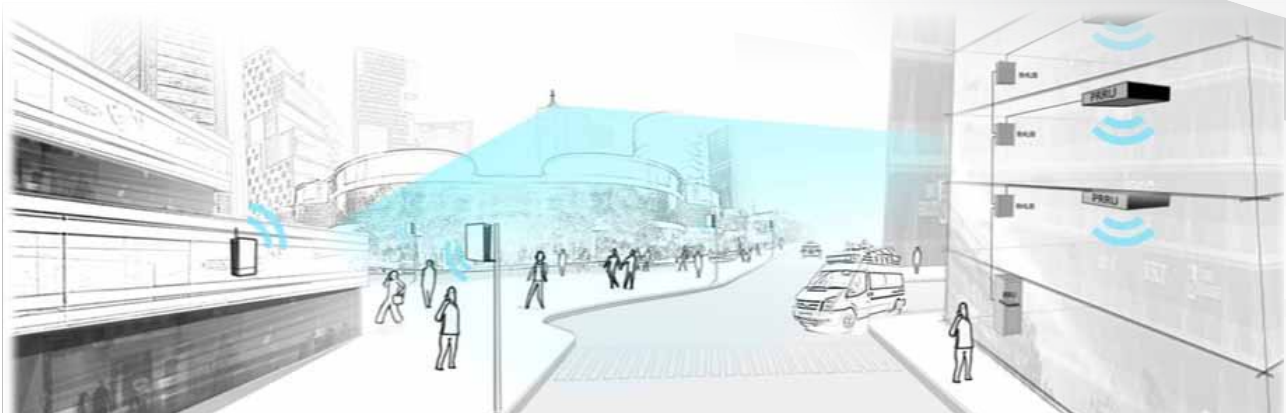


# U-LTE: Unlicensed Spectrum Utilization of LTE



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# 1.Introduction

## 1.1 Motivations of U-LTE

The ever-increasing MBB traffic load leads to a pressing need for additional spectral resources of cellular systems, which are deployed in the spectrum mainly from 700MHz to 2.6GHz. More operators are now facing the challenge of soaring traffic with ever increasing number of people using mobile broadband services, as well as the traffic demand per person. While mobile broadband system (MBB) in licensed spectrum is highly efficient due to its exclusive occupancy of the spectrum, the amount of available licensed spectrum can be limited and costly.

On the other hand, the amount of unlicensed spectrum assigned or currently planned to be assigned is comparable to or even more than the amount of licensed spectrum, as illustrated in Figure 1. Some operators have already deployed a large amount of WiFi APs to offload some cellular traffic to unlicensed spectrums. However, such efforts are not always achieving the expected targets in terms of network performance improvement or cost reduction. Various reasons contribute to such unexpected results, including the investment on backhaul and core network in addition to the existing cellular infrastructures, the inferior performance of WiFi technology, as well as the lack of good coordination between IMT and WiFi systems, which enforces manual switch between systems and results in low-efficient use of spectrum and poor user experience.

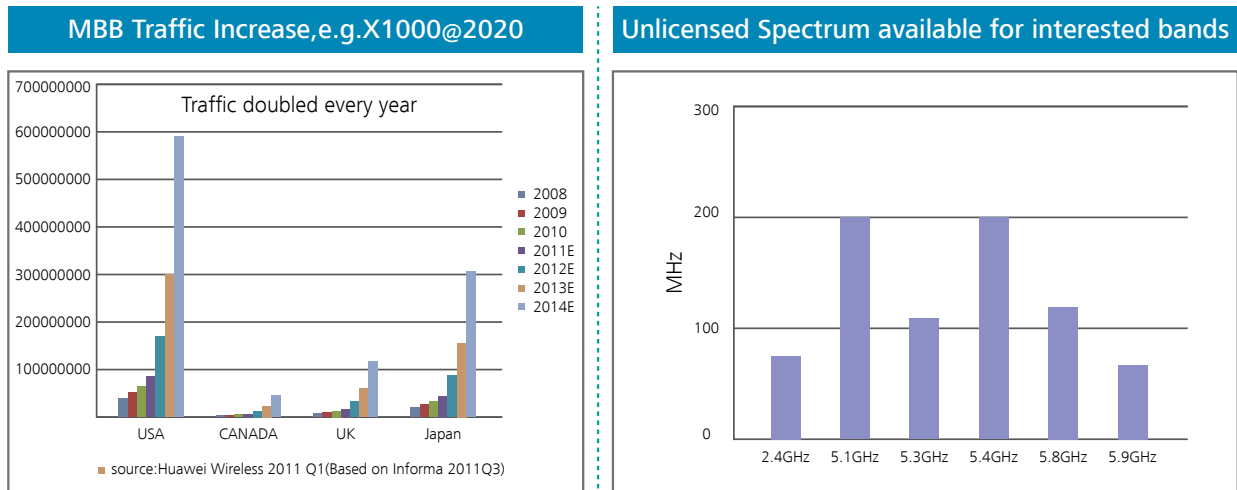


Figure 1: MBB traffic increase and available unlicensed spectrum in interested bands

LTE, as an International Mobile Telecommunications-Advanced (IMT-Advanced) system, is currently the most advanced mobile telecommunication technology. Many operators are upgrading their networks to LTE system and making a roadmap toward LTE-Advanced system. LTE operating in licensed spectrum will be the prominent deployment across the world. To further expand LTE capacity to meet the traffic demands, a natural way is to integrate unlicensed carrier into the overall LTE system by adapting LTE air interface to operate in the unlicensed spectrum, named as Unlicensed LTE (U-LTE).

## 1.2 Design Principles of U-LTE

The design principles for U-LTE include:

- **Principle 1: Integration with the licensed spectrum.** Unlicensed carriers should be integrated into and therefore take advantage of the existing LTE system deployed in licensed carriers for efficient usage as well as system co-existence purposes.
- **Principle 2: Minimum change of the LTE air-interface.** The fundamental numerology and design of LTE should remain with only necessary changes while the advanced features of LTE, e.g., eNB-based resource allocation and scheduling, link adaptation, control channel robustness to interference, uplink power control, are used to ensure point-to-point and system performance, in terms of both end-to-end QoS and physical layer transmission quality.
- **Principle 3: Ensuring co-existence.** Coexistence of multiple systems within unlicensed spectrum, enabled by appropriate mechanism(s) and regulation rule(s), will stimulate competition and technology innovation and hence achieve maximal value of the unlicensed spectrum.



## 2.U-LTE Concept

### 2.1 Deployment Scenarios

Due to the generally low power restriction imposed by regulations on transmissions in the unlicensed spectrum, the coverage in unlicensed band will be relatively small. Moreover, as unlicensed spectrum is usually in higher-frequency bands compared to licensed ones, coverage holes in the unlicensed band are expected in licensed and unlicensed co-site deployment. In addition, the use of unlicensed spectrum should follow regulatory restriction(s) to reduce negative impact on nearby co-existing systems. This may result in noncontiguous/opportunistic use of unlicensed spectrum and render the transmission of important control and common channels of LTE system in unlicensed carriers as un-reliable. Therefore, the existing LTE system in the licensed spectrum with good coverage jointly operating with an unlicensed carrier is the key enabler for efficient use of unlicensed spectrum.

Therefore, as shown by Figure 2, operator-deployed small cells with co-located unlicensed and licensed carriers are the prioritized scenario. In this case, low extra cost for new sites or backhaul could be expected. In addition, inter-site aggregation between licensed carriers and unlicensed carriers is also possible when high speed backhaul between Macro node and LPN is available, e.g., in case of optical fiber between Macro eNB and remote radio head (RRH) in the lower right sub-figure of Figure 2. Regarding the target bands, 5G Hz is more preferred with detailed analysis given in Chapter 3.

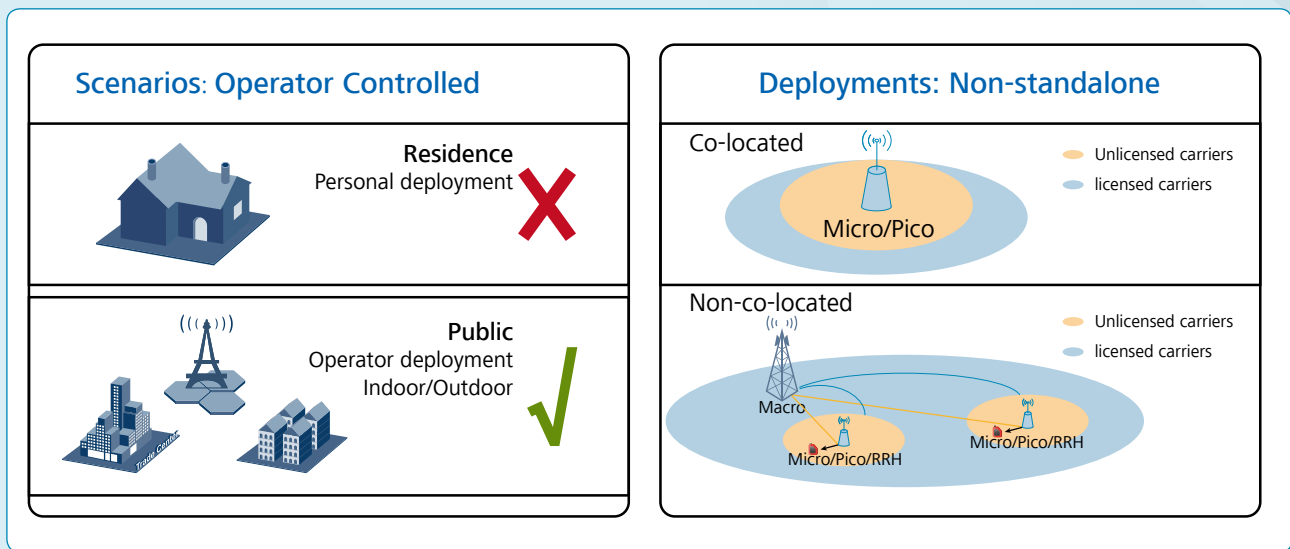
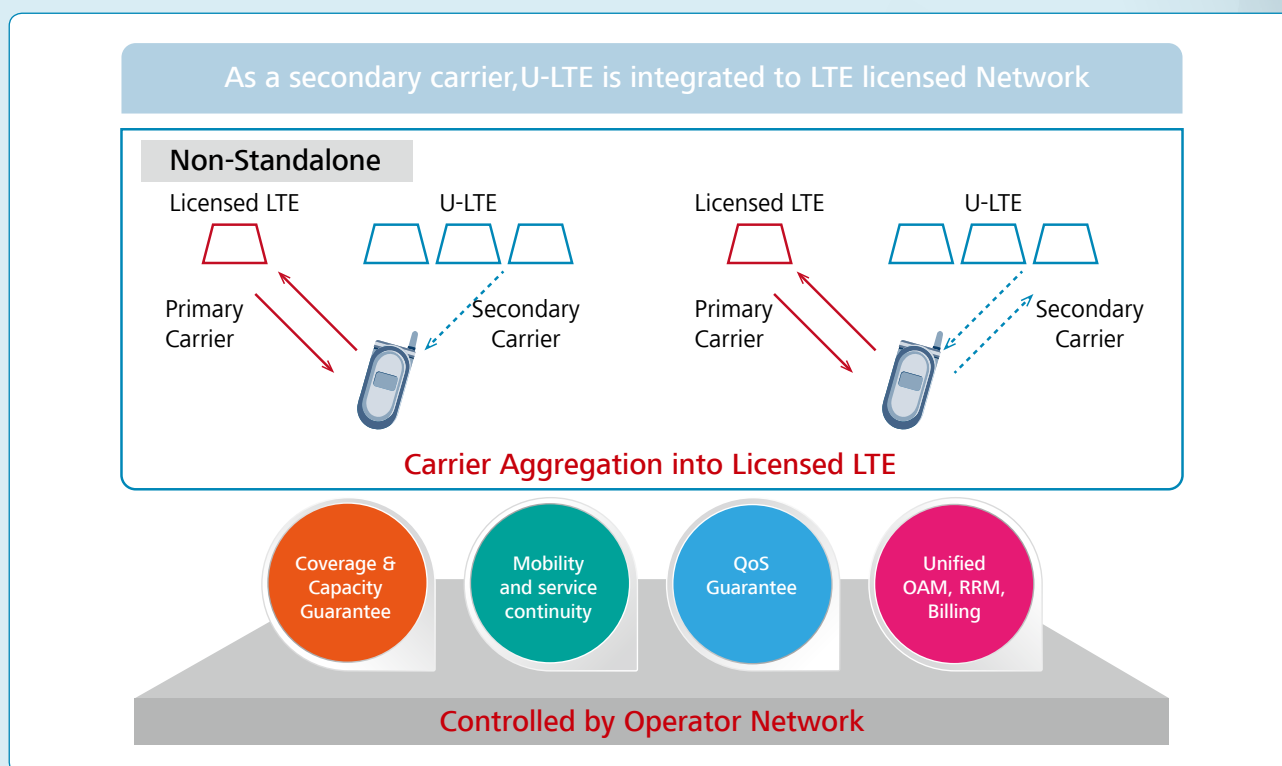


Figure 2: Target scenarios for U-LTE deployment

## 2.2 Basic Operating Mechanisms

As mentioned by Design Principle 1, the integration between unlicensed and licensed carriers both operating LTE is the key operating mechanism. The Carrier Aggregation (CA) mechanisms defined in LTE Rel-10 to Rel-12 can serve this purpose in target scenarios, where the unlicensed carriers are operated as Secondary Carriers associated to and controlled by the existing licensed LTE Primary Carriers, thus the joint operation and flexible offload between licensed and unlicensed carriers can be easily achieved. Regarding the possible operating modes, the unlicensed spectrum can be operated as a TDD (DL+UL) carrier or a DL-only carrier, regardless of the operating mode of primary component carrier in the licensed spectrum.



**Figure 3: Integrated operation of unlicensed and licensed carriers**

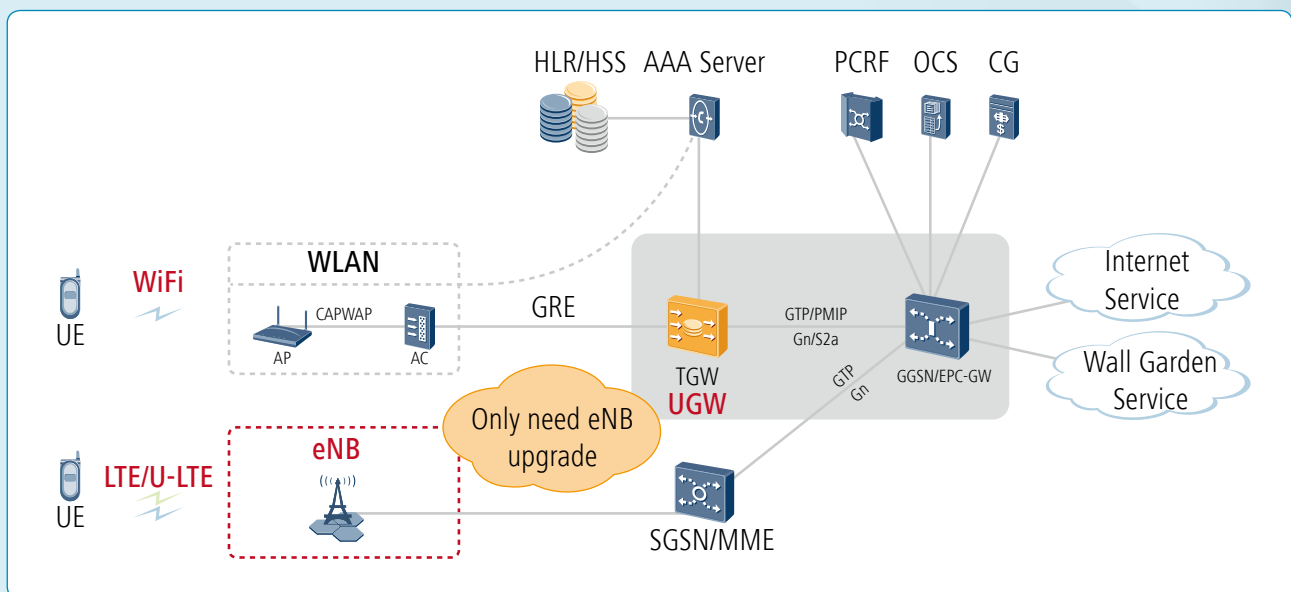
As illustrated by Figure 3, through carrier aggregation, unlicensed carriers can be well integrated within the operator's network while preserving the key benefits of LTE technology. For example, UE mobility is still under the control of the licensed LTE network, while the joint scheduling between LTE and U-LTE carriers is done in the centralized nodes for smooth load shifting and channel adaptation. Security and service QoS can also be ensured due to the assistance of the licensed LTE network. The interference mitigation schemes defined (and to be enhanced) for dense LTE network (especially in small cell enhancement related work) can also be helpful for handling the interference scenarios experienced by the integrated U-LTE spectrum. Most importantly, the advantage of the economy of scale can be achieved due to the reuse of basic LTE physical-layer design and numerology so that additional development and implementation cost may be insignificant.

## 2.3 Values

Compared to the currently used technologies in the unlicensed spectrum, U-LTE can potentially provide many benefits in terms of operator OPEX/CAPEX reduction as well as better end user experience.

- **Reuse of existing infrastructures to reduce additional CAPEX/OPEX cost.**

The CAPEX of U-LTE deployment can be kept at a reduced level for operators because of the lower cost of unlicensed spectrum and all the existing backhaul, core network and even sites deployed for licensed LTE carriers can be reused for the operation of unlicensed spectrum with updates only in eNBs (as shown in Figure 4). In addition, U-LTE would provide more efficient use of unlicensed spectrum compared to other unlicensed technologies which may in turn lower the efforts of operators in deploying cells to offer a given amount of traffic offload by unlicensed spectrum.



**Figure 4: Potential infrastructure changes for U-LTE compared to Wifi**

From an operational perspective a common RAN framework across the whole network allows unified operation and management between licensed and unlicensed spectrum, including OAM configuration, authorization, charging and RRM management, illustrated as in Figure 5. Also joint scheduling and flexible traffic offload between both layers can be easily achieved, since the secondary component cells (U-LTE layer) could be activated/deactivated by Primary cell (LTE layer) in the time scale of tens of milliseconds and the network can select licensed or unlicensed layers for traffic offload in a dynamic and OPEX-efficient way.

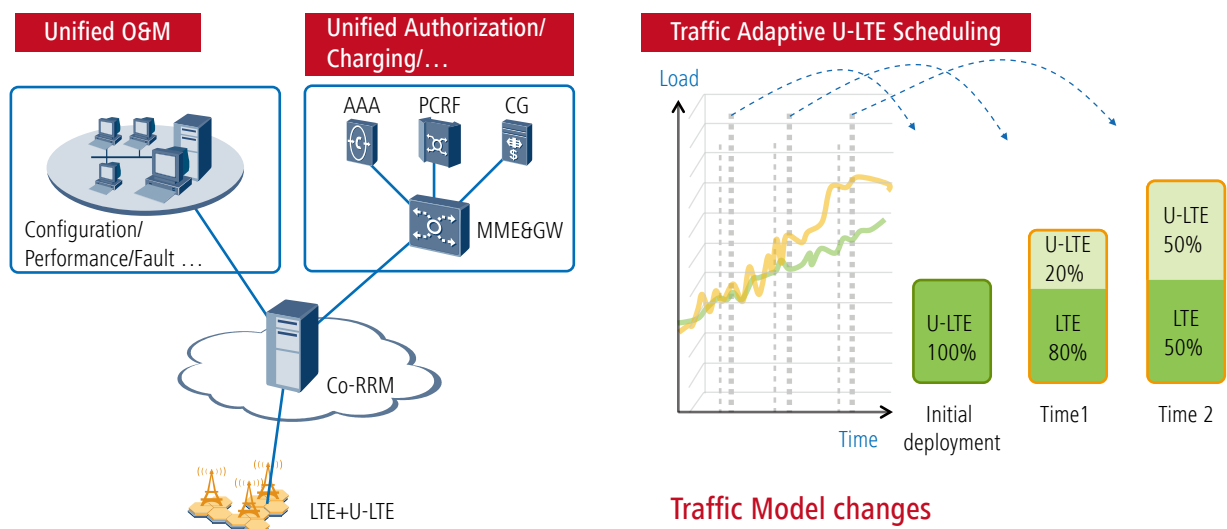


Figure 5: Unified operation between licensed and unlicensed layers

• **Good end user experience and more operator revenue.**

As an integrated part of the LTE system, the enabling or disabling of the unlicensed secondary carriers can be seamlessly controlled by the network without need of manual configuration by the user. In this sense, U-LTE can enable traffic volume to be carried on an unlicensed or licensed carrier in a transparent way from the user perspective as shown in Figure 6.

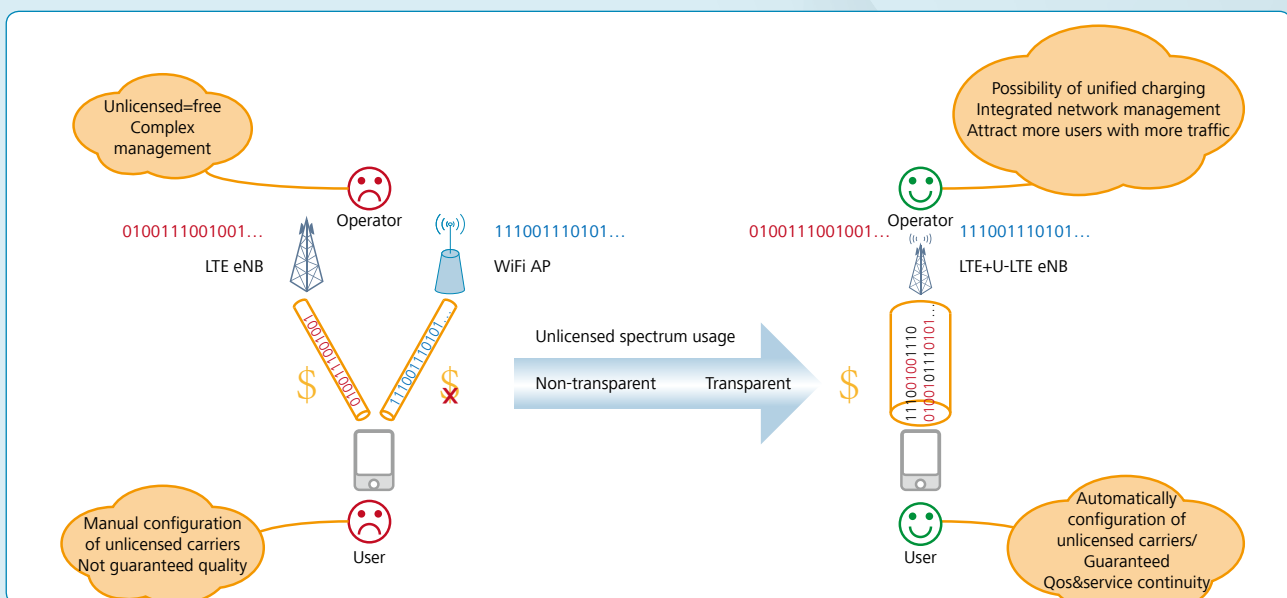
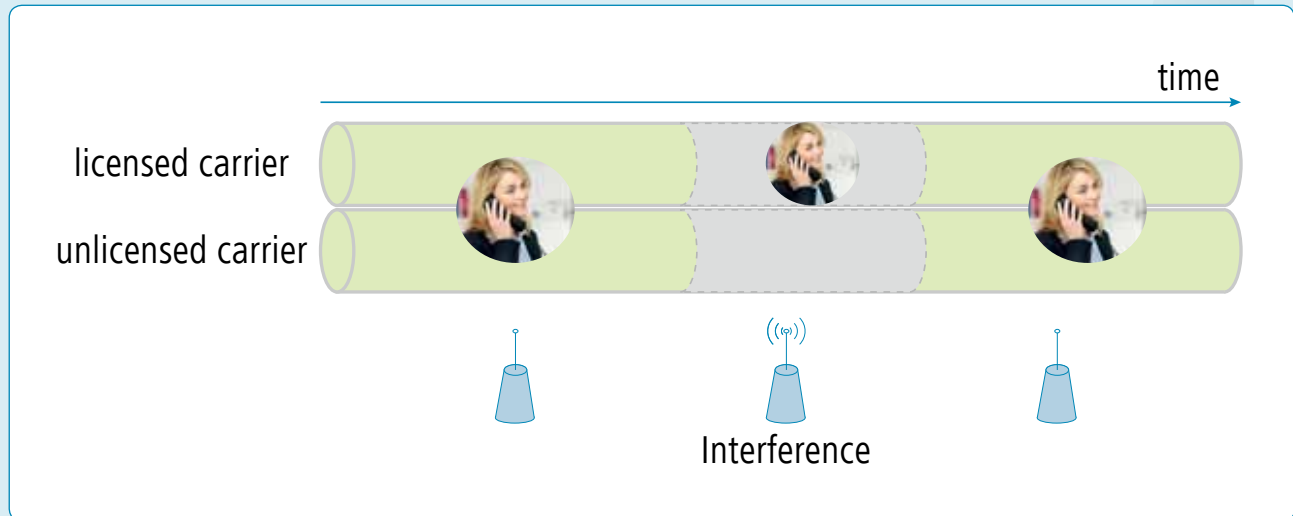


Figure 6: Traffic volume is offered in a joint and transparent way



On the other hand, the existence of licensed Primary cell also ensures the basic service continuity and QoS guarantee, especially for low-latency traffic. Figure 7 provides a simple example in which the continuity of voice traffic can be guaranteed even in case of the existence of neighboring interference in unlicensed layer.



**Figure 7: Service continuity guaranteed by licensed layer**

From an end user point of view, efficient and convenient use of unlicensed spectrum would eventually lead to better service experience. With both U-LTE and WiFi capabilities on the same unlicensed carrier, network can provide more flexibility for UEs to be served by appropriate RAT based on the available access point, charging mode, service quality, etc.

As a result, the user experience improvement and transparent use of unlicensed spectrum could provide operators more flexibility on charging strategy to get larger revenue from exploiting unlicensed spectrum (compared to before). It would in turn encourage operators to exploit unlicensed spectrum.



•LTE, as the most advanced mobile telecommunication technologies, ensures highly efficient use of unlicensed spectrum.

Specifically, better coverage and higher system throughput can be achieved by the LTE air interface compared to WiFi even in isolated deployment scenarios, as illustrated by Figure 8, while in dense deployment LTE is expected to achieve even larger performance advantages over WiFi by its inherent interference mitigation mechanisms.

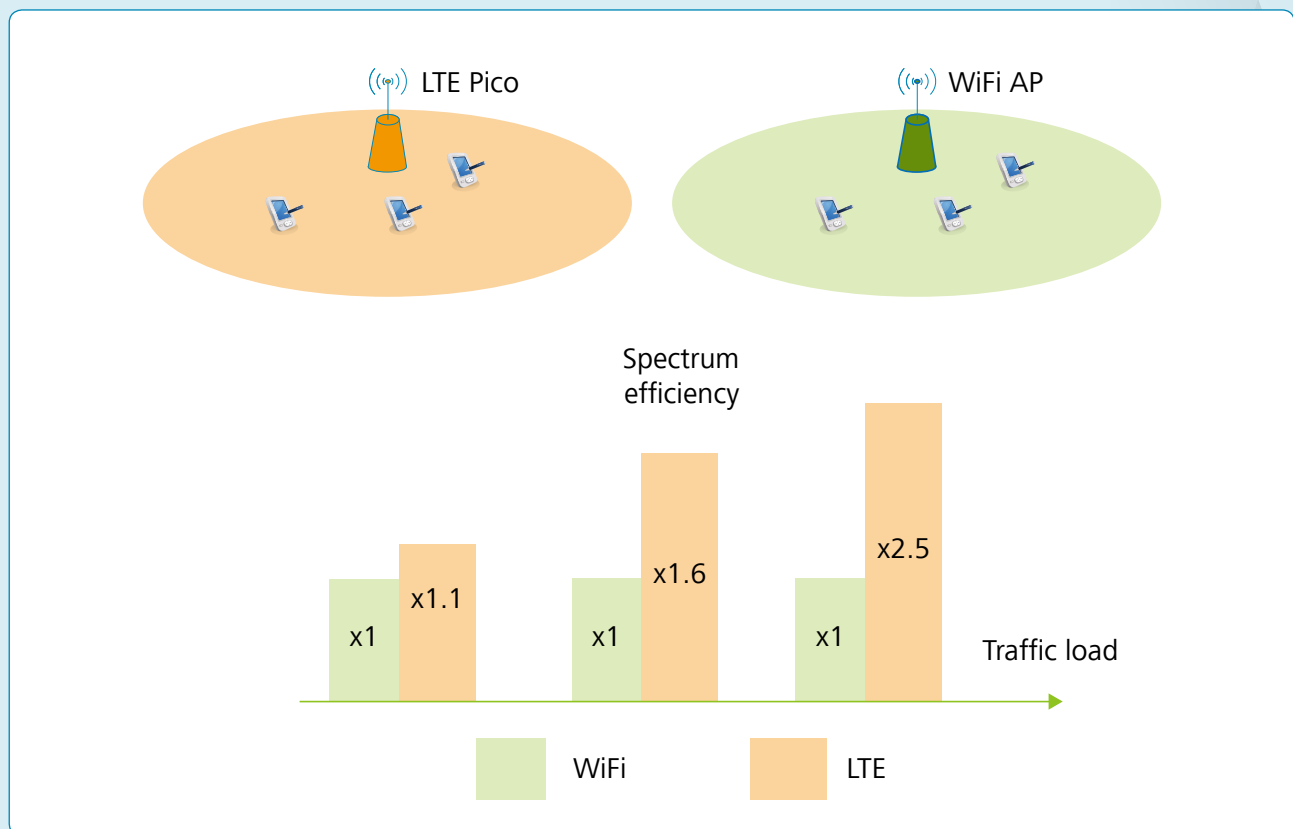


Figure 8: Spectrum efficiency comparison between WiFi and LTE in sparse deployment



## 3. Spectrum and Regulations

### 3.1 Spectrum Analysis

To select the appropriate unlicensed bands for U-LTE first-wave deployment, following aspects are relevant and should be taken into account:

- **Availability of large amounts of bandwidth from global assignment perspective**

Since the 2.4GHz band is already crowded with residential and even public deployments, the 5G Hz band is the main candidate in terms of relatively large amounts of unlicensed spectrum with globally common availability, as well as relatively good channel propagation performance. Within the 5GHz band, the 5150-5250MHz and 5250-5350MHz blocks are also widely used by residential WLAN in indoor/outdoor scenarios and hence these blocks are not preferred.

- **Regulation restriction**

The candidate band should allow for both indoor and outdoor deployment and transmit power should be high enough as operator deployment is the main target scenarios for U-LTE.

- **Co-existence with existing IMT licensed bands**

Given U-LTE would be operated as a Secondary cell controlled by a aggregated licensed Primary cell, the band combination should be chosen to avoid strong inter-modulation interference between each other, especially in-device interference for the given unlicensed band (assuming the licensed component band need not be selected to represent the most likely deployment cases but rather the cases that are most common across different regions). For example, though 5G Hz band is supposed to be well isolated from current IMT cellular bands, some cross-band emission issues (e.g., the inter-modulation interference between 5470~5725MHz band and the 1.8GHz band) may prohibit their aggregation.

Table 1 summarizes the regulations on 5GHz band in several important regions. By jointly considering above principles, 5725~5850MHz block is recommended to be the first choice for the U-LTE deployment, followed by the 5470~5725MHz block, both of which can provide at least 125M Hz bandwidth without significant interference from most of LTE licensed spectrum.

**Table 1: 5GHz sub-bands deployments permission and band combination analyses**

Sub-bands	5150-5250MHz	5250-5350MHz	5470-5725MHz	5725-5825MHz
EIRP	17dBm/23dBm	23dBm/30dBm	23dBm/30dBm	23dBm/30dBm/36dBm
US/Canada	Indoor	Indoor/Outdoor	Indoor/Outdoor* <sup>3</sup>	Indoor/Outdoor* <sup>1</sup>
EU	Indoor	Indoor	Indoor/Outdoor	NA
Korea	Indoor	Indoor/Outdoor	Indoor/Outdoor* <sup>4</sup>	Indoor/Outdoor
Japan	Indoor	Indoor	Indoor/Outdoor	NA
China	Indoor	Indoor	NA	Indoor/Outdoor* <sup>1,*2</sup>
Australia	Indoor	Indoor/Outdoor	Indoor/Outdoor	Indoor/Outdoor
India	Indoor	Indoor	NA	Indoor/Outdoor
Inter-modulation interf with licensed bands	2.6GHz, 1.7GHz 800MHz	2.6GHz, 1.7GHz 800MHz	1.8GHz, 900MHz	1.9GHz, 1.4GHz

\*1 Bands allocated by China/US are 5725-5850MHz.

\*2 China 5725-5850MHz is shared license among operators, open for WAS and RLAN

\*3 Bands 5600-5650 is not permitted in US.

\*4 Bands 5650-5725MHz is for broadcast relay service in Korea.



### 3.2 Other Requirements by Regulations

Taking 5GHz as the target band, in addition to the transmission power and indoor/outdoor use summarized in Table 1, some additional compliance rules are also defined by regulations in different regions to meet diverse requirements [1][2][3][4], as shown in Table 2. Among these, mechanism of Dynamic Frequency Selection (DFS), targeted for the semi-static sensing and avoiding interference to non-IMT systems, such as radar systems, is widely adopted by many regional regulations. Listen-Before-Talk (LBT) is designed and enforced by EU regulations, imposing a flexible and fair coexistence among IMT systems by enabling quick channel sensing (several micro seconds) and dynamic channel occupancy (<13 ms). Transmission Power Control (TPC), though not broadly used, is also a method to restrict the power leakage to neighbor bands. Of course, other basic restrictions on undesirable emission are also defined in a technology-agnostic way.



**Table 2: Application of TPC/DFS/LBT in 5GHz**

Region	(5250-5350MHz)	(5470-5725MHz)	(5725-5825MHz)
China	TPC/DFS	-	TPC/DFS
US	TPC/DFS	TPC/DFS	-
EU	TPC/DFS/LBT	TPC/DFS/LBT	-

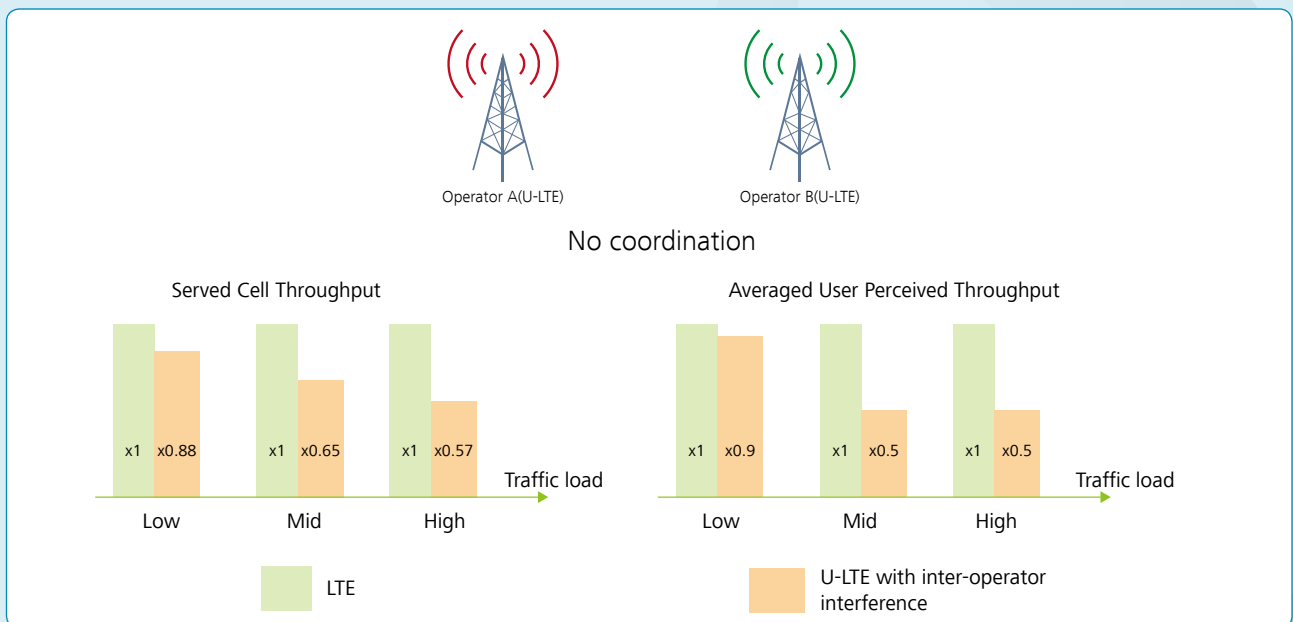
Regarding the legal use of unlicensed spectrum over a global range and economics of scale, it is desirable for U-LTE to have a common design to comply with the diverse requirements under regulations of different regions. That is, it is beneficial and recommended to take into account the compliance with LBT/TPC/DFS from the beginning of U-LTE design.

## 4.Co-existence Issues

Due to the non-exclusive use of unlicensed spectrum, co-existence issues should be addressed from the beginning of the U-LTE design in order for co-existence between U-LTE deployments of different operators as well as between multiple RATs (e.g., U-LTE and Wi-Fi systems). This chapter provides some insight on the co-existence issues introduced by U-LTE based on the evaluation of LTE and WiFi performance in closely deployed scenarios.

### 4.1 Inter-operator U-LTE Co-existence

If multiple operators deploy U-LTEs in the same unlicensed band, the lack of joint network planning may result in geographical overlapping or even closely-located U-LTE cells and hence severe cross-site/operator interference. Figure 9 shows the performance degradation within an unplanned deployment (10m distance between U-LTE nodes from different operators). It is obvious that compared with well-planned licensed LTE deployment, user experience degrades due to the closely-located inter-operator interference.

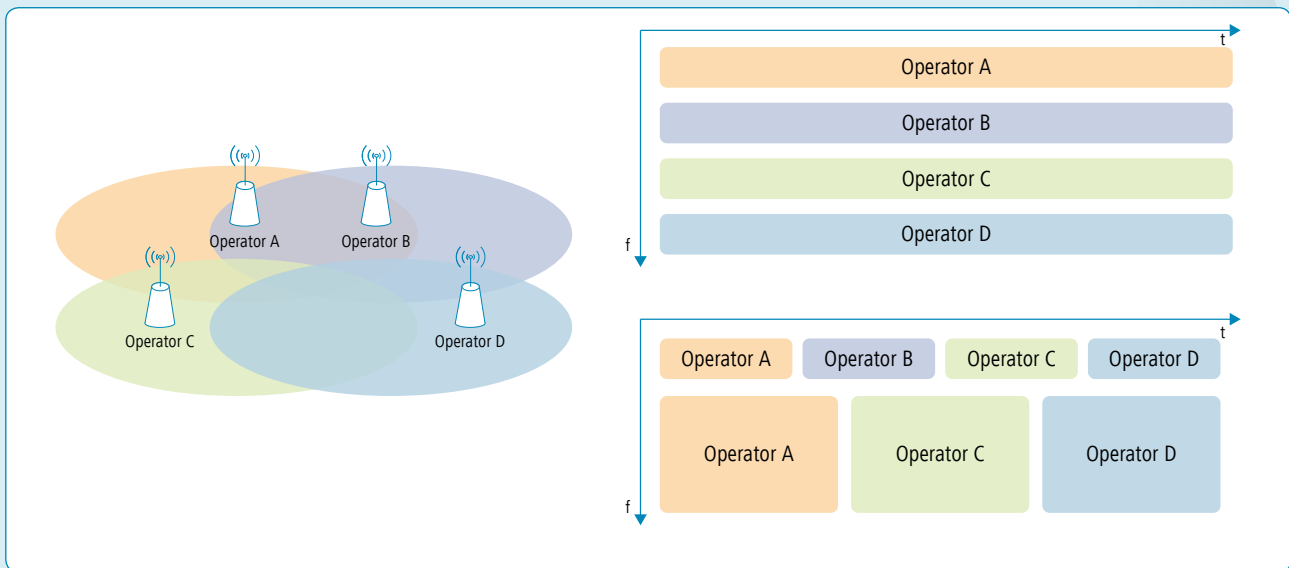


**Figure 9: Performance degradation in inter-operator co-existence scenario**

Two general options could be adopted to mitigate such interference and achieve good sharing of unlicensed spectrum by multiple operators:

- Option 1:** An agreement could be reached between multiple operators for orthogonal/exclusive use of the unlicensed spectrum within a given region (as illustrated in the top right sub-figure of Figure 10). The agreement can totally avoid inter-operator interference, with the cost of potentially inefficient use of spectrum due to the lack of dynamic spectrum sharing. In some countries, it could be difficult to reach such an agreement, due to the competition between operators (as usually). Even in case of possibly good cooperation between operators, such an agreement exclusive use of unlicensed spectrum by a group of players may still be problematic.

• **Option 2:** Relatively dynamic schemes for shared use of unlicensed radio resources. The use of unlicensed spectrum depends on the instantaneous/semi-static traffic load of U-LTE (bottom right sub-figure in Figure 10). Such a flexible and efficient occupancy/release of the unlicensed carriers requires some dynamic coordination and information exchange between operators. Despite the lack of standard backhaul between operators, the monitoring of LTE transmission over the air interface could provide potentially enough cooperation information between LTE Nodes from different operators.



**Figure 10: Sharing of unlicensed spectrum between operators**

## 4.2 Coexistence between Different RATs

Given WiFi has been widely deployed as the most popular access technology for unlicensed spectrum, co-existence of U-LTE and WiFi systems is an important scenario. Due to the fundamental differences in the PHY/MAC design between LTE and WiFi, a direct implementation of LTE may impact the opportunistic channel occupancy of co-channel WiFi especially in some high-load cases.

As an example, Figure 11 provides the performance comparison in case of closely-deployed U-LTE Pico nodes and WiFi APs. Several cases are considered:

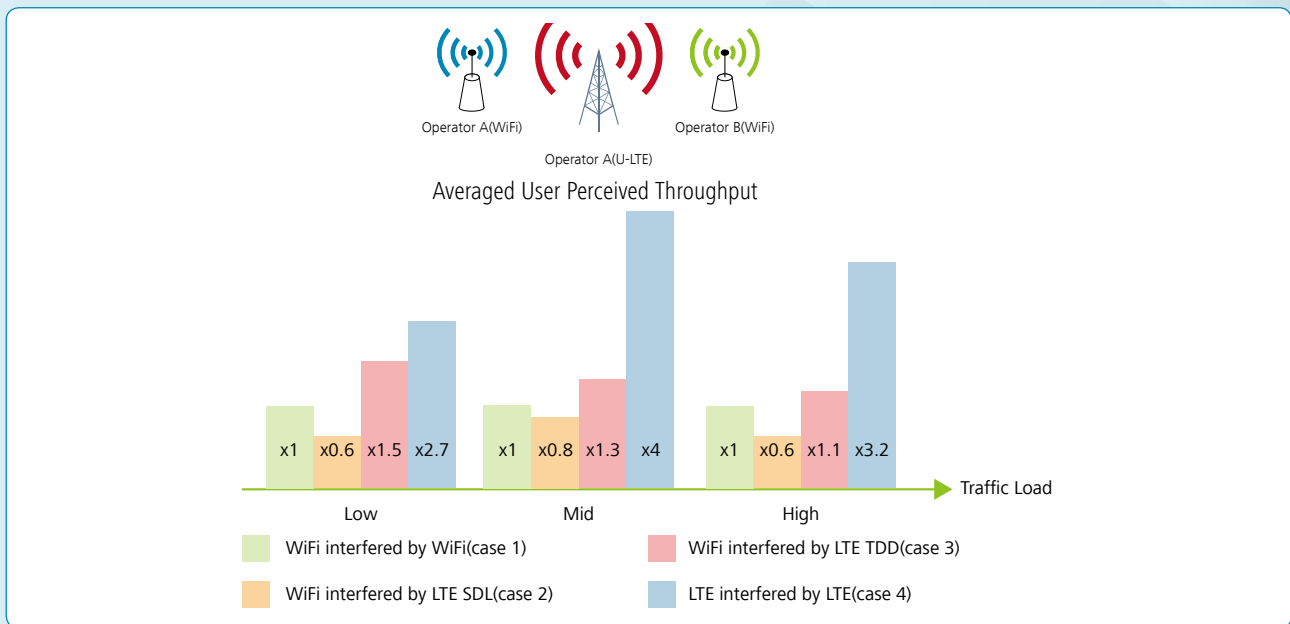
- Case 1: a WiFi AP is interfered by a paired WiFi AP.
- Case 2: a WiFi AP is interfered by a paired U-LTE Pico which is operating in DL only mode.
- Case 3: a WiFi AP is interfered by a paired U-LTE Pico which is operating in TDD mode (with UL/DL configuration 1), in which LTE UL subframes are muted to facilitate the access of paired WiFi AP.
- Case 4: an U-LTE Pico is interfered by a paired U-LTE Pico both of them are operating DL only mode (same case as in section 4.1).



In all cases, the target AP is closely located with its paired interfering AP (10m distance). Note that the U-LTE node performs with ideal small cell on/off by which the turning-on of U-LTE node is only based on the arrival of packets and during the off-state no signal is transmitted.

From the target AP perspective, it is observed that with the increase of traffic load, the competition for resources from paired interfering AP would significantly deteriorate the performance of WiFi. LTE Pico performs much more robust even with high-load interfering AP nearby. Several factors contribute to this result, including link adaptation and HARQ retransmission in LTE, and etc.

On the other hand, as the paired interfering AP, U-LTE Pico (especially with TDD mode with fake UL subframes in case 3) can be seen as a similar or more friendly neighbor to WiFi (compared to case 1) even without assistance of additional transmission restriction (e.g., LBT) , which means less performance degradation of WiFi is observed if the interfering AP is U-LTE rather WiFi AP, especially in low-load cases.



**Figure 11: Performance in case of co-existence of LTE Pico and WiFi APs**

In summary, for operators to exploit unlicensed spectrum where is already crowded with unlicensed deployment, LTE is a better choice to offer good performance in terms of robust self-protection, as well as less impact on the existing competing systems. Even for less-used spectrum, LTE deployment can provide future-assured performance with respect to the possibly subsequent deployment in the vicinity.

Of course, despite the potentially less impact of LTE to neighboring WiFi, it is still preferred to adopt the co-existence mechanisms, including TPC/DFS/LBT as mentioned in section 3.2, into U-LTE to meet the requirements imposed by regional regulations, and achieve more efficient co-existence between different systems.



## 5. Potential impacts to LTE Air Interface

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The co-existence issues and requirements by regulations necessitate some modifications to the existing LTE air interface, for the compliance to listen-before-talk (LBT) required by some regulations, in order for fair and efficient co-existence while still keeping or even enhancing advantages of LTE system.

### • Enhancements of CA mechanism to facilitate opportunistic use of channel

As required by LBT rules, the transmission of both traffic data and the common channels of U-LTE should be based on the knowledge of channel vacancy by instantaneous channel sensing. As mentioned above, in an integrated LTE framework, unlicensed carriers should be operated as secondary carriers (U-Scell) associated to a licensed LTE primary carrier through carrier aggregation (CA). The activation and deactivation of Scells defined in CA can already enable the opportunistic use of unlicensed spectrum, which, however, is still based on the always-on common channel transmission, continuous channel measurement and corresponding reports in LTE Rel-11 and before. Such a restriction will be solved to some extent by the standardization of small cell on/off in LTE Rel-12 where quick on-off switching of a cell will be supported and during cell off period UE would quit legacy channel measurement. Of course, further enhancements to ensure more flexibility in terms of opportunistic synchronization /measurement / scheduling of Scell might be needed.

### • Adapting LTE frame structure with respect to LBT requirements

Two types of LBT schemes are defined by regulation [1]: named as FBE (Frame Based Equipment) and LBE (Load Based Equipment). The differences between FBE and LBE include whether a strict frame structure should be followed, interference avoidance mechanism, and channel occupancy time. For both schemes, some efforts are needed to ensure the consistency between the strict frame structure defined in existing licensed LTE layer and the opportunistic occupancy of unlicensed band, and at the same time allow for flexible channel sensing and occupancy to offer a potentially good channel contention capability.

### • Support of UL transmission

LBT basically represents a mechanism of transmitter sensing by which each device decides its transmission opportunities based on self-detection of channel availability. However, in LTE the UL transmission grant and channel availability sensing are decided by the eNB and UE respectively. Thus it could be even more difficult to support UL transmission with respect to the case that an eNB may schedule a UE UL grant but this UE fails to get access the channel in scheduled time due to contention. These problems should be addressed to ensure UL transmission can be supported without change of basic centric-scheduling mechanism in LTE.

### • Enhanced interference coordination with respect to more complex interference scenarios in unlicensed spectrum

Sensing-based channel occupancy provides a preliminary mechanism to achieve interference coordination between co-existing nodes. Further coordination and handshake mechanisms over the air interface between inter-operator U-LTE nodes can allow efficient use of unlicensed spectrum even in high load scenarios, in which the simple channel sensing and avoidance may not work well.

## 6.Summary

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The ever-increasing MBB traffic load leads to a pressing need for additional spectral resources of cellular systems. Given more and more operators have already deployed LTE systems, it is in the interests of the operators to expand LTE capacity to meet the traffic demands by integrating numerous unlicensed bands into the overall LTE system, named as U-LTE. In U-LTE, unlicensed spectrum would be operated as a secondary carrier aggregated with a licensed primary carrier, to provide flexible and efficient traffic offloading in public operator network, while relying on existing LTE CN and RAN architectures to guarantee access authority, security, mobility & QoS management. With respect to the availability of large bandwidth and co-existence issue, 5.8G and 5.4G Hz bands are preferred for the first-wave of U-LTE deployments. Regarding the potential co-existence between U-LTE and other unlicensed RATs, some enhancements to LTE air interface could be considered to meet requirements imposed by regional regulations and facilitate global deployment of U-LTE.

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