-Advanced Pro is supported by new features in 3GPP Releases 13 and 14 and by Nokia innovations.

LTE-Advanced Pro is backwards compatible with existing LTE networks and can co-exist on the same frequencies, enabling a smooth rollout. The quality and performance of LTE-Advanced Pro is not only important in the short term but also in the long term when 5G radio will be deployed. 5G is expected to use LTE for the control plane in the first phase, with the 5G radio used for boosting user plane data rates. An excellent 5G experience will only come with high quality LTE networks. 5G will further boost the data rates and capacity beyond LTE-Advanced Pro by using larger bandwidths and spectrum above 6 GHz.

Nokia is the innovation leader for the evolution of LTE-Advanced Pro and for new network architecture solutions such as Liquid Applications, with its integration of content to the radio network, Nokia Smart Scheduler, radio cloud scalable architecture and active antennas.

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Further reading

Press release: Nokia Networks, Ooredoo Qatar, China Mobile achieve 4.1 Gbps speed with TDD-FDD carrier aggregation

Press release: T-Mobile US, Inc. plans to enhance its small cell deployment of Nokia Flexi Zone with Licensed Assisted Access functionality

White paper: Nokia LTE-Unlicensed

White paper: Nokia Active Antenna Systems

White paper: Nokia Liquid Applications

White paper: LTE-M - Optimizing LTE for the Internet of Things

Nokia AirFrame

Abbreviations

ARQ	Automatic Repeat Request
CRAN	Centralized RAN
D2D	Device-to-Device
DRX	Discontinuous Reception
EPC	Evolved Packet Core
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
FeICIC	Further enhanced Inter-Cell Interference Coordination
HSPA	High Speed Packet Access
IoT	Internet of Things
ITS	Intelligent Traffic System
LAA	License Assisted Access
LTE	Long Term Evolution
LWA	LTE – Wi-Fi Aggregation
MEC	Mobile Edge Computing
M2M	Machine-to-Machine (IoT)
MIMO	Multiple Input Multiple Output
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RAN	Radio Access Network
TDD	Time Division Duplex
TCP	Transmission Control Protocol
TTI	Transmission Time Interval
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle

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