Evolving Mobile Networks in Licensed and Unlicensed Spectrum

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Abstract— With currently deployed mobile networks saturating in coverage, spectral efficiency and peak throughput, it is a high time for the mobile network operators to determine the correct strategy for future deployments to satisfy the increasing demand of data hungry devices all over the world. There are obviously many solutions to this problem however we will try to focus our attention in this paper on the most viable ones from a mobile network perspective in terms of the use of licensed and unlicensed spectrum

Index Terms— LTE, MIMO, HOM, Carrier Aggregation, Small Cells, DC, WiFi Offload, LAA, LTE-U, LWA, RRH

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1 INTRODUCTION

In recent years, mobile data usage has been increasing at an exponential rate by almost doubling every year and is expected to continue. Under pressure from more users, more devices and more applications, mobile networks have to transport higher traffic loads, which are straining the current infrastructure and frustrating the subscribers when they cannot use the services they have paid for. Essentially, the problem can be summarized as a scenario of higher traffic load due to growing penetration of smartphones, laptops and tablets, more applications and higher per-subscriber traffic. This demands a higher capacity with more base stations, more spectrum, new techniques, multiple interfaces and effective traffic management.

Thus to meet the above challenge in the domain of licensed spectrum, we have the LTE enhancements like MIMO (2x2/4x4), Higher Order Modulation (HOM) 256 QAM Downlink and CA (Carrier Aggregation) as LTE Advanced features. Besides the above enhancements, LTE small cell deployments are one of the most popular long term strategies of mobile operators worldwide because they provide the capacity boost needed in the near term, along with the flexibility and compact form factor needed for highly-localized deployments in high traffic environments. Last but not the least, distributed base stations with Remote Radio Head (RRH) capability greatly help mobile operators to resolve cost, performance, and efficiency challenges when deploying new base stations on the road to fully developed 4G networks.

On the other hand in the mixed domain of licensed and unlicensed spectrum, we have methods like WiFi Offloading, Licensed Assisted Access (LAA), LTE Unlicensed (LTE-U) and LTE WiFi (WLAN) Aggregation (LWA).

While it is understood that no single product or technology will accommodate the current and future increase in data traffic, many solutions, working in concert, can and should be considered. The challenge for mobile operators is not the decision of which solution to select, but how to best integrate multiple technologies within their networks and how to find the right balance to maximize their cumulative benefits.

Thus the focus of this paper is to provide information on key challenges and comparisons in the various approaches in both licensed and unlicensed spectrum domain to help the mobile operators integrate multiple technologies in their networks. It also explains how to to leverage the existing assets to facilitate the evolution of their networks.

2 LICENSED SPECTRUM DOMAIN ONLY

2.1 MIMO

Operators and device manufacturers have identified MIMO technology as one means to improve performance for LTE, starting with 2x2 solutions and moving to 4x4 MIMO in the future. However, unlike other wireless technologies that have moved to 4x4 MIMO, such as WiFi, a significant design challenge has limited LTE's movement to 4x4 MIMO. MIMO technology is an effective method to overcome the effects of multipath fading and has successfully been applied in Wi-Fi networks. Cellular systems are now evolving to utilize MIMO and the specifications for LTE-Advanced, or LTE-A, can actually support up to 8x8 MIMO. However, MIMO adoption for LTE has been constrained by the challenge of designing multiple antennas in a compact smartphone form factor that are not only sufficiently high gain but also have a low enough correlation factor between the different antenna combinations. Most of today's high-end handsets do not even incorporate 2x2 MIMO. Instead, they often rely on a single main antenna and a second diversity (receive only) antenna. The typical 4G LTE smartphone can support data rates in the 70-100 Mbps range using this 1x2 MIMO configuration. The two antennas are usually located as far as possible from one another to achieve sufficient spatial diversity to maximize isolation and minimize the correlation factor. Given the challenges of designing high performing antennas for MIMO applications, smartphone manufacturers are trying to increase mobile data rates through use of an alternative approach using dual-band (or more) carrier aggregation which is discussed in later sections. Despite speed enhancements that can be realized through carrier aggregation, 4x4 MIMO continues to serve as a technology that can offer even higher data rates while utilizing precious spectrum more efficiently. As noted earlier, 4x4 MIMO requires four antennas of high efficiency that are gain balanced and independent of each other; i.e., exhibit low cor-

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relation. This is a major design challenge for a smartphone-sized device. Adding carrier aggregation introduces yet another level of complexity for the antenna designer, as it is very difficult to achieve high gain and low correlation across multiple bands. Antenna co-location becomes harder to accomplish as more antennas are packed into one device. While many antenna designers can physically fit four MIMO antenna structures
into a smartphone, the structures would likely be located so close to one another that the multiple transmission paths would be highly correlated, diminishing MIMO performance.
Further complicating matters, today's smartphones also contain multiple other antennas to support WiFi, GPS, Bluetooth and NFC, which not only take up physical device space, but
can also exacerbate signal interference. Integrating four antenna structures into a smartphone-sized device is considered one of the biggest challenges for widespread 4x4 MIMO adoption.

2.2 HOM (Higher Order Modulation)

The introduction of high order modulation can be a straight forward way to increase the special efficiency. It is known that the performance gain for higher order modulation will need higher SINR or smaller EVM. Hence it implies that it is mostly suitable for small cells primarily and it is very sensitive to the EVM. In a typical scenario for small cell, higher SINR ranges can be expected, especially for isolated indoor cases. Hence, there could a large percentage of UEs which could satisfy the geometry requirement for 256 QAM, e.g. >20 dB. Further, a small cell normally operates with lower TX power due to the small coverage, which also makes it more feasible to implement certain high order modulation. Supporting 256-QAM will increase the peak data rate of a UE in theory by 33 % since modulation order increases from 6 to 8. Although HOM can provide great performance gain over lower order modulation, they still have some constraint factor in practical small cell deployment. For example, systems which employ higher order modulation schemes are potentially more sensitive to multipath propagation effects, inter-cell interference and thermal noise as well as the degradations imposed by practical manufacturing constraints.

2.3 CA (Carrier Aggregation)

CA is a key feature of LTE-Advanced that enables operators to create larger "virtual" carrier bandwidths for LTE services by combining separate spectrum allocations. CA is the primary feature deployed by operators with commercial LTE-Advanced service. The need for CA in LTE-Advanced arises from the requirement to support bandwidths larger than those currently supported in LTE (up to 20 MHz) while at the same time ensuring backward compatibility with LTE. The benefits of this aggregation include higher peak data rates and increased average data rates for users. CA enables the combination of up to five LTE Release 8 (Rel-8) compatible carriers. As a result, operators can provide high throughput without wide contiguous frequency band allocations, and they can ensure statistical multiplexing gain by distributing the traffic dynamically over multiple carriers. With CA, operators also can take asymmetrical bands into FDD use because there can be downlink-only frequency bands. CA combinations are specified within 3GPP RAN Working Group 4. CA combinations are divided into intra-band (contiguous and non-contiguous) and inter-band. Intra-band contiguous and inter-band combinations, aggregating two Component Carriers (CCs) in downlink, are specified in 3GPP Rel-10. 3GPP Rel-11 offers many more CA configurations, including non-contiguous intra-band CA and Band 29 for inter-band CA, which is also referred as Supplemental Downlink. Release 12 will include CA of FDD and TDD frequency bands, as well as support of aggregation of two CCs in uplink and three CCs in downlink. CA can currently provide bandwidths up to 100 MHz. Aggregated carriers can be adjacent or non-adjacent even at different frequency bands. The result is that basically all of an operator's frequency allocations can be used to provide LTE services. CA provides spectrum efficiency and peak rates nearly on par with single wideband allocation. In some heterogeneous deployment scenarios, CA performance can be even better because flexible frequency reuse can be arranged between local area nodes to provide better inter-cell interference coordination. CA supports cross component carrier scheduling, where the control channel at one carrier can be used to allocate resources at another carrier for user data transmission. It can be used to provide both frequency diversity and interference coordination in frequency domain at the same time, underlining its significance as a powerful technology for effective utilization of radio resources. Note that the uplink gain tends to lower than be lower than the downlink gain because the User Equipment (UE) cannot always utilize multi-carrier transmission due to limited transmit power. CA has also been designed to be a future-proof technology, with great potential into and beyond Release 12. By extending aggregation to more carriers and enabling aggregation of additional licensed spectrum, CA will play a key role in enabling both IMT-Advanced and the use of emerging spectrum allocations. There also will be multiple and varied deployments of CA tailored to operators' specific requirements.

2.4 Small Cell Enhancements

At the time when cellular networks were initially deployed based on GSM the deployment scenarios considered cells with similar cell size, i.e. homogeneous network topologies were used. However, soon different cell sizes were needed to address various capacity requirements. In today's 3G/4G networks heterogeneous network deployments are widely applied. They may include scenarios with small cells deployed within a macro umbrella cell. Small cell scenarios pose challenges in real life networks. Potential improvements for LTE small cells have been investigated throughout a study item phase in 3GPP to address improve mobility robustness, reduce signaling load and enhance per-user throughput. The study focusing on high layer aspects resulted into the definition of the dual layer connectivity feature. This essential modification allows a UE to consume radio resources from two different network nodes. DC (Dual Connectivity) assumes different carrier frequencies in macro and pico cell, that the UE runs two MAC entities, i.e. it utilizes radio resources provided by two distinct schedulers, and that the UE needs to support two UL carriers. eNBs involved in DC for a certain UE assume two different roles. An eNB either acts as a Master eNB (MeNB) or as a Secondary eNB (SeNB). A Master Cell Group (MCG) / Secondary Cell Group (SCG) is defined as a group of serving cells associated with the MeNB/SeNB, comprising of the Primary Cell (PCell) / Primary SCell (PSCell) and optionally of one or more Secondary Cells (SCells). In DC a UE is connected to one MeNB and one SeNB, i.e. the UE operates two MAC entities and two separate RLC entities for each data flow on each of the MeNB and SeNB.

2.5 RRH (Remote Radio Head)

The network upgrades required to deploy networks based on LTE standard must balance the limited availability of new spectrum, leverage existing spectrum, and ensure operation of all desired standards. This all must take place at the same time during the transition phase, which usually spans many years. Distributed open base station architecture concepts have evolved in parallel with the evolution of the standards to provide a flexible, cheaper, and more scalable modular environment for managing the radio access evolution. For example, the Open Base Station Architecture Initiative (OBSAI) and th Common Public Radio Interface (CPRI) standards introduced standardized interfaces separating the Base Station server and the remote radio head (RRH) part of a base station by an optical fiber. The RRH concept constitutes a fundamental part of a state-of-the-art base station architecture. RRH-based system implementation is driven by the need to reduce both CAPEX and OPEX consistently, which allows a more optimized, energy-efficient, and greener base deployment. Either CPRI or OBSAI may be used to carry RF data to the RRH to cover a three-sector cell.

3 MIXED DOMAIN OF LICENSED AND UNLICENSED SPECTRUM

All the LTE technological innovations mentioned in section 2 above provide a good solution to the ever increasing data traffic demand however all these methods are using the licensed spectrum which is scarce and expensive. Over and above with the above mentioned innovations, we have extracted all the juice from spectral efficiency perspective from the given licensed spectrum. Clearly, there is a need to tap on the localized unlicensed spectrum resource with a mix of both LTE and WiFi technology to meet the upsurging data traffic demands. The following sub-sections provide brief description and key challenges associated with the various methods.

3.1 WiFi Offloading

WiFi networks come to the rescue of network operators. Idea is to offload, on-the-fly, some or all of the data traffic from LTE network. to Wi-Fi network. This should happen in a seam-less fashion so that subscriber is not required to intervene for authentication etc and data traffic should not stop when this handover happens. Wi-Fi becomes an obvious choice for network operators due to low cost, ubiquitous availability, it is unlicensed and is re-usable. It can help improve cellular coverage and increase capacity through spectrum reuse in areas where most of the data traffic is being generated e.g. in a building. Thus cellular network shall be used for high QoS intensive traffic as well as mobility requirements e.g. VOIP, where as Wi-FI shall be used for low QoS data traffic e.g. downloads, web surfing etc. Existing Wi-Fi networks offer following challenges to LTE - Wi-Fi offload:

- Un-Trusted access points do not provide secure connection to EPC (Evolved Packet Core).
- Existing APs (Access Points) do not provide a means to authenticate with core network using cellular network credentials
- Existing APs do not provide a means to obtain same IP Address (as obtained via LTE network) via the WiFi network
- Existing Wi-Fi networks do not facilitate a means to UE by which it can select an AP which can provide it connectivity to core network of their server provider.

3.2 LAA (Licensed Assisted Access)

The introduction of carrier aggregation in LTE-Advanced required the distinction between a primary cell (PCell) and a secondary cell (SCell). The PCell is the main cell with which a user equipment (UE) communicates and maintains its connection with the network. One or more SCells can be allocated and activated to the UEs supporting carrier aggregation for bandwidth extension. Since the unlicensed carrier is shared by multiple systems, it can never match the licensed carrier in terms of mobility, reliability, and quality of service. Hence in LAA, the unlicensed carrier is considered only as a supplemental downlink (DL) SCell assisted by a licensed PCell via carrier aggregation. LAA deployment scenarios encompass scenarios with and without macro coverage, both outdoor and indoor small cell deployments, and both co-located and non-co-located (with ideal backhaul) cells operating in licensed and unlicensed carriers. Key technical feature of LAA is LBT (Listen Before Talk). LBT is a procedure whereby radio transmitters first sense the medium and transmit only if the medium is sensed to be idle, which is also called clear channel assessment (CCA). The CCA utilizes at least energy detection (ED) to determine the presence of signals on a channel. To summarize, the LAA supplements a licensed primary carrier with unlicensed secondary carriers via carrier aggregation. The 3GPP aimed at not only meeting the regulatory requirements but also ensuring fair coexistence with existing Wi-Fi networks. These design goals have led to significant changes at the LTE physical layer for LAA. Based on the evaluations contributed to 3GPP provided from a wide spectrum of sources, there is a consensus that LAA can fairly coexist with Wi-Fi networks serving various traffic types.

3.3 LTE-U (LTE Unlicensed)

LTE-U is based on the 3GPP Release 12 LTE technology to be used in the unlicensed spectrum. LTE-U uses adaptive on/off duty cycle as a mechanism to share the medium with existing Wi-Fi network. Like LAA, LTE-U also uses carrier aggregation between a primary LTE component carrier in a licensed band and one or more low power secondary component carriers deployed in the unlicensed spectrum. However, it is an effort in expanding the usage of LTE to unlicensed spectrum which is outside 3GPP in the LTE-U Forum. It has published specifications and studies for minimum base station and UE requirements and co-existence with Wi-Fi. The focus of the LTE-U Forum based solution is for deployment options and regions where LBT is not required.

3.4 LWA (LTE WiFi Aggregation)

A new alternative for LTE and WLAN interworking is data aggregation at the radio access network, where an Evolved NodeB (eNB) schedules packets to be served on LTE and Wi-Fi radio links. This is similar to the carrier aggregation and dual connectivity features defined in Release 10 and Release 12. The advantage of this solution is that it can provide better control and utilization of resources on both links. This can increase the aggregate throughput for all users and improve the total system capacity by better managing the radio resources among users. In contrast to the previously developed offloading solutions which rely on policies and triggers, scheduling decisions for each link can be made at a packet level based on real-time channel conditions and system utilization. Furthermore, data aggregation at the Radio Access Network (RAN) can be implemented without any changes to the core network since the WLAN radio link effectively becomes part of the Enhanced Universal Terrestrial Radio Access Network (EUTRAN).

4 HANDLING THE CAPACITY CRUNCH – A CASE STUDY

The Fig.1 below illustrates the network capacity crunch. As mentioned before, the biggest challenge facing mobile operators and their technology suppliers is in satisfying this exponential growth in data traffic. The proportion of users with smartphone and other mobile broadband devices is increasing. Per user data demands are escalating with always on, always with you access to a burgeoning array of applications and services including those delivered from network-intensive video and cloud services. LTE networks are already providing headline speeds approaching 100 Mbps, but these are only possible under ideal conditions on lightly loaded networks and where user equipment is close to the base station radio antenna. Also, many technologies and features introduced in previous releases are being enhanced and supplemented with new additions in 3GPP Releases 12 and 13 as covered in the previous sections. These developments will increase network capacity, while also providing more consistent service quality, with the product of three compounding factors: Spectrum Employed x Spectrum Efficiency x Network Density (scaled as 3 x 6 x 56 = 1008).

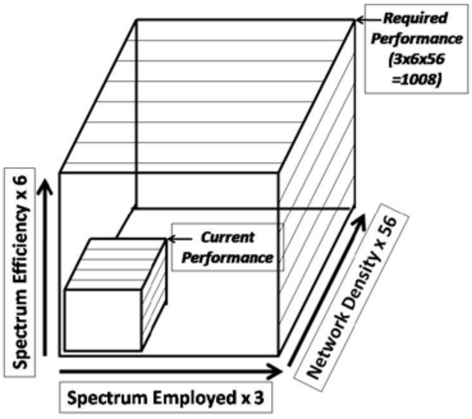

Fig. 1. Network Capacity Crunch

plish the required scaled performance in conjunction with the descriptions provided in the previous sub-sections:

4.1 3x Increase in Spectrum Employed

Existing bands will be refarmed for more efficient use. New licensed bands, including higher frequencies for hot-spot demand zones will be introduced. This will all be used in combination with unlicensed spectrum, if suitable, while possibly exploiting cognitive radio techniques to access and manage the latter. TDD mode LTE is unleashing access to unpaired spectrum. Carrier aggregation including the combination of different bands and modes will increase total capacity, headline speeds and trunking efficiency.

A combination with the unlicensed spectrum as described by various techniques in Section 3 (WiFi Offloading, LAA, LTE-U & LWA) is perhaps the biggest driver in this dimension.

4.2 6x Improvement in Spectral Efficiency

A plethora of technologies are helping increase the amount of data transported per Hz of spectrum used, to reduce latency and increase speeds with emphasis on average speeds achievable across the entire cell including cell edges. Improving consistency of service performance, rather than just peak speed depending on time and place is the key. Higher-order modulation to 256QAM, coordinated multiple point transmission and interference management techniques will improve cell-edge performance. 3D MIMO and massive antenna beamforming with arrays of as many as 64 antenna elements enable additional frequency reuse within cell sectors. With strong consensus in 3GPP to maintain LTE's OFDMA air interface in the downlink, some 3G participants favour introducing something similar to improve uplink performance.

4x4 MIMO and 256 QAM methods as described in Section 2 are clearly the most powerful methods to push increased amount of data per Hz for all users.

4.3 56x Higher Average Cell Density

The addition of many small cells in HetNet configurations including macro, micro, pico femto, relay stations and even clouds of antennae will provide the biggest boost to capacity through extreme frequency reuse. With 70 per cent of traffic at home or in the office, buildings present both opportunities (e.g., access to power and backhaul) and difficulties (e.g., signal attenuation). Improved backhaul, and sidehauling via X2 interface (for inter-cell signalling), will support techniques such as baseband pooling and inter-cell coordination that can most efficiently and effectively orchestrate resources with the large arrays of radio heads that will be deployed in high-demand locations. There are initiatives to simplify management across cells with rationalised signalling and control maintained at the macro layer, and introduction of phantom cells in high-density small cell layers.

The Small Cell Enhancements and Remote Radio Heads as described in Section 2 coupled with the above methods provide a smart solution to step up the higher average cell density.

5 CONCLUSION

The massive growth in data traffic carried by mobile broadband systems, with integration of video with social networking and the massive acceptance of mobile computing is anticipated to put severe pressure on the existing LTE networks. In order to meet the expected requirements, the industry will be compelled to evolve the cellular system with the techniques mentioned in Section 2 and Section 3 to accomplish the multi-fold capacity increase as well as support of new capabilities and services. The enabling technologies discussed in this paper will allow LTE to be a highly efficient, cost effective and flexible system that will fulfill the expected end user expectations. In particular the enabling technologies will enhance the capacity, provide the efficient network operation, flexible multi-RAT access to support the diverse applications and new services that are expected in the future.

It is expected that the very precise and brief description of the methods provided in this paper will help provide the mobile operators at large, a crisp guideline to make meaningful decisions while facing the ongoing network capacity crunch issues.

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