WiTech
Simplify the wireless networks

LTE: a real disruptive technology and business opportunity?

October 2012

White Paper

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Founded in October 2003 as a spin-off of the University of Pisa, WiTech has quickly become a leading company operating in the telecommunication market with a focus on next generation wireless technologies.

WiTech provides high performance managed services and solutions to create a measurable business value for its international clients, including network operators & service providers, vendors & manufactures, regulators, analysts & consulting firms and universities.

Focusing on Technology Consulting, WiTech has an in-depth expertise in developing the cost modeling of telco networks to understand the actual costs and improve pricing and market entry decisions. Moreover, WiTech has a global track record with the assessment of business cases for telco initiatives ensuring the best possible alignment between business and technology strategies from the outset. In addition, WiTech manages efficiently the entire RFI/RFQ process, developing accurate RFI/RFQ documents and evaluating submitted proposals, as well as selecting the vendor best suited to requirements and negotiating the contract. Furthermore, WiTech has extensive experience in preparing reports and white papers on the hottest topics in the telco industry, driven by both clients' and WiTech's interest.

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WiTech has earned several industry recognitions, both national and international, thanks to its hard work made of an inborn innovative and creative inclination.

For additional information you can visit us at www.witech.it, or you can contact us at info@witech.it or at +39 050 77 50 56.

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EXECUTIVE SUMMARY

Nowadays, it is not only people who require an 'always on' connection to the Internet gaining access to innovative applications (e.g. video streaming, social networks, content publishing, web conferences, etc.), but also things, that need to communicate among themselves through the Internet anytime and anywhere creating smart environments. This paradigm is the Internet of Things!

All this means that the demand for mobile broadband is expected to grow exponentially in the next few years with a CAGR of 96% from 2010 to 2015, driven also by the availability of new UE, including tablets, routers, M2M, smartphones, etc.

This forces the adoption of new generation technologies, such as LTE, with the consequent need for changes for all players of the Telecom market, starting from network operators and service providers, proceeding to regulators and standardization and industry bodies and, finally, moving to vendors.

But is LTE a real disruptive technology and business opportunity?

It is not easy to find an answer to this question straightaway because several circumstances come into play. It is certain that LTE offers real potentialities to network operators thanks to the advanced features and functionalities supported. However there are several critical factors, which can turn the LTE initiative from a potential success into a total failure and, they therefore need to be properly and carefully analyzed and defined.

This white paper wants to introduce some of the main topics of the report, which is a valid help to explore the emerging world of LTE not only from a technological but also a business perspective, along six paths of investigation:

- Key drivers for the LTE adoption
- Overview of LTE and its evolution LTE Advanced
- Candidate spectrum bands and licensing experience to date
- Current status of the LTE ecosystem
- Operator plans, commitments, trials, deployments, launches
- Critical factors for the LTE business case.

The increasing demand for mobile broadband represents the main driver for LTE, whose adoption involves deep changes for the entire Telecom market. Network operators and service providers need to redefine their business model and redesign their network infrastructure to fully enable the Internet of Things. Regulators need to outline new strategies for a forward-looking spectrum management capable of supporting network operators and service providers in their initiatives. Standardization and industry bodies need to ensure an industry alignment for LTE deployments through the E2E interoperability among different vendors and across different network elements. Vendors need to become the suppliers of feature-rich and cost competitive solutions taking into account the real requirements of network operators and service providers.

In comparison with legacy 3GPP systems, LTE and its evolution LTE Advanced have introduced enhanced features and functionalities. Specifically, OFDM and MIMO have been included in the radio air interface respectively to defeat multipath environments increasing the spectral efficiency, and to boost the peak data rate or to enhance the signal robustness. Moreover, a flat all-IP and PS domain optimized core network has been defined to provide reduced latency and improved QoS, support for only packet switched services, separation between the U-plane and C-plane traffic handling, convergence and seamless internetworking with legacy 3GPP and non-3GPP systems. In addition, the heterogeneous networks approach has been introduced to combine different cell types (macrocells, microcells, picocells, etc.) across multiple RAT and on multiple spectrum bands. Finally, the SON capabilities, including the functionalities of self-configuration, self-optimization and self-healing, have been defined to optimize the network deployment and management.

The 3GPP has identified several paired and unpaired spectrum bands (thirty-four in total) in order to support not only FDD operations but also TDD operations providing network operators higher flexibility to deploy mobile networks based on frequency availability and investment possibilities. Some spectrum bands are particularly of interest in the deployment of LTE systems (e.g. 700, 800, 900, 1700/2100, 1900, 2000, 2300, 2600 and 3500 MHz), as confirmed by the worldwide licensing experience to date.

The LTE ecosystem is quite complex if compared with any of the previous technologies, because it includes a lot of players (e.g. users, network operators and service providers, regulators and standard bodies, vendors). However, all these players are closely cooperating to speed up the evolution of the LTE ecosystem to avoid replicating the experience of 3G technologies. Looking at the current trends and focusing on UE, for example, around 250 new devices have been announced over the past year.

The number of LTE network deployments is quickly growing across the globe involving more and more countries and network operators. At the moment, 312 network operators are investing in LTE in 98 different countries. Specifically, there are 64 commercial networks in 34 countries, 253 commercial network commitments in 84 countries and 59 pre-commitments trials in 14 countries. In addition, 129 commercial network commitments are expected by the end of 2012.

LTE has real business potentialities, as deduced through the business case sample[1] provided. Thus, network operators can benefit from higher flexibility in the realization of the infrastructure, defining better suited deployments according to their specific business models and fully seizing the business opportunities offered. Nevertheless, many aspects can undermine the LTE success. Hence, performing an in-depth scenario and sensitivity analysis becomes a must to understand the dynamics of the technical and economic feasibility of the LTE initiative depending on the critical factors, whose little changes could make the investment not profitable.

[1] *The 10-year business case sample refers to an Italian incumbent mobile operator and it has been carried out by means of the business case analysis tool TEA|LTE from WiTech. Specifically, this mobile operator needs to migrate its nationwide mobile network from the legacy 3G technology to the emerging LTE technology in order to offer attractive triple play services to both residential and business users in a mobile and fixed access. It is worth highlighting that this business case sample is imaginary and it does not represent any Italian incumbent mobile operator. Therefore, all possible references to real business strategies and network deployments are merely casual.*

1. A SMOOTH MIGRATION TOWARDS 4G

This section mainly provides a thorough overview of the key factors, which make LTE a promising technology to cope with the emerging market needs including the increasing demand for mobile broadband. In addition, it presents the structure of this white paper providing a high level description of topics covered in each section.

1.1 LTE: a promising technology

The Telecom market is continuously changing and reinventing itself to meet the growing demand of mobile broadband driven by the availability of new UE (e.g. tablets, routers, M2M, smartphones, etc.), as well as by the widespread diffusion of disruptive applications (e.g. video streaming, social networks, content publishing, web conferences, etc.) and the Internet of Things.

Therefore, new technologies need to be adopted. Keeping an eye on the surrounding technological landscape, the trends are well defined: 4G technologies and, in particular, LTE represents the evolutionary path towards the new generation.

Thus, LTE opens the door for broadband services through traditional and non traditional UE also combining the fixed and mobile access in a hybrid approach and looking at areas which have not been fully explored yet, such as consumer electronics and appliances, health care, public utilities and telematics.

This is supported by several advantages and benefits, which LTE provides including:

- Higher capacity: As LTE supports wider channel bandwidths as well as the MIMO feature (i.e. spatial multiplexing), it provides higher data rates truly enabling innovative services, such as video streaming
- Deployment flexibility: Thanks to the support for heterogeneous networks, LTE gives the possibility of focusing coverage and capacity extensions through the combination of local area sites (e.g. picocells and femtocells) with medium and wide area sites (e.g. micro and macro cells), that spread across multiple RAT and operate in both licensed and unlicensed spectrum bands.
- Self-optimizing network capability: LTE supports self-configuration, self-optimization and self-healing, reducing the effort in time and money required to deploy and manage the network.
- Spectrum flexibility: Since LTE supports various spectrum bands and channel bandwidths, it enables network operators to define better suited deployments according to their specific business model.
- Lower latency: LTE reduces the E2E latency both on the C-plane and U-plane, providing a direct service advantage for interactive services, such as multiplayer gaming and rich multimedia communications.
- QoS: Through a detailed QoS differentiation, LTE allows meeting specific QoS requirements of each service in order to ensure a real user experience.

- Improved coverage: Thanks to the MIMO feature (i.e. transmit diversity) and lower spectrum bands (e.g. 800 MHz), LTE has coverage and in-built penetration advantages over legacy 3GPP systems.
- Security: LTE provides enhanced security through advanced mechanisms, defined on the basis of architectural design decisions, internetworking with legacy 3GPP and non-3GPP systems, new services to be provided and alocal-based security approach.
- Higher mobility: LTE works in high mobile speeds scenarios (even up to 500 Km/h depending on the spectrum band).

However, in order to fully take advantage of the aforementioned benefits and seize the business opportunity offered by LTE it is required to properly analyze the main critical factors for the success of the LTE initiative.

1.2 Structure of this white paper

The remainder of this white paper is structured as follows:

- Section 1: This section provides a clear and concise overview of the LTE technology, including the standardization timeline, the main technical features implemented and, eventually, the performance comparison between LTE and its evolution.
- Section 2: This section discusses the possible spectrum bands, which can be adopted for LTE deployment across the globe and presents a picture of trends and outcomes of the earliest auctions and attributions of LTE spectrum bands.
- Section 3: This section aims at highlighting the framework for the analysis of the critical factors of an LTE initiative.
- Annex A: This annex describes the business case analysis tool TEA|LTE from WiTech.

2. LTE TECHNOLOGY PRIMER

This section provides a clear and concise overview of the LTE technology. More specifically, it firstly presents the standardization timeline for LTE and beyond. It then describes the main technical features implemented in LTE and LTE Advanced, setting out advantages and benefits introduced by each one. Finally it shows the results of the comparison between LTE and its evolution to outline their performance.

2.1 A clear standardization path

LTE describes the last standardization work of the 3GPP providing a new high speed radio access method for mobile communication systems and representing the natural evolution of legacy 3GPP/non-3GPP systems towards emerging IMT Advanced systems[2].

The concept of LTE was discussed for the first time in 2004 in Toronto, with the initiative RAN Evolution Workshop. This initiative gathered more than forty network operators, vendors and research institutes (including the 3GPP) who provided their considerations about the evolution of the UTRAN.

Following the Toronto Workshop, in December 2004 the 3GPP launched a feasibility study in order 'to develop a framework for the evolution of the 3GPP radio access technology towards high data rate, low latency and packed optimized radio access technologies'. This study, hence, settled out technical specifications for a new radio access network capable of supporting mobile broadband.

The first LTE specifications were provided in the Release 8 that was frozen in December 2008 and published in March 2009. In this Release, the 3GPP defined a new PHY layer using OFDMA in DL and SC-FDMA in UL as well as supporting channel bandwidth between 1.4 and 20 MHz. This Release defined options for both FDD and TDD operations, a suite of MIMO capabilities and interference coordination techniques. In addition it provided several other enhancements related to common IMS, service continuity between LTE systems and legacy 3GPP systems and multimedia priority systems.

After the completion of the Release 8, the 3GPP turned to the Release 9, which was subsequently completed in March 2010. Several features and capabilities were added; specifically -emergency and location-based services, enhancement for CSFB and MBMS, self-organizing network feature, dual layer beamforming, femtocells, vocoder rate adaptation based on cell loading, IMS Centralized Services and UICC.

While the 3GPP was completing the Release 9, it recognized the need to develop a new solution to meet the IMT Advanced requirements and make the evolution of LTE a candidate for future new spectrum bands still to be identified. Therefore, the 3GPP worked on a study item called LTE Advanced, which represented the keystone of the Release 10. This Release, completed in March 2011, added new features and performance enhancements, including carrier aggregation, MIMO enhancements, relaying, SON enhancement, coordinated multipoint and heterogeneous networks.

[2] *The IMT Advanced systems promise to provide best-in-class performance such as peak and sustained data rates and corresponding spectral efficiencies, capacity, latency, overall network complexity and quality-of-service management. In addition, they promise to support innovative and multimedia applications, including, but not limited to, video, file uploading and downloading without size limitations (e.g., FTP), streaming video and streaming audio, IP Multicast, location based services, VPN connections, VoIP, instant messaging and on- line multiplayer gaming. Finally they promise to enable the mobile user with an 'always-on' experience while also preserving battery life. [5]*

When the Release 10 was almost complete, the 3GPP started to focus on the Release 11 planning with a target deadline timeframe expected for September to December 2012. Several enhancements are planned to be added, such as carrier aggregation and ICIC enhancements.

Figure 1 provides the standardization timeline for LTE and beyond.

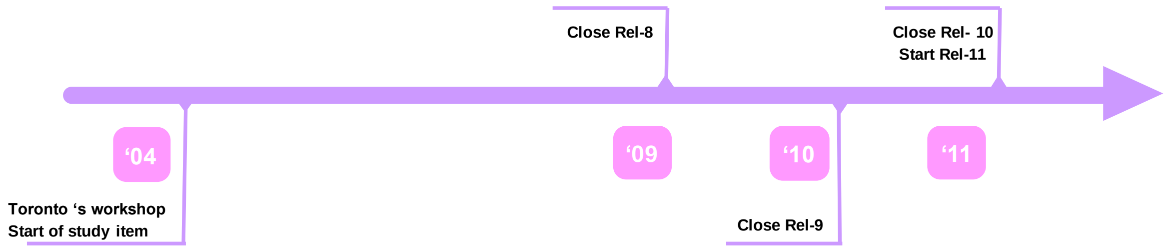

Figure 1 – Standardization timeline for LTE and beyond

2.2 How LTE works

LTE promises to considerably improve performance in comparison with legacy 3GPP systems. More specifically, the goal of LTE is to provide high data rates, low latency, spectrum flexibility, higher mobile speeds, real E2E QoS and packet-optimized network.

In order to achieve these targets several features have been added, as shown in Figure 2, including OFDM, MIMO, advanced interference coordination techniques, evolved core network, SAE bearer model and SON capabilities. A detailed analysis of the aforementioned features is provided in the following sections.

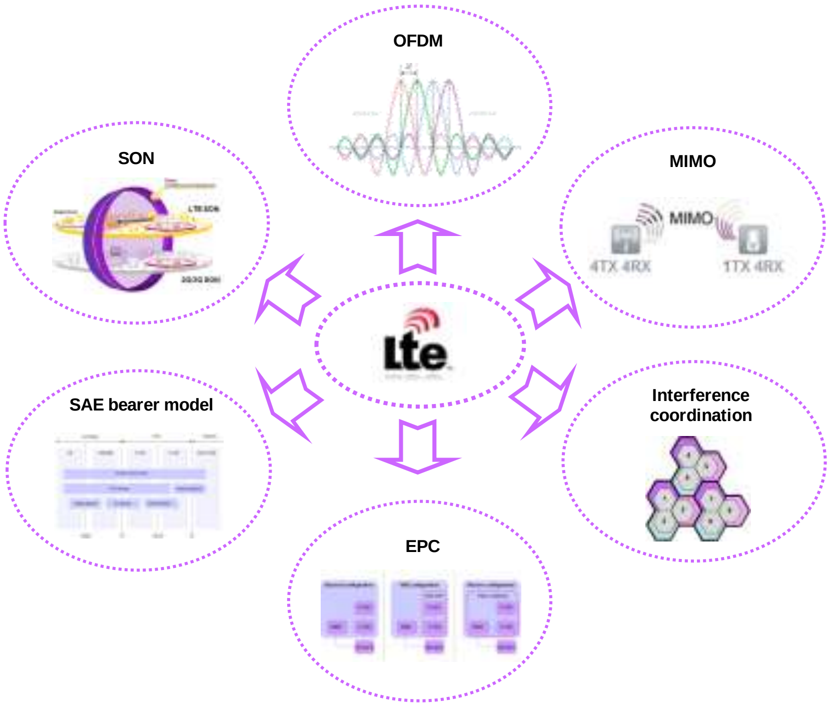

Figure 2 – LTE features

2.2.1 Targets

The main requirements for the design of LTE were identified at the beginning of the 3GPP work item [6]. A brief and clear summary is provided below.

- ***Peak data rate***
  The peak data rate should have targeted 100 Mbps in DL and 50 Mbps in UL.

- ***Latency***
  - ***Control Plane***
    The target for the transition time from the idle mode to the connected mode should have been less than 100 ms; whilst the target for the transition time from the dormant state to the connected mode less than 50 ms.
  - ***User Plane***
    The latency target should have been less than 5 ms.

- ***Spectrum efficiency***
  Spectrum efficiency should have been 3-4 times better than the Release 6 in DL (i.e. higher than 5 bps/Hz), whereas spectrum efficiency 2-3 times better than the Release 6 in UL (i.e. higher than 2.5 bps/Hz).

- ***Mobility***
  Performance should have been optimized for low mobile speeds from 0 to 15 km/h. However higher mobile speeds (up to 350 Km/h) should have been supported.

- ***Spectrum flexibility***
  Scalable channel bandwidths of 1.4, 3, 5, 10, 15 and 20 MHz in both DL and UL should have been supported, as well as FDD and TDD for paired and unpaired spectrum bands respectively.

- ***Architecture***
  LTE should have been packet switched domain optimized, assuming that all operations were based on a packet type.

- ***Internetworking***
  Interworking with legacy 3GPP and non-3GPP systems (such as WiMAX and Wi-Fi) should have been ensured, including inter-system handover to and from 3GPP systems.

- ***Quality of service***
  E2E QoS should have been supported. In addition, VoIP service should have been provided with at least as good radio and backhaul efficiency and latency as voice traffic over the 3GPP systems.

- ***Costs***
  LTE should have reduced CAPEX and OPEX ensuring low investments and operational costs compared to the earlier systems.

Table 1 summarizes the main key targets for LTE.

Table 1 – LTE key targets

Performance indicator		LTE
Peak data rate		DL: 100 Mbps UL: 50 Mbps
Latency	C-plane	< 50 - 100 ms
	U-plane	< 5 ms
Spectrum efficiency[3]	Peak	DL: > 5.0 bps/Hz UL: > 2.5 bps/Hz
	Average[4]	DL: > 1.60 bps/Hz UL: > 0.66 bps/Hz
	Cell-edge[5]	DL: > 0.04 bps/Hz UL: > 0.02 bps/Hz
Mobility		Up to 350 Km/h
Channel bandwidth		Up to 20 MHz

2.2.2 Evolved radio air interface

In comparison with legacy 3GPP systems, LTE has introduced several features to address the aforementioned requirements [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], but the most important ones are OFDM and MIMO that constitute the major differentiation over legacy 3GPP systems.

OFDM

OFDM[6] is a multi carrier transmission which works by splitting the signal into multiple narrowband signals that are simultaneously transmitted on different sub-carriers partially overlapped but orthogonal, as shown in Figure 14. The number of sub-carriers defines the size of the OFDM symbol (i.e. of FFT).

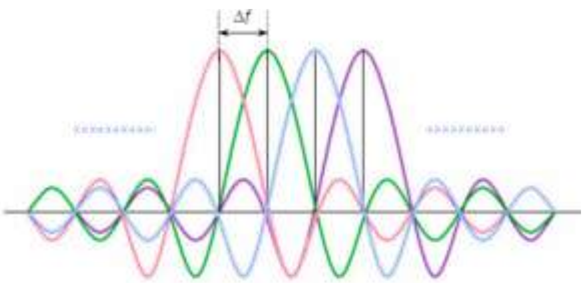

Figure 3 – Frequency representation of OFDM

OFDM has superior performance mostly in multipath environments, characterized by several paths between the transmitter and the receiver due to the presence of obstacles (such as trees, buildings,

3 This spectrum efficiency has been estimated by assuming four antenna elements at eNB side and 2 antenna elements at UE side.

4 The average spectrum efficiency is defined as the aggregate throughput of all users normalized by the overall bandwidth divided by the number of sites.

5 The cell-edge spectrum efficiency is based on the cell-edge user throughput. It is defined as the 5% point of the CDF of the user throughput normalized with the overall cell bandwidth.

6 OFDM is not a new technology, but it was patented by Bell Labs in 1970. Today it is used in different systems, such as ADSL, DAB, DVB, Wi-Fi and WiMAX.

mountains, hills and other natural or manmade structures or objects). In these environments, hence, OFDM allows defeating multipath through its narrowband nature. In addition, OFDM limits the intersymbol interference through its structure (cyclic prefix) and increases the spectral efficiency thanks to the orthogonality between sub-carriers.

MIMO

MIMO uses multiple antenna elements at TX/RX to either increase the peak data rate or enhance the signal robustness. More specifically, LTE supports up to four transmit and receive antenna elements in DL, whilst one transmit antenna element and up to four receive antenna elements in UL.

Three main modes of MIMO can be pointed out: spatial multiplexing, transmit diversity and beamforming.

Spatial multiplexing relies on sending independent signals from two or more different antenna elements in order to increase the peak data rate by a factor that depends on their numbers. Transmit diversity relies on sending the same signal from multiple antenna elements in order to enhance the coverage radius. Spatial multiplexing and transmit diversity are tied through the adaptive antenna switching. This such technique, currently implemented in the majority of eNB supporting MIMO, allows switching between the spatial multiplexing and transmit diversity based on the quality of the radio propagation channel in order to fully benefit from MIMO. Figure 4 provides a high level description of the way these techniques work.

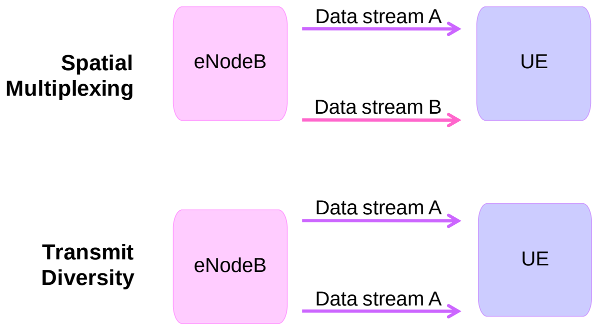

Figure 4 – Spatial multiplexing and transmit diversity

Beamforming allows automatically chancing the directionality of the antenna radiation pattern through advanced signal processing capabilities in order to dynamically minimize interference, maximize intended signal reception and improve the management of the system power and spectrum allocation. Figure 5 provides a high level description of the way this technique works.

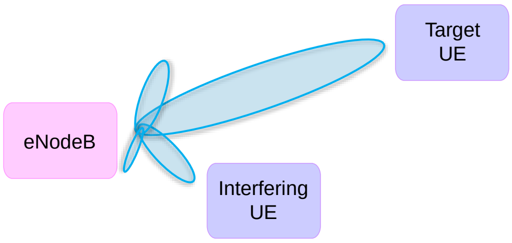

Figure 5 – Beamforming

Multiple access techniques

In DL the multiple accesses is based on OFDMA. In detail, OFDMA is an extension of OFDM in which available sub-carriers are assigned to different users based on their capacity demand and radio channel propagation conditions. As shown in Figure 6, multiple users can be scheduled to receive data simultaneously like in FDMA, but their mutual interference is reduced thanks to the orthogonality among sub-carriers.

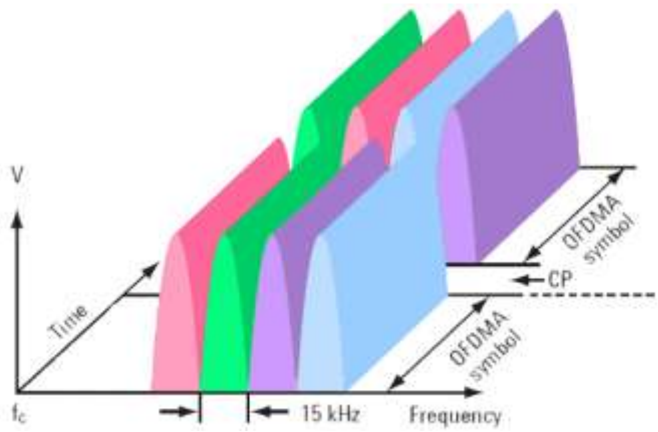

Figure 6 – OFDMA scheme

In addition, OFDMA is used in combination with TDMA and, therefore, resources are partitioned in the time-frequency plane.

The main drawback of OFDMA is the high PAPR. Since OFDMA consists of several sub-carriers in the frequency domain, that is several sinusoidal waves in the time domain, it is characterized by a strong variation of the signal envelope, as depicted in Figure 7. This results in the need to use expensive non-linear PA with low power consumption mainly at UE side.

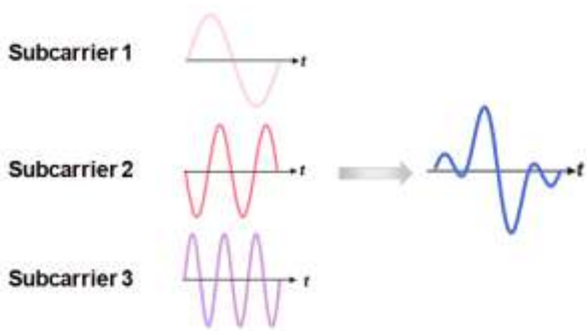

Figure 7 – High PAPR challenge

To solve this critical issue, in UL the power efficient SC-FDMA is implemented. This is a variant of OFDM and is generated through a DFTS-OFDM. Like in OFDM the channel bandwidth is divided into multiple sub-carriers, however in SC-FDMA the sub-carriers are transmitted sequentially and not in parallel, as shown in Figure 8. Therefore, since only one sub-carrier is used at a time, PAPR is reduced and, consequently, a more efficient PA implementation can be carried out.

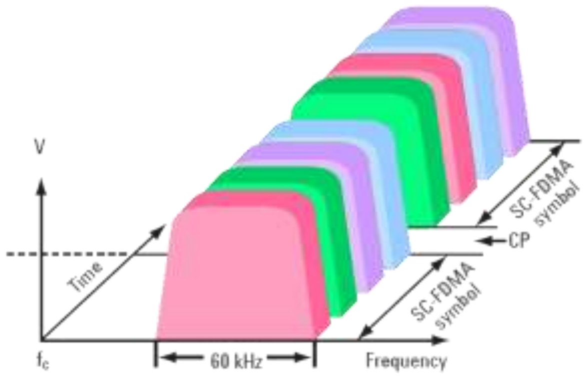

Figure 8 – SC-FDMA scheme

Duplexing format

LTE can accommodate both paired spectrum bands for FDD and unpaired spectrum bands for TDD. Specifically, there are two different versions, i.e. LTE FDD and LTE TDD (also called TD-LTE), whose main differences are summarized in Table 2.

Table 2 – LTE FDD vs LTE TDD

Parameter	LTE FFD	LTE TDD
Spectrum	Paired spectrum bands to allow DL/UL transmissions	Unpaired spectrums to allow DL/UL transmissions
DL/UL asymmetry	No support for the dynamic change of DL/UL ratio	Support for the dynamic change of DL/UL ratio
Guard band / Guard period	Duplex separation to isolate DL/UL transmissions	Guard period to isolate DL/UL transmissions
Synchronization	No synchronization among eNB	Synchronization among eNB
Hardware platform	More complex and, thus, more expensive	Less expensive
Channel reciprocity	Different radio propagation channels in DL/UL	Same radio propagation channel in DL/UL

As deduced from Table 2, LTE FDD is backward compatible with existing 3GPP networks and, therefore, it has gained an early lead in LTE deployments. LTE TDD[7], instead, appears as an exciting alternative, because it makes unpaired spectrum bands an attractive asset with a more realistic price, supports asymmetric services and delivers similar performance to LTE FDD.

[7] *LTE TDD provides an excellent evolution path for TD-SCDMA and WiMAX systems towards 4G.*

UE categories

The 3GPP has defined five different UE categories, often referred to as UE classes, which are summarized in Table 3.

Table 3 – UE classes

Parameter	Class 1	Class 2	Class 3	Class 4	Class 5
Peak rate DL/UL [Mbps]	10/5	50/25	100/50	150/50	300/75
Channel bandwidth [MHz]	20	20	20	20	20
Modulation DL	64QAM				
Modulation UL	16QAM			64QAM	
MIMO DL	Optional		2x2		4x4

As shown in Table 3, 64QAM is mandatory in DL whereas it is optional in UL with the exception of Class 5. In addition, regardless of whatever class a UE belongs in, it supports different MIMO configuration: Class 1 does not support MIMO; Classes 2 to 4 support 2x2 MIMO and, finally, Class 5 supports 4x4 MIMO.

However, some capabilities are not specified in the UE classes, such as inter-RAT capabilities and duplexing format.

Interference coordination

A considerable requirement for LTE is the improvement of cell edge coverage and throughput performance in comparison with the Release 6. In noise-limited scenarios, cell edge performance can be improved through a higher power gain, achieved by using high gain antennas, increasing transmit power, adopting beamforming or transmit diversity. Instead in interference-limited scenarios, cell edge performance can be enhanced by using interference coordination techniques to mitigate the interference at cell edge.

Three different techniques of interference coordination have been identified: Power Control, FFR and SFR.

Power control allows adapting the transmit power level to support a specific data rate in DL and UL on the basis of radio propagation channel conditions.

FFR is based on the concept of frequency reuse partitioning, according to which users with a high signal quality (located in the inner cell) adopt a lower reuse factor whilst users with a low signal quality (located in the outer cell) adopt a higher reuse factor. Figure 9 provides a sample of FFR that assumes the reuse-1 for users in the inner cell while the reuse-3 for users in the outer cell. In this case, the total frequency resource is divided into four main segments: one segment, representing the secondary band, is used in the inner cell with reuse-1; the three remaining segments, representing the primary band, are used in the outer cell with reuse-3.

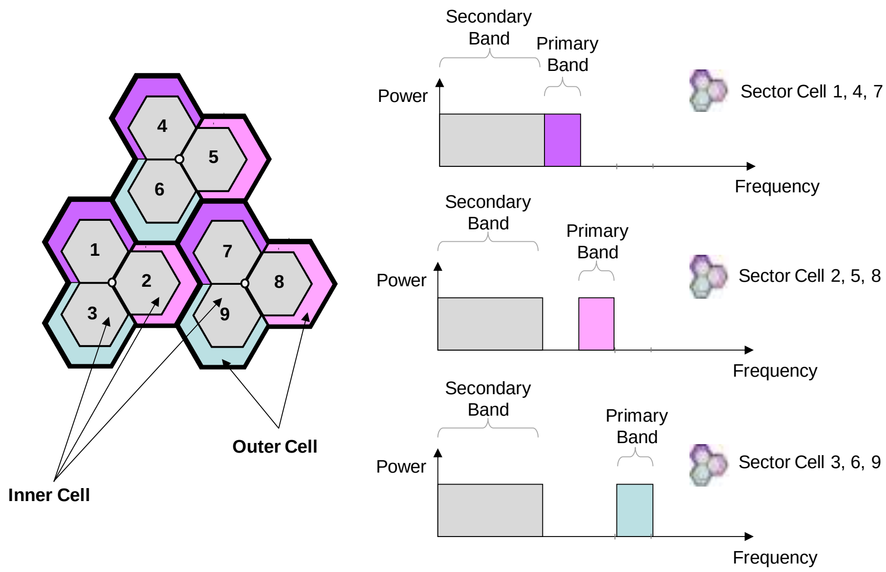

Figure 9 – FFR

However, FFR has the main drawback of the spectrum inefficiency, because the segments of the primary band used for cell edge users in the neighboring cells are left empty in a given cell. This means that in each cell two segments of the primary band are unused.

This issue is addressed thanks to SFR, where all the segments can be used in all the cells. For example, for a soft reuse-3, the total frequency resource is divided into three segments: the primary band consists of one segment while the secondary band of two segments, as depicted in Figure 10. To reduce the interference to cell edge users in the neighboring cells, a lower transmit power is applied to the secondary band.

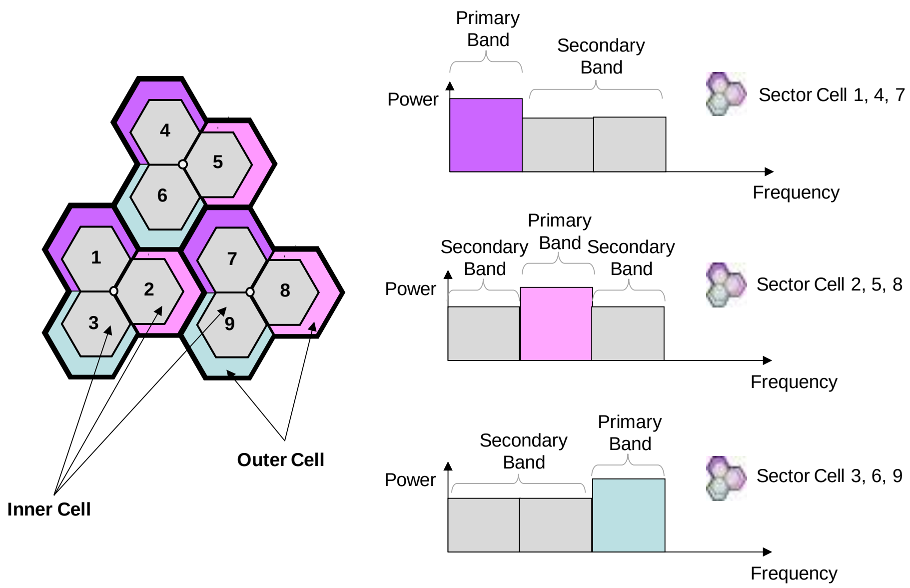

Figure 10 – SFR

2.2.3 Simplified core network

LTE needs to address specific requirements, as specified previously, including reduced latency and improved QoS, support for only packet switched services, separation between the U-plane and C-plane traffic handling, convergence and seamless internetworking with legacy 3GPP and non-3GPP systems.

Therefore, in order to overcome these challenges, the 3GPP has defined a new simplified architecture, called EPS, as a combination of an evolved radio access part -called E-UTRAN, and an IP based core network - called EPS [20], [21], [22], [23], [24], [25], [26].

As depicted in Figure 11, EPS is made up of various network elements each of which is inter-connected through standard interfaces, enabling network operators to select different network elements from different vendors with the maximum flexibility.

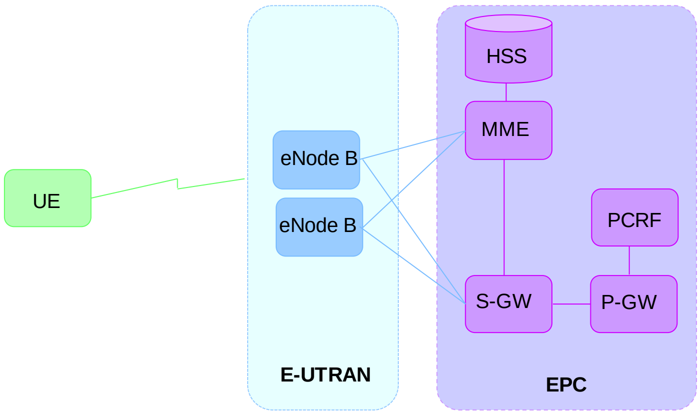

Figure 11 – High level view of EPS

E-UTRAN

As shown in Figure 11, E-UTRAN consists of only one network element; eNB[8] that is connected to UE through the interface LTE-Uu, to EPC through the interface S1 and to another eNB through the interface X2. eNB implements all radio-related functions, including RRM (radio bearer control, radio admission control, radio mobility control, scheduling and dynamic allocation of resource to UE), IP packet header compression, security and connectivity to EPC (the signaling towards MME and the bearer path towards S-GW).

EPC

As depicted in Figure 11, EPC is mainly made up of three network elements: S-GW, P-GW and MME.

- S-GW represents the user-plane node providing a data path between eNB and P-GW. It provides various functions, including mobility anchoring for inter-eNB handovers, management of mobility between LTE and legacy 3GPP systems, support for lawful interception and charging functionalities, packet routing and forwarding (eNB, P-GW).

[8] *The RNC inherited form BSC has disappeared from E-UTRAN and eNB is directly connected to the core network through the S1 interface. Therefore, the features supported by RNC and BSC have been distributed between eNB, MME and S-GW.*

- P-GW constitutes the termination point of the PDN interface. It provides several functions, including mobility anchoring with non-3GPP systems, per-user-based packet filtering (DPI), policy and charging enforcement, support for charging, support for lawful interception, packet routing and forwarding (S-GW and PDN), packet screening (firewall functionalities) and IP addressing allocation for UE.

- MME is a pure signaling entity inside EPC and is in charge of signaling and control functions, updates of tracking area, management of mobility states that support roaming and paging, UE attach/detach, bearer management control and security.

The 3GPP has not specified the hardware configuration of the EPC architecture and, hence, each EPC component supplier can implement various configurations. However, three main hardware configurations can be picked out, as depicted in Figure 12: the 'classical configuration', the 'SAE configuration' and, finally, the 'one box configuration'. In the 'classical configuration' each network element is implemented in a distinct equipment; in the 'SAE configuration' S-GW and P-GW are combined in the same equipment called SAE-GW and, finally, in the 'one box configuration' the whole EPC architecture is realized in a unique equipment.

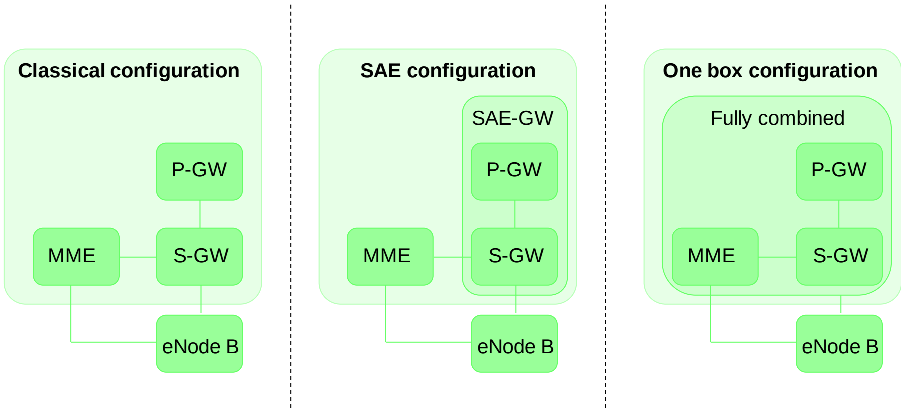

Figure 12 – Possible hardware configurations of EPC

Besides S-GW, P-GW and MME, EPC includes other network elements such as PCRF and HSS:

- PCRF mainly coordinates QoS between PDN and EPC. It provides functionalities such as QoS policy negotiation with PDN, charging policy, policy and charging control rules at set-up of a new bearer.

- HSS is the concatenation of HLR and AuC, two network elements already present in legacy 3GPP systems. HLR is in charge of storing and updating, when necessary, the database containing all user subscription information (such as user identification and addressing, service subscription state and SLA). AuC is in charge of generating security information from user identity keys for mutual network-terminal authentication and protection of data and signaling transmitted between network and UE.

Evolution towards EPC

EPC represents a radical change from legacy 3GPP systems due to several aspects, such as the departure from the circuit-switched domain. This means that a migration path towards EPC needs to be properly defined guaranteeing service continuity, with a focus on voice and SMS services.

Regarding the migration from legacy 3GPP systems, a smooth step-by-step approach could be adopted in order to minimize changes. This means that initially EPC is deployed as an overlay on top of legacy 3GPP systems.[9] Then, a software upgrade of legacy 3GPP interfaces into new LTE S-interfaces is applied to guarantee the internetworking.[10] Finally, a unique gateway (S-GW plus P-GW) is used by legacy 3GPP and LTE access.

Regarding the migration from non-3GPP systems (e.g. WiMAX), the main requirement to achieve a seamless integration with EPC is to provide an appropriate authentication infrastructure. Thus, EPC is connected to the WiMAX system through P-GW on the data plane; whereas to the AAA server through HSS and BBERF through PCRF on the control plane.

2.2.4 QoS differentiation

Since various services need to be provided through LTE, such as VoIP, web browsing, video telephony and video streaming more advanced QoS mechanisms are requested in order to assure the real user experience. Each service, therefore, has specific QoS requirements: for example VoIP has more stringent requirements in terms of delay and delay jitter than web browsing and FTP.

This results in the SAE bearer model, shown in Figure 13, which is very similar to GPRS bearer model [25], [27].

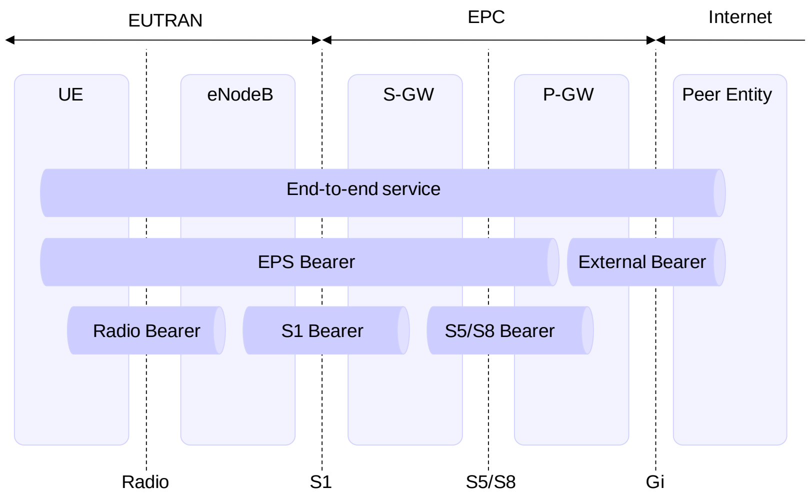

Figure 13 – SAE bearer model

In EPS, QoS flow called EPS bearer is established between UE and P-GW. More specifically, when receiving an IP packet from the Internet, P-GW performs a packet classification based on certain predefined parameters and sends an appropriate bearer (S5/S8 bearer) to S-GW that, in turn, transmits a specific bearer (S1 bearer) to eNB. Depending on the bearer received eNB maps the IP packet into the appropriate radio bearer, which transports the IP packet from eNB to UE.

Due to the 'always-on' concept a default bearer with quite basic QoS capabilities is always available to each UE registered to the system. However, additional bearers, called dedicated bearers, can be associated to a specific registered UE when services with more stringent QoS are requested.

9 In this phase, the internetworking is enabled by P-GW that supports in-built GGSN functionalities including Gn interface. The Gn interface can be also applied between SGSN and MME.

10 In this phase, SGSN is connected to MME (S3-interface) and S-GW (S4-interface), and RNC to S-GW (S12-interface).

Each bearer is characterized by two or four QoS parameters, depending whether it is associated to a real-time or best effort service:

- QCI: It identifies a set of logically configured values for priority, delay and loss rate. Specifically, the 3GPP has defined nine classes of standardized QCI, as shown in Table 4.

Table 4 – QCI classes

QCI	Resource type	Priority	Packet delay budget [ms]	Packet error loss rate	Example services
1	GBR	2	100	10^{-2}	Conversational voice
2		4	150	10^{-3}	Conversational video (live streaming)
3		5	300	10^{-6}	Non-conversational video (buffered streaming)
4		3	50	10^{-3}	Real time gaming
5	Non-GBR	1	100	10^{-6}	IMS signaling
6		7	100	10^{-3}	Voice, video (live streaming), interactive gaming
7		6	300	10^{-6}	Video (buffered streaming)
8		8	300	10^{-6}	TCP based (e.g. www, e-mail), chat, FTP, P2P file sharing, progressive video, etc.
9		9	300	10^{-6}	Best effort

- ARP: It indicates the priority of the specific bearer compared to other bearers.
- GBR: Specified only in case of real-time services, it identifies the bit rate guaranteed for the specific bearer.
- MBR: Specified only in case of real-time services, it identifies the maximum bit rate for the specific bearer.
- AMBR: Specified only in case of real-time services, it indicates the total maximum bit rate UE can have when multiple IP packets are associated to the same bearer.

2.2.5 Security

In setting security features, the 3GPP has taken into account several aspects, including architectural design decisions, internetworking with legacy 3GPP and non-3GPP systems, new services to be provided and local-based security approach.

As a result, the 3GPP has included additional features into all network elements from UE through the core network [21], [22]. Specifically:

- A hierarchy of security keys has been introduced, supporting dynamic key changing thanks to explicit re-keying or implicit key-refresh procedures.
- Two different security procedures for NAS and AS have been adopted to ensure confidentiality and integrity protection for signaling and user data in EPS.

- The forward security has been added to ensure that MME provides a new key after handover in case of failure during handover.
- Security functions have been introduced between LTE and legacy 3GPP networks.

2.2.6 Mobility

LTE's goal is to provide a seamless mobility. This means that the continuity of the user experience has to be guaranteed, when a user is moving from one eNB to another eNB (intra-RAT mobility) or from the LTE system to legacy 3GPP and non-3GPP systems (inter-RAT mobility) and vice versa, while being in a VoIP session or downloading files.

In the case of the intra-RAT mobility, two different handover procedures have been defined: through the X2 interface and through the S1 interface. The handover through the X2 is directly performed between two eNB in order to speed up the preparation phase; whereas the handover through the S1 interface is carried out by MME and is similar to the handover implemented in the UMTS system.

In the case of the inter-RAT mobility, the handover procedure depends on RAT involved. For example, for mobility from the LTE system towards the 3G system, the handover procedure can reuse the S1-handover with some exceptions. Instead of mobility towards the CDMA system, dedicated procedures have been introduced in LTE based on the tunneling of the CDMA signaling between UE and the CDMA system over the S1 interface.

2.2.7 SON

SON aims at substantially reducing the effort required to deploy and manage the network [28]. This has an impact on radio planning as well as on the O&M interface to the eNB.

More specifically, in the Release 8 the self-configuration functionality has been defined, that is the one-time process of automating a specific event by means of the O&M interface and the network management module. For example, a new base station is automatically configured and integrated into the network through a simple download of configuration parameters and software.

Among the implemented features, ANR is very significant. In detail, ANR allows the automatic discovery and setup of neighbor relations, when UE moves from the serving eNB to the target eNB, as well as the automat set up of the LTE unique X2 interface between eNB, primarily used for handover. In this way the manual handling of neighbor relations is minimized as well as decreasing the number of dropped connections (due to missing or incorrect neighbor relations) with a consequent increase of the number of successful handovers.

2.2.8 Voice and SMS services over LTE

Since in EPC there is no CS domain to handle voice calls, a number of possible solutions have been investigated to provide voice and SMS services, as outlined below:

- Circuit Switched Fall Back: a network and UE based mechanism by which active UE on LTE is required to re-tune on legacy 3GPP systems and, thus, performs CS fallback from LTE in order to access legacy CS based services (i.e. voice and SMS).
- Voice over LTE[11]: a mechanism that uses IMS and SIP specifications developed by the 3GPP as its basis to address voice and SMS services over LTE. Specifically, the voice call continuity between IMS over PS access and CS access is guaranteed by SRVCC.
- Voice over LTE via Generic Access: based on the existing 3GPP GAN standard, the voice call continuity between LTE and legacy 3GPP systems is guaranteed through the implementation of a gateway, also called VANC, which connects existing MSC to EPC.

Since VoLGA has been constantly loosing traction in the industry due to the adoption of VoLTE by GSMA, VoLTE represents the optimal solution to provide voice and SMS services. However, the road towards VoLTE is not so clear and it mainly depends on the initial LTE coverage and chosen deployment strategy. Network operators with aggressive LTE roll-out plans would likely adopt VoLTE immediately; whist network operators starting with spotty LTE coverage would probably deploy CSFB as a first step to avoid too frequent call handovers between the CS and PS domain.

2.3 LTE Advanced and beyond

In early 2008 ITU-R issued a Circular Letter to invite candidate RIT for IMT Advanced. In this Circular Letter, key features of IMT Advanced were listed. The following are the general system requirements and features that the IMT Advanced systems need to support [5]:

- Higher spectral efficiencies and peak data rates
- Lower latencies to enable new delay-sensitive applications
- Mobility Support:
    - Stationary (Fixed applications)
    - Pedestrian (Pedestrian speeds up to 10 km/h)
    - Typical Vehicular (Vehicular speeds up to 120 km/h)
    - High Speed Vehicular (Vehicular speeds up to 500 km/h)
    - Optimized system performance for low mobility environments

[11] *VoLTE is a GSMA initiative formally announced on February 15 2010. In establishing the VoLTE initiative, GSMA has adopted the work of the One Voice Initiative as the basis of the work to lead the global mobile industry towards a standard way of delivering voice and messaging services for LTE. Using IMS specifications developed by 3GPP as its basis, GSMA have expanded upon the original scope of One Voice work to address the entire E2E voice and SMS ecosystem by also focusing on roaming and interconnect interfaces, in addition to the interface between customer and network.*

    - Seamless application connectivity to other mobile and IP networks

- Support for larger cell sizes and improved cell-edge performance
- Low-cost and low-complexity UE for worldwide use
- Mobile user interface
- Ubiquitous Access
- Improved unicast and multicast broadcast services
- Provision for PAN / LAN / WAN co-location and coexistence.

The 3GPP decided to respond to this Circular Letter in order to make LTE Advanced a candidate for future new spectrum bands still to be identified. The timeline for IMT Advanced and LTE Advanced is provided in Figure 14, where the top shows the timeline of the ITU-R, whilst the bottom summarizes the timeline of the 3GPP.

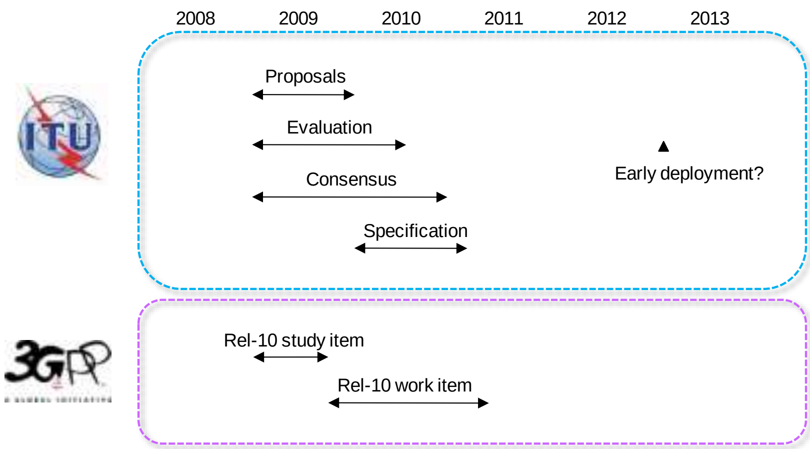

Figure 14 – Timeline for IMT Advanced and LTE Advanced

Regarding the timeline of the ITU-R, in March 2008, the ITU-R issued a Circular Letter indicating a cut-off date of October 2009 for submission of candidate RIT proposals and a cut-off date of June 2010 for submission of the technology evaluation report to the ITU. In October 2010 the ITU Working Party 5D (WP 5D) decided that the first two RIT to meet the IMT Advanced requirements were 3GPP LTE Advanced and IEEE 802.16m [29].

Regarding the timeline of the 3GPP, as previously indicated, the 3GPP started the study item while it was completing the Release 9. In September 2009 the 3GPP formally submitted LTE Advanced to the ITU as an IMT Advanced candidate technology and in March 2011 the Release 10 was completed.

2.3.1 Targets

Defining the LTE Advanced specifications, the 3GPP has taken into account two different key drivers: firstly to meet or even to exceed the IMT Advanced specifications; secondly to make LTE Advanced backwards compatible[12] with LTE being not a new radio access standard but rather the evolution of LTE[13].

Therefore, the following requirements for LTE Advanced have been defined [30]:

- ***Peak data rate***
  The peak data rate should have targeted 1 Gbps in DL, whilst 500 Mbps in UL
- ***Latency***
  - ***Control Plane***
    The target for the transition time from the idle mode to the connected mode should have been less than 50 ms, including the set-up of the U-plane; whilst the target for the transition time from the dormant state to the connected mode less than 10 ms.
  - ***User Plane***
    The target latency should have been less than 5 ms[14]
- ***Spectrum efficiency***
  The peak spectrum efficiency should have been 30 bps/Hz in DL, whilst 15 bps/Hz in UL. The average spectrum efficiency and the cell-edge spectrum efficiency targets have been defined depending on the MIMO configuration.
- ***Mobility***
  Mobile speeds up to 350 Km/h (or even up to 500 Km/h depending on the spectrum band) should have been supported.
- ***Spectrum flexibility***
  Additional spectrum bands should have been included, as well as channel bandwidths wider than 20 MHz. Further, FDD and TDD should have been supported for paired and unpaired spectrum bands respectively.

Table 5 summarizes some of the key targets related to IMT Advanced and LTE Advanced and, as shown, the targets for LTE Advanced are more stringent that those of IMT Advanced.

12 It means that it should be possible to deploy LTE-Advanced in spectrum already occupied by the first release of LTE with no impact on existing LTE UE. A direct consequence of this requirement is that for a LTE UE a LTE-Advanced-capable network should appear as a LTE network.

13 The migration towards LTE Advanced should require hardware and/or software upgrades depending on the specific features to be implemented.

14 LTE-Advanced should reduce the U-plane latency compared to LTE (Release 8).

Table 5 – IMT Advanced and LTE Advanced key targets

Performance indicator		IMT Advanced	LTE Advanced
Latency	C-plane	< 100 ms	< 10 - 50 ms
	U-plane	< 10 ms	< 5 ms
Spectrum efficiency[15]	Peak	DL: 15 bps/Hz UL: 6.75 bps/Hz	DL: 30 bps/Hz UL: 15 bps/Hz
	Average	DL: 2.2 bps/Hz UL: 1.4 bps/Hz	DL: 2.6 bps/Hz UL: 2.0 bps/Hz
	Cell-edge	DL: 0.06 bps/Hz UL: 0.03 bps/Hz	DL: 0.09 bps/Hz UL: 0.07 bps/Hz
Mobility		Up to 500 Km/h	Up to 500 Km/h
Channel bandwidth		Up to 40 MHz	Up to 100 MHz

2.3.2 Additional technology components

To address LTE Advanced requirements, as described previously, the 3GPP has added new features to LTE [31], including carrier aggregation, MIMO enhancement, coordinated multipoint, relaying, heterogeneous networks and SON enhancement, as shown in Figure 15.

This has been favored by the technology evolution, including the availability of more spectrums, enhanced baseband processing capability, implementation of multiple power amplifiers in UE, availability of eNB with four/eight antenna elements, capability to deploy four/eight antenna elements at UE side, multiband capability of eNB and UE, availability of optical transport and low cost picocells.

15 This spectrum efficiency has been estimated by assuming four antenna elements at eNB side and 2 antenna elements at UE side.

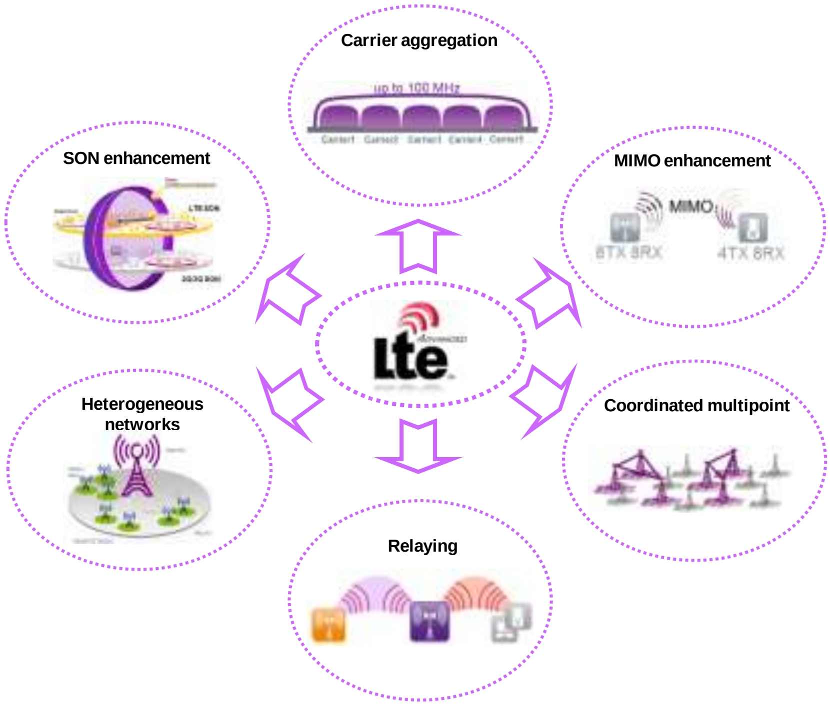

Figure 15 – Additional LTE Advanced features

Carrier aggregation

Carrier aggregation provides high data rates without the need of contiguous spectrum to exploit the highest flexibility in spectrum usage and, at the same time, improves single user throughput by distributing the traffic dynamically over multiple carriers.

In detail, carrier aggregation allows combining up to five carriers to support channel bandwidths up to 100 MHz. These carriers need to be LTE compatible in order to support legacy LTE UE and can be both contiguous and non-contiguous even at different frequency bands.

In the Release 10, two different spectrum bands have been identified both for intra-band and inter-band aggregation. More specifically, the 2000 and 2300 MHz spectrum bands have been pointed out for intra-band aggregation, whereas the 2000 and 800 MHz spectrum band for inter-band aggregation.

MIMO enhancement

The number of transmit and receive antenna elements has been increased in order to enhance peak data rate as well as improve radio propagation channel conditions. Specifically, LTE Advanced supports up to eight transmit and receive antenna elements in DL, whereas up to four transmit antenna elements and eight receive antenna elements in UL.

Coordinated multipoint

Coordinated multipoint allows improving coverage and capacity performance through an active interference cancellation, by transforming the interference from another eNB into a useful signal at cell edge.

In DL the coordinated multipoint enables coordinated scheduling and beamforming[16] as well as the joint processing[17] from two or more physically separated locations. However, to support these operations a feedback from UE is required, containing channel properties, noise and interference measurements.

In UL the coordinated multipoint is restricted to use of the coordinated scheduling[18], because when two or more UE are transmitted from different places there is no realistic mechanism to share the data between UE for the precoding.

Relaying

Relaying enables focus coverage and capacity extensions by means of relay nodes using the LTE Advanced radio interface for self-backhaul.

In detail, UE communicates with RN which in turn communicates with the Donor eNB through a new air interface. The Donor eNB, in addition to serving one or more RN, can communicate with non-relayed UE directly.

Two different types of RN have been defined: type 1 and type 2. The RN type 1 effectively creates its own cell (e.g. it transmits its own cell ID and own synchronization and reference signals) and, therefore, from the UE perspective it looks like an eNB. Instead the RN type 2 cannot create its own cell and, thus, the control information is transmitted directly by the Donor eNB whilst the data information is transmitted through the RN.

Heterogeneous networks

Heterogeneous networks enable focus coverage and capacity extensions by combining local area sites (such as picocells, femtocells, repeaters and relays) with medium and wide area sites (such as macrocells and microcells), that spread across multiple RAT[19] and operate in both licensed and unlicensed spectrum bands.

This more complex network poses a new set of challenges including interference coordination, handover among different-scale cells to provide seamless mobility, self-configuration and self-optimization capability, security management between cells of different ownership (consumer, enterprise, network operator) and, finally, service continuity to guarantee a real user experience.

SON enhancement

In LTE Advanced SON has been further improved thanks to the introduction of additional SON functionalities, such as self-optimization and self-healing. Self-optimization represents the continuous process of using environmental data (e.g. UE and eNB measurements) to optimize the current network settings; whilst self-healing denotes the process of recovering from an exceptional event caused by unusual circumstances (e.g. changing of interference conditions).

---

16 The transmission data to a single UE is available at the serving eNB only, but user scheduling/beamforming decisions are made with coordination among eNB.

17 The transmission data to a single UE is available at multiple eNB. In case of joint processing, data is transmitted simultaneously from multiple eNB; whereas in case of dynamic cell selection, data is transmitted from one eNB at a time.

18 The coordinated scheduling in UL implies the coordination among multiple eNB to control interference.

19 A range of different RAT, including GSM, UMTS, HSPA, LTE, WiMAX and Wi-Fi, should all co-exist.

Among the features implemented, MDT is very important. This is an automated solution involving UE active in order to collect data (e.g. coverage vs position and dropped call vs position) to monitor and detect coverage problems. This allows minimizing drive test activities, that are expensive in terms of staff, time and equipment needed, and hence to reduce costs for network deployment and operations.

2.4 Performance in a nutshell

In order to better understand how LTE has been evolved and, hence, how performance has been enhanced, a close and consistent comparison of LTE vs LTE Advanced has been carried out, based on the following parameters:

- Spectrum flexibility: It denotes the capability of supporting various spectrum bands and channel bandwidths. This enables network operators to deploy LTE networks according to their specific needs in terms of spectrum regulation, availability of radio resources and the possibility of purchasing spectrum licenses.
- Coverage: It denotes the ability to better address coverage requirements in different scenarios, such as indoor, outdoor and vehicular. This allows the reduction of the site count in coverage-limited scenarios and, hence, minimizes TCO.
- Capacity: It denotes the capability of supporting high data rates in DL and UL. This allows the reduction of the site count in capacity-limited scenarios and, hence, minimizes TCO.
- Response: It denotes the ability to reduce the E2E latency both on C-plane and U-plane. This enables network operators to offer innovative and multimedia services, guaranteeing a real user experience.
- Mobility: It denotes the capability of supporting high mobile speeds. This means that the technology can operate not only in typical vehicular scenarios (up to 120 Km/h) but also in high speed vehicular scenarios (up to 500 km/h).
- QoS: It denotes the ability to assure the real user experience, providing differentiate QoS levels tailored to specific services.
- Security: It denotes the ability to securely exchange signaling and user data in all network elements from UE through the core network.
- Deployment flexibility: It denotes the possibility of deploying local area sites as well as medium and wide area sites, based on various radio access technologies, in order to focus coverage and capacity extensions.
- Self-optimizing network capability: It denotes the capability of supporting self-configuration, self-optimization and self-healing functionalities in order to reduce the effort required to deploy and manage the network.
- Standard and maturity: It denotes the support provided by industry and standard bodies in order to favor the worldwide diffusion of the technology, creating a widespread ecosystem and, thus, providing economies of scale.

Table 6 shows LTE and LTE Advanced performance at a glance.

Table 6 – LTE and LTE Advanced performance at a glance[20]

	LTE	LTE Advanced
Spectrum flexibility	●●○	●●●
Coverage	●●○	●●●
Capacity	●●○	●●●
Response	●●○	●●●
Mobility	●●○	●●●
QoS	●●●	●●●
Security	●●●	●●●
Deployment flexibility	●○○	●●●
Self-optimizing network	●○○	●●●
Standard and maturity	●●○	●●●

As depicted in Table 6 and as well expected, LTE Advanced has a better performance than LTE from several points of view.

Specifically, LTE Advanced provides more spectrum flexibility than LTE. Therefore, new spectrum bands (thirty-four in total) have been included in the Release 10, as specified in the following session; as well as the addition of the carrier aggregation feature in the Release 10 to support up to 100 MHz channel bandwidth.

Moreover, LTE Advanced has a better performance in terms of coverage and capacity thanks to various additional features, such as MIMO enhancement that includes 8x8 configuration in DL and 4x8 configuration in UL; coordinated multipoint that allows transforming eNB interference into a useful signal at cell edge and, finally, relaying that provides focused coverage and capacity extensions.

In addition, since LTE Advanced has been designed to address IMT Advanced requirements including the support of high speed vehicular scenarios, it can operate up to 500 Km/h unlike LTE that can operate up to 350 Km/h.

Furthermore, LTE Advanced enables network operators to deploy different types of sites (macro sites, micro sites, picocells, femtocells, repeaters and relays) spreading across multiple radio access technologies as well as combining them in the same network, on the basis of the specific business model adopted.

Besides, LTE Advanced includes additional SON functionalities, such as self-optimizing and self-healing, that allow optimizing the network deployment and maintenance, as well as reducing investments and costs for operations.

Finally, since LTE Advanced has been included among IMT Advanced technologies by ITU, industry and standard bodies are expected to put more effort into accelerating the adoption, deployment and expansion of this technology across the globe.

[20] *The symbol ●●● denotes high performance, the symbol ●●○ medium performance and finally the symbol ●○○ low performance.*

3. CRITICAL FACTORS FOR THE LTE BUSINESS CASE

This section aims at highlighting the framework for the analysis of the critical factors of an LTE initiative.

3.1 Framework

In order to explore the potentialities of the very promising LTE technology, a business case sample for a nationwide initiative has been analyzed, covering both the technological and business perspective.

This analysis has been carried out by means of TEA|LTE, a specialized decision support tool developed by WiTech and built over eight years of extensive industry experience supporting major operators and equipment suppliers in several strategic initiatives and projects.

TEA|LTE allows analyzing the business case for LTE initiatives with an integrated and iterative way, taking into account all critical aspects (marketing, technical, economic and financial ones) at the same time and, hence, avoiding focusing on each single facet separately. Specifically, this tool features comprehensive market and revenue forecast models, well calibrated technical modeling tailored to the LTE technology, calculation of CAPEX and OPEX as well as TCO, analysis of P&L and Cash Flow with the close evaluation of key performance indicators.

TEA|LTE is based on the proprietary technical-economic model TEA designed by WiTech.

The TEA model aims at capturing all relevant elements for the business case analysis and, hence, forecasting market and revenues, performing the network dimensioning and, finally, estimating all key economic and financial projections and indicators. To perform this, the TEA model takes into account a number of sound technical-economic principles, such as the real representation of the territory and demography of the area of interest, the inclusion of the customer base and the legacy network, the satisfaction of both coverage and capacity requirements, the identification of the proper structure of capital and operational expenses.

Specifically, the TEA model consists of four modules according to the main analyses that it can perform:

- The Market Analysis module evaluates properly the potential market for LTE and makes reliable revenue forecasts for the LTE services to be offered, taking into account territorial and socio-demographic parameters, identifying target segments, defining service profiles, choosing types of UE and, finally, forecasting revenues.

- The Technical Analysis module realizes the dimensioning the LTE infrastructure in terms of access, backhaul and core network. In detail, it defines the required bill of quantities (eNB, logical sectors, radio links, MME, S-GW and P-GW) by considering coverage and capacity requirements, technology and equipment characterization, path loss model for the link budget analysis and legacy assets.

- The Economic & Financial Analysis module assesses the feasibility of the LTE initiative after having calculated all the economic and financial projections (TCO, P&L, Cash Flow, Balance Sheet) and indicators (Gross Margin, EBITDA, EBIT, Net Income, NPV, IRR, PBP, Funding Peak, etc.).

- The Scenario & Sensitivity Analysis module allows evaluating the influence of parameter and boundary condition changes in order to identify the most critical factors for the success of the LTE initiative, as well as to perform a fast and iterative fine-tuning of the LTE business case.

Figure 16 provides a high level picture of the TEA engineering model showing the main inputs and outputs for the aforementioned modules. Further details about TEA|LTE are provided in Annex A.

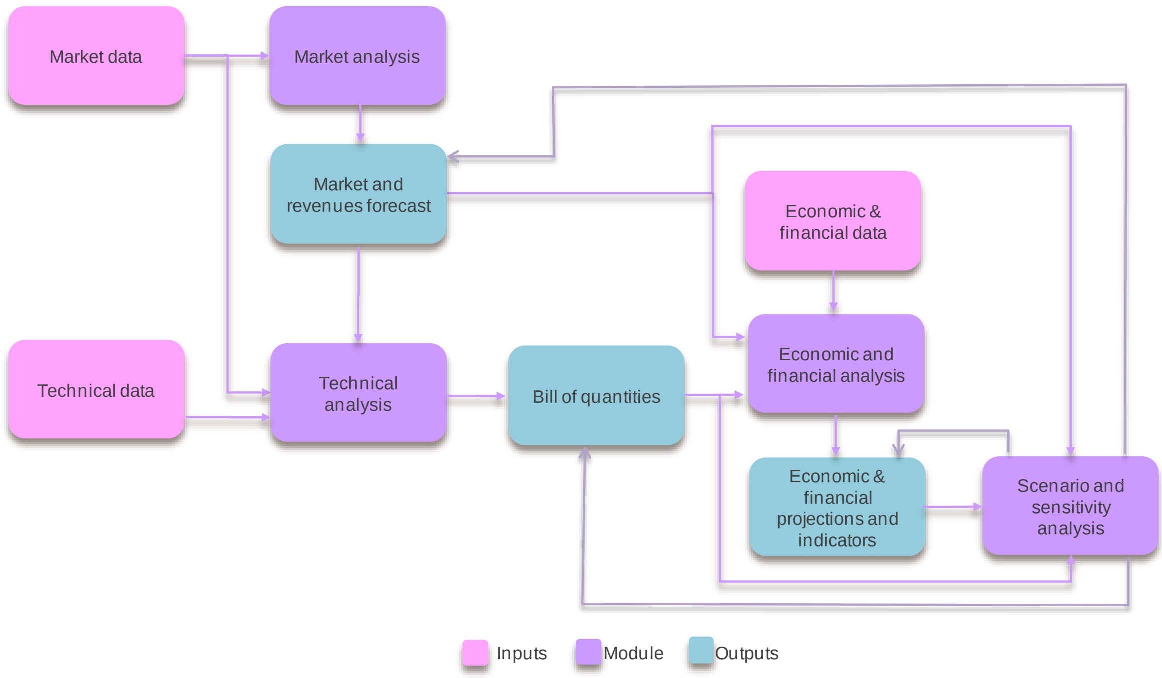

Figure 16 – High level view of the technical-economic model TEA

ACRONYMS

2G	2nd Generation Mobile System
3G	3rd Generation Mobile System
3GDT	3G Direct Tunnel
3GPP	3rd Generation Partnership Project
4G	4th Generation Mobile System
AAA	Authentication, Authorization, and Accounting
ACMA	Australian Communications and Media Authority
ADSL	Asymmetric Digital Subscriber Line
AES	Advanced Encryption Standard
AGC	Automatic Gain Control
AGPS	Assisted GPS
AMBR	Aggregated Maximum Bit Rate
AMC	Adaptive Modulation and Coding
ANACOM	Autoridade Nacional de Comunicações
ANCOM	National Authority for Management and Regulation in Communications of Romania
ANR	Automatic Neighbour Relation
AP	Access Point
APJ	Asia Pacific Japan
ARCEP	Autorité de Régulation des Communications Électroniques et des Postes
ARP	Allocation and Retention Priority
AS	Access Stratum
ASK	Amplitude Shift Keying
ASIC	Application-Specific Integrated Circuit
ATCA	Advanced Telecom Computing Architecture
ATPC	Automatic Transmit Power Control
AuC	Authentication Centre
AWS	Advanced Wireless Services
B-SON	Backhaul Self Organizing Network
BBERF	Bearer Binding and Event Reporting Function
BBU	Base Band Unit
BEM	Block Edge Mask
BIPT	Belgian Institute for Postal services and Telecommunications
BS	Base Station
BSC	Base Station Controller
BTS	Base Transceiver Station

CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditures
CCA	Combinatorial Clock Auction
CCTV	Closed Circuit Television
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CE	Consumer Equipment
CEPT	Conference of European Postal and Telecommunications
CES	Circuit Emulation Services
CGN	Carrier Grade Network
CIR	Committed Information Rate
CMOS	Complementary Metal-Oxide Semiconductor
CMU	Compact Modem Unit
COS	Cost Of Service
CPE	Customer Premises Equipment
CRC	Communications Regulation Commission
CS	Circuit Switched
CSFB	Circuit Switched Fallback
DC-HSPA	Dual Carrier High Speed Packet Access
DFTS-OFDM	DFT Spreading OFDM
DAB	Digital Audio Broadcasting
DBDM	Dual Band Dual Mode
DBPSK	Differential Binary Phase Shift Keying
DBS	Direct Broadcast Satellite
DDNS	Dynamic DNS
DECT	Digital Enhanced Cordless Telecommunications
DFS	Dynamic Frequency Selection
DFT	Discrete Fourier Transform
DHCP	Dynamic Host Configuration Protocol
DL	Down Link
DLNA	Diplexer Low Noise Amplifier
DNS	Domain Name System
DPI	Deep Packet Inspection
DSP	Digital Signal Processing
DVB	Digital Video Broadcasting
DVR	Digital Video Recorder
E2E	End To End
E-UTRA	Evolved Universal Terrestrial Radio Access

E-UTRAN	Evolved Universal Terrestrial Radio Access Network
EBIT	Earnings Before Interest and Taxes
EBITDA	Earnings Before Interest, Taxes, Depreciation and Amortization
ECC	Electronic Communications Committee
EDGE	Enhanced Data Rates For GSM Evolution
EETT	Hellenic Telecommunications and Post Commission
EIRP	Equivalent Isotropically Radiated Power
EMEA	Europe, Middle East and Africa
EMF	Electromagnetic Field
eNB	Enhanced Node B
EPC	Evolved Packet Core
EPS	Evolved Packet System
ETH	Ethernet
ETSI	European Telecommunications Standards Institute
EVDO	Evolution Data Optimized
FAP	Fair Access Policy
FCC	Federal Communications Commission
FDD	Frequency Division Duplexing
FDMA	Frequency Division Multiple Access
FE	Fast Ethernet
FEC	Forward Error Correction
FFR	Fractional Frequency Reuse
FFT	Fast Fourier Transform
FM	Frequency Modulation
FTP	File Transfer Protocol
FXS	Foreign Exchange Station
GAN	General Access Network
GB	Gigabytes
GbE	Gigabit ETH
GBR	Guaranteed Bit Rate
GE	Giga ETH
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
GPS	Global Positioning System
GPU	Graphics Processing Unit
GRE	Generic Routing Encapsulation
GSA	Global mobile Suppliers Association
GSM	Global Systems Mobile

GSMA	GSM Association
GTP	Group Termination Point
H-FDD	Half Frequency Division Duplexing
HD-SDI	High Definition Serial Digital Interface
HBS	High BS
HD	High Definition
HDMI	High Definition Multimedia Interface
HLR	Home Location Register
HO	Handover
HRPD	High Rate Packet Data
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
HSU	High SU
HTTP	HyperText Transport Protocol
HTTPS	Hypertext Transfer Protocol Secure
I&C	Installation & Commissioning
ICIC	Inter-Cell Interference Coordination
ICRST	Industry Canada
ID	Identity
IDU	Indoor Unit
IEEE	Institute of Electrical & Electronics Engineers
IGMP	Internet Group Management
IMS	Internet Protocol Multimedia Subsystem
IMT	International Mobile Telecommunication
IP	Internet Protocol
IPOE	Industrial High Power PoE
IPS	Intrusion Prevention System
IRR	Internal Rate of Return
ISM	Industrial, Scientific and Medical
ISP	Internet Service Providers
ISR	Interrupt Service Routine
ISTAT	Istituto nazionale di statistica
IT	Information Technology
ITU	International Telecommunication Union
KCC	Ministry of Communications and Information
L2TP	Layer 2 Tunneling Protocol
LAN	Local Area Network
LCD	Liquid Crystal Display

LED	Light Emitting Diode
LGA	Land Grid Array
LOS	Line Of Sight
LTE	Long Term Evolution
LU	Local Unit
M2M	Machine To Machine
MAC	Media Access Control
MB	Megabytes
MBMS	Multimedia Broadcast and Multicast Service
MBR	Maximum Bit Rate
MCS	Modulation and Coding Scheme
MDI	Medium Dependent Interface
MDIX	Medium Dependent Interface, Crossover
MDT	Minimization Drive Test
MEF	ETH Forum
MIMO	Multiple Input Multiple Output
MMC	MultiMediaCar
MME	Mobility Management Entity
MMS	Multimedia Messaging Service
MPLS	Multiprotocol Label Switching
MSAU	Multi-Station Access Unit
MSC	Mobile Switching Centre
MTS	Mobile TeleSystems
MU	Management Unit
MVNO	Mobile Virtual Network Operator
NAS	Non-Access Stratum
NAS	Network Attached Storage
NASDAQ	National Association of Securities Dealers Automated Quotation
NAT	Network Address Translation
NDS	Network Domain Security
NET	Network
NGMN	Next Generation Mobile Networks
NLOS	Non Line Of Sight
NMHH	National Media and Infocommunication Authority
NPT	Norwegian Post and Telecommunications Authority
NVP	Net Present Value
O&M	Operations & Maintenance
ODM	Original Design Manufacturer

ODU	Outdoor Unit
OEM	Original Equipment Manufacturer
OFCOM	Office of Communications
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OFTA	Office of the Telecommunications Authority
OMS	Operation and Maintenance Subsystem
OPEX	Operational Expenditures
OS	Operational System
OSS	Operations Support System
P2P	Peer To Peer
P-GW	Packet Data Network Gateway
P&L	Profit & Loss
PA	Power Amplifier
PAN	Personal Area Network
PAPR	Peak-to-Average Power Ratio
PAT	Port Address Translation
PBP	Payback Period
PC	Personal Computer
PCI	Peripheral Component Interconnect
PCRF	Policy Control and Charging Rules Function
PCS	Personnal Communication Services
PDH	Plesiochronous Digital Hierarchy
PDN	Packet Data Network
PDP	Policy Decision Point
PE	Provider Edge
PHY	Physical
PIR	Peak Information Rate
PMP	Point To Multipoint
POE	Power Over Ethernet
POP	Population
POS	Point Of Sales
PPPOE	Point-to-Point Protocol Over Ethernet
PPTP	Point to Point Tunneling Protocol
PS	Packet Switched
PTP	Point To Point
QAM	Quadrature Amplitude Modulation
QCI	QoS Class Indicator

QoS	Quality Of Service
QPSK	Quadrature Phase Shift Keying
R&D	Research & Development
RADIUS	Remote Authentification Dial in User Service
RAM	Random-Access Memory
RAN	Radio Access Network
RAT	Radio Access Technology
RF	Radio Frequency
RIP	Routing Information Protocol
RIT	Radio Interface Technologies
RN	Relay Node
RNC	Radio Network Controller
RRH	Remote Radio Head
RRM	Radio Resource Management
RRU	Remote Radio Unit
RX	Receiver
S-GW	Serving Gateway
SAE-GW	System Architecture Evolution Gateway
SC-FDMA	Single Carrier Frequency Division Multiple Access
SAE	System Architecture Evolution
SATA	Serial Advanced Technology Attachment
SCP	Secure Copy
SD	Secure Digital
SDH	Synchronous Digital Hierarchy
SDHC	Secure Digital High Capacity
SDR	Software Defined Radio
SFR	Soft Frequency Reuse
SFP	System File Protection
SG&A	Sales General & Administrative
SGSN	Serving GPRS Support Node
SIGTRAN	Signaling Transport
SIM	Subscriber Identity Module
SIP	Session Initiation Protocol
SLA	Service Level Agreement
SMA	Sub Multi Assembly
SME	Small Medium Enterprise
SMRA	Simultaneous Multiple Round Ascending
SMS	Short Message Service

SNMP	Simple Network Management Protocol
SNTP	Simple Network Time Protocol
SOC	System On Chip
SOHO	Small Office Home Office
SON	Self Organizing Network
SONET	Synchronous Optical Network
SRVCC	Single Radio Voice Call Continuity
SSH	Secure Shell
SSL	Solid State Logic
STC	Saudi Telecom Company
SU	Subscriber Unit
SUI	Stanford University Interim
SWOT	Strengths Weaknesses Opportunities Threats
TD-LTE	Time Division Long Term Evolution
TD-SCDMA	Time Division Synchronous Code Division Multiple Access
TCO	Total Cost Of Ownership
TCP	Transmission Control Protocol
TD	Time Division
TDD	Time Division Duplexing
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TEA	Technical Economic Analyses
TFTP	Trivial File Transfer Protocol
TRA	Telecommunications Regulatory Authority of Bahrain
TRAI	Telecom Regulatory Authority of India
TSG	Technical Specification Group
TX	Transmitter
UE	User Equipment
UKE	Prezes Urzędu Komunikacji Elektronicznej
UI	User Interface
UICC	Universal Integrated Circuit Card
UL	Up Link
UMTS	Universal Mobile Telephone System
UPS	Uninterruptible Power System
URL	Uniform Resource Locator
US	United States
USB	Universal Serial Bus
USIM	Universal SIM

UTRA	Universal Terrestrial Radio Access
UTRAN	Universal Terrestrial Radio Access Network
VANC	VoLGA Access Network Controller
VDSL	Very High Speed Digital Subscriber Line
VGA	Video Graphics Array
VHF	Very High Frequency
VLR	Visitor Location Register
VoIP	Voice Over IP
VoLGA	Voice Over LTE via Generic Access
VoLTE	Voice Over LTE
VPN	Virtual Private Network
VRRP	Virtual Router Redundancy Protocol
WAN	Wide Area Network
WDS	Virtual Router Redundancy Protocol
WEP	Wired Equivalent Privacy
Wi-Bro	Wireless Broadband
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WP	Working Party
WPA	Wi-Fi Protected Access
WRC	World Radiocommunication Conference
WSVGA	Wide Super Video Graphics Array
WVGA	Wide Video Graphic Array
xDSL	x Digital Subscriber Line
XPIC	Cross Polarisation Interference Canceller

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ANNEX A – TEA|LTE: THE LTE BUSINESS CASE ANALYSIS TOOL

TEA|LTE is one of the members of the TEA family. It is made up of powerful and unique applications (TEA|LTE and TEA|WiMAX) that WiTech has built over eight years of extensive industry experience supporting major operators and equipment suppliers in several strategic initiatives and projects. The tools enable thorough techno-economic analyses in support of accurate and reliable business cases for LTE and WiMAX initiatives in a fast and dependable manner.

Specifically, TEA|LTE allows analyzing the business case for a LTE network initiative with a holistic approach, in an integrated and iterative way. The tool features comprehensive market and revenue forecast models, well calibrated technical modeling tailored to the LTE technology, calculation of TCO as well as detailed P&L and Cash Flow with close evaluation of key performance indicators.

This is performed through four main integrated analyses, that is Market Analysis, Technical Analysis, Economic & Financial Analysis and, finally, the Scenario & Sensitivity Analysis.

- The Market Analysis evaluates properly the potential market for LTE and at making reliable revenue forecasts for the LTE services to be offered. This analysis is performed taking into account various elements, such as:
  - Extension of the geographical areas (up to 5) to be served and their specific scenario distribution, the Market segments (up to 6) to be addressed
  - Service profiles (up to 6) to be offered
  - Market segment penetration per year
  - Impact of churn.

  Figure 17 shows the work flow for the Market Analysis.

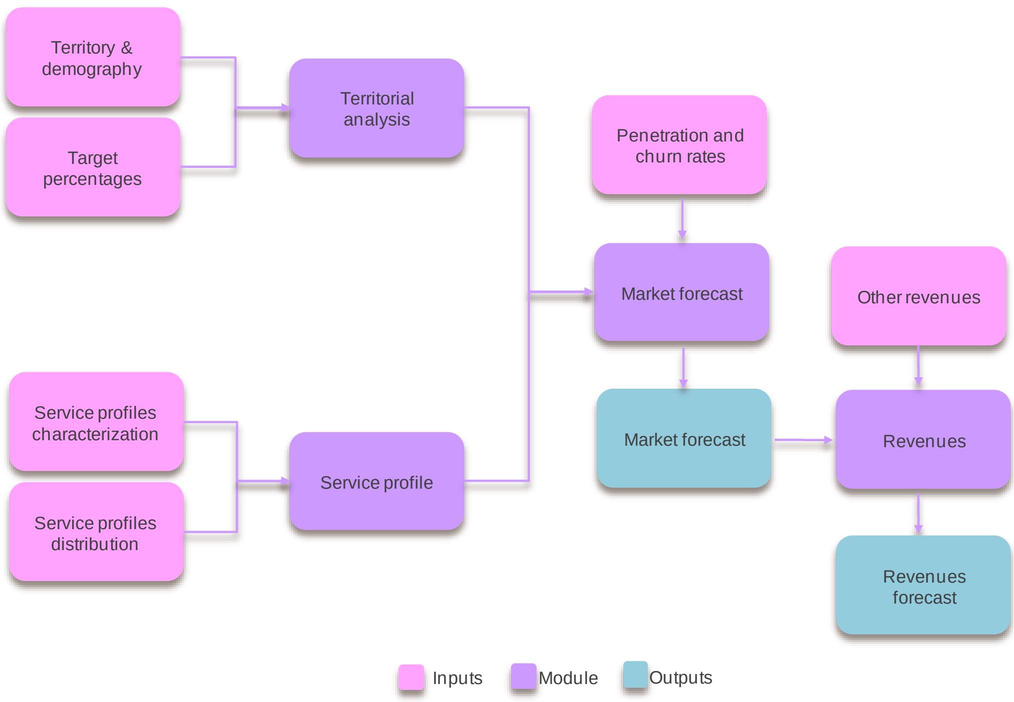


Figure 17 – Work flow for the Market Analysis

- The Technical Analysis performs the dimensioning the LTE infrastructure in terms of access, backhaul and core network. In detail, this analysis defines the required bill of quantities (eNB, logical sectors, radio links, MME, S-GW and P-GW) by considering:
  - Technology characterization
  - Type of eNB (up to 3) and UE (up to 6)
  - Path loss model for the link budget analysis
  - Down and up link capacity demand per year
  - Existing backbone infrastructures
  - Wireless backhaul technology distribution.

  Figure 18 shows the work flow for the Technical Analysis.

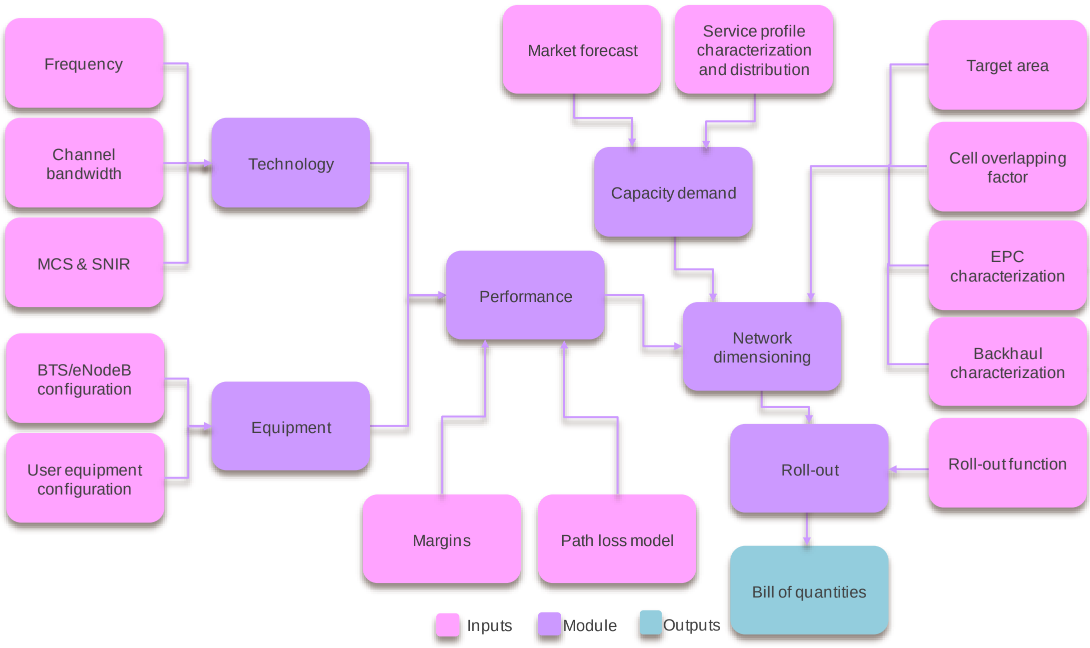


Figure 18 – Work flow for the Technical Analysis

- The Economic & Financial Analysis assesses the feasibility of the LTE initiative after having calculated all the economic and financial projections (TCO, P&L, Cash Flow, Balance Sheet) and indicators (Gross Margin, EBITDA, EBIT, Net Income, NPV, IRR, PBP, Shareholder Value, etc.). This analysis is carried out taking into consideration:
  - CAPEX & OPEX
  - Depreciations
  - Interest rate on borrowings, tax rate, discount rate
  - Financing
  - Equity
  - Perpetual growth.

  Figure 19 shows the work flow for the Economic and Financial Analysis.

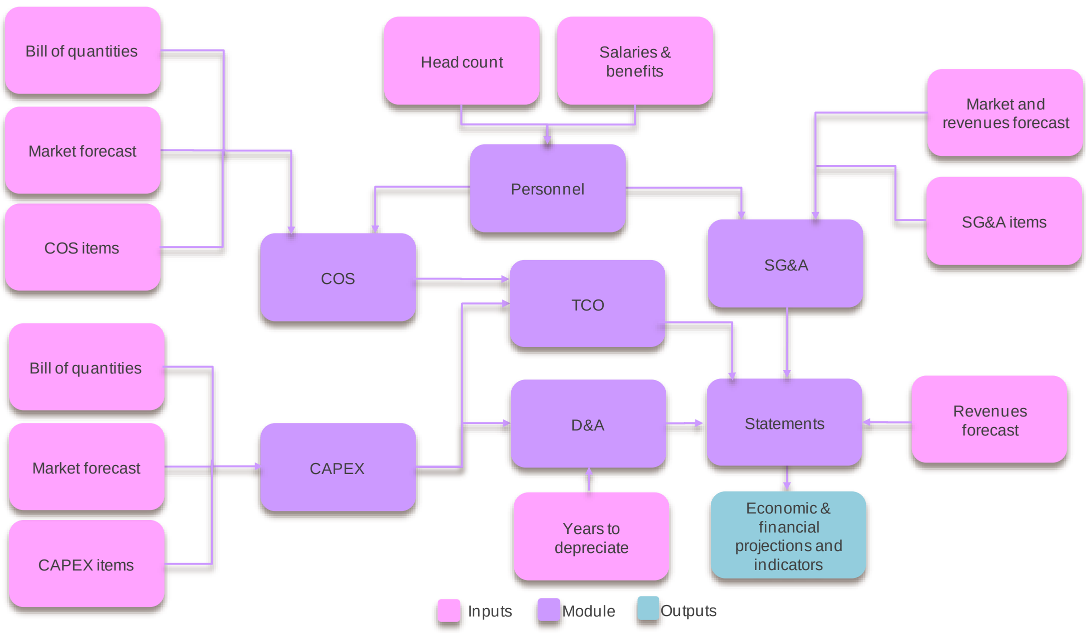


Figure 19 – Work flow for the Economic and Financial Analysis

- The Scenario & Sensitivity Analysis allows evaluating the influence of parameter and boundary condition changes in order to identify the most critical factors for the success of the LTE initiative, as well as to perform a fast and iterative fine-tuning of the LTE business case.

At the end of the aforementioned analyses, a very detailed report is automatically compiled and published in editable and PDF formats. The report contains a complete summary (with tables, diagrams and charts) of input parameters and assumptions, the results of the market analysis, the outcome of the technical modeling, and the economic and financial statements for up to ten years.

A fast and simplified configuration of more than 500 different input variables and assumptions (with suggested/best-practice-recommended values) allows a fine-tuned setting of the tool. An interactive, dashboard-styled and very easy-to-use GUI provides users with optimum interactivity and the ability to perform fine-grained scenario & sensitivity analyses to align the business case with a company's strategies, analyzing the influence of parameter changes and the consequence of fundamentally changed boundary conditions in real time.

Figure 20 provides a picture of the environment of TEA|LTE.

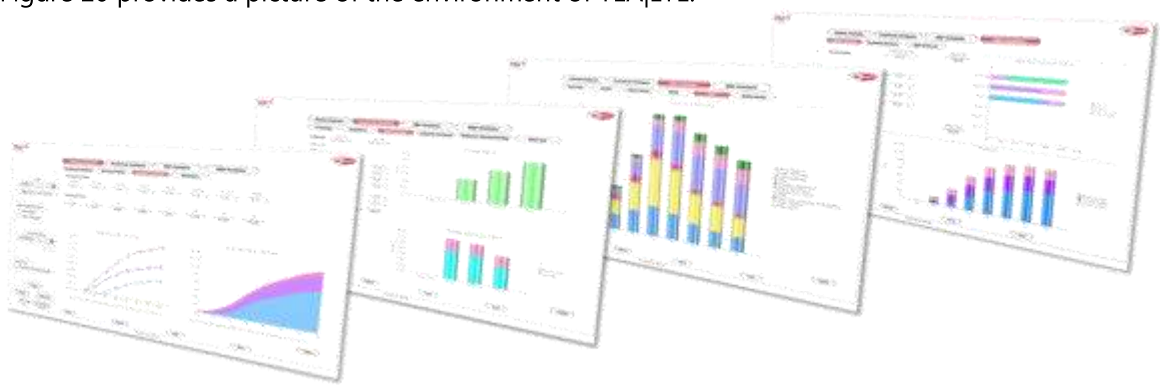
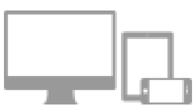


Figure 20 – Environment of TEA|LTE

WITECH – WIFI CLOUD

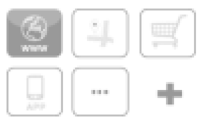
The Cloud Solution for next gen WiFi Hotspot services

WiFi Cloud is WiTech's innovative solution to provide new generation managed WiFi Hotspot services, capable of enriching end customers' experience.
WiFi Cloud enables telco carriers and system integrators to deliver their customers a complete self-managed solution. Through a simple control panel, it enables a fully self-management of access connectivity services, splash portal and web apps.
WiFi Cloud leverages on the cloud approach, both public, hosted in the Amazon Web Services Cloud infrastructure, and private, hosted in the data center of the Managed Service Provider. In addition, it allows a fast initiative setup thanks also to the vendor agnostic concept.



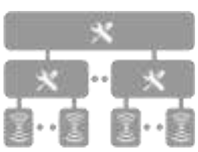
Splash portal

The splash portal is a fully customizable web responsive portal for multi- device user experience



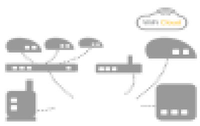
Web apps: new experience, new concept, new revenues

A powerful set of web applications and tools both enhances the user experiences and provides new value and revenue stream for WiFi Hotspot service providers



Multi-level and distributed access policies management

WiFi Cloud permits different players to self-manage the WiFi Hotspot service based on a tree-based hierarchical enforcement



Vendor agnostic

WiFi Cloud is an application level solution, integrated with the most famous vendors access and network devices as well as popular firmware

Public or private cloud delivery

WiFi Cloud can be hosted in the Amazon Web Service cloud infrastructure (public cloud) or in a private data center (private cloud)

Carrier class wngine

Based on WROP, WiFi Cloud supports any business model and access service guaranteeing a high level of reliability and flexibility