Spectrum Toolbox Survey: Evolution Towards 5G

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Abstract. The ever increasing needs for more spectrum resources, and the new Radio Access Technologies (RAT) to serve Mobile Broadband (MBB) services add to the complexity of the Spectrum Toolbox in mobile networks landscape. This paper briefly describes a collection of available frequency bands, spectrum aggregation mechanisms, licensing and duplexing schemes, as well as spectrum sharing and refarming techniques. With such a classification, Spectrum Toolbox is defined and its evolution directions are discussed. It covers 3GPP LTE evolution from its first version in Release 8 up to the Release 14, which deals with LTE-A Pro enhancements. Studies on the new non-backwards compatible RAT are also covered. Finally, the potential evolution towards emerging 5G ecosystem, in the context of future Spectrum Toolbox enhancements, is presented.

Keywordss: 3GPP evolution · 5G · LTE-A pro · Spectrum management · Spectrum toolbox · WRC-15

1 Introduction

The ever increasing mobile data demand in cellular networks calls for more spectrum resources and for novel spectrum access schemes. This in turn increases the overall complexity of mobile networks. Recent 3GPP Rel-13 standardization in the Radio Access Networks (RAN) group, as well as discussions covered during 3GPP on "5G RAN" and Licensed-Assisted Access (LAA) workshops, gave clear indication on the requirement of further spectrum allocation flexibility improvements.

This paper presents Spectrum Toolbox, which may serve as a simple guide through spectrum-related solutions in mobile system landscape. Spectrum Toolbox covers such aspects as frequency bands overview, spectrum aggregation mechanisms, licensing and duplexing schemes, as well as spectrum sharing and refarming techniques. Based on 3GPP RAN standardization status[1], a brief introduction to the available solutions is presented, focusing on LTE and WLAN spectrum resources and their classification, with the aim to provide indications on further system developments towards 5G.

The remainder of this paper is organized as follows: after a brief summary on recent radio access related standardization and regulatory events, Sect. 3 covers overview of

[1] As of 2015/12.

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3GPP solutions for spectrum access techniques classifying Spectrum Toolbox elements. In Sect. 4, discussion on potential future development directions is presented, followed by the final conclusions in Sect. 5.

2 Setting up the Scene for Spectrum Toolbox Discussion

This chapter presents the outcomes of recent standardization and regulatory events (i.e. late 2015 timeframe), including LAA workshop, “5G RAN” workshop, as well as World Radio Conference (WRC-15). These discussions set up the scene for the evaluation of Spectrum Toolbox, covered in the following sections.

3GPP RAN workshop on LAA[2] collected inputs from various unlicensed spectrum stakeholders, including IEEE802 committee, Wi-Fi Alliance (WFA), Wireless Broadband Alliance (WBA), as well as from the regulatory bodies representatives [1]. The goal of the workshop was to strengthen technical collaboration, especially in the areas of coexistence evaluation for unlicensed Industrial, Scientific and Medical (ISM) bands among different actors, and to follow up with finalization of the LAA feature in 3GPP specifications. The main conclusions of the workshop were related to the Listen Before Talk (LBT) mechanism design to provide fair coexistence between LTE and WLAN users within 5 GHz ISM band. Coexistence testing and performance requirements definition discussion was also started, focusing on DL-only operation of LAA within Rel-13 timeframe (while UL LAA is expected to be covered in Rel-14).

3GPP workshop on “5G RAN” development directions collected ideas and requirements on the next generation mobile networks, including 5G timeline feasibility discussion [2]. In terms of spectrum allocation for 5G, the below 6 GHz spectrum, as well as millimeter Wave (mmW) spectrum bands were discussed for new, non-backwards compatible 5G RAT, which is expected to be developed in parallel to the LTE-Advanced Pro[3] in coming 3GPP releases. As a facilitator for the technical feasibility studies and performance benchmarks, work on mmW channel models will first have to be concluded, covering spectrum bands ranging from 6 GHz up to 100 GHz[4] [3].

WRC-15 conference purpose was to allocate new frequency bands for various mobile services, ranging from road safety to global flight tracking use cases [4]. New spectrum allocation was agreed for Mobile Broadband (MBB) communication services within L-band (i.e. 1427–1518 MHz), and within lower part of the C-band (i.e. 3.4–3.6 GHz). More detailed spectrum allocation breakdown is covered in Table 1.

During WRC-15, decision on spectrum agenda studies for the next WRC-19 conference was taken, aiming at identification of 5G frequency bands above 6 GHz. In the studies the following bands are supposed to be considered: 24.25–27.5 GHz, 31.8–33.4 GHz, 37–43.5 GHz, 45.5–50.2 GHz, 50.4–52.6 GHz, 66–76 GHz, 81–86 GHz. Furthermore, it was decided that the broadcasting and mobile industry players in

[2] More details on LAA covered in Sect. 3.2. LAA is also called LTE-Unlicensed (LTE-U).

[3] LTE evolution in Rel-13 and beyond.

[4] However, the 5G RAT is to be defined for both below and above 6 GHz spectrum.

Table 1. WRC-15 decisions on spectrum allocation for 4G mobile services [4]

Frequency band	Geographical distribution	Spectrum availability
470–694/698 MHz	Some APAC and American countries	Auction in the USA
694–790 MHz	Global band, now including EMEA	60 MHz
1427–1518 MHz	Global band, in most countries	91 MHz
3300–3400 MHz	Global band, not Europe/North America	100 MHz
3400–3600 MHz	Global band, in most countries	200 MHz
3600–3700 MHz	Global band, not Africa/some APAC	100 MHz
4800–4990 MHz	Some APAC and American countries	190 MHz

Europe, have to conclude on the opportunity of mobile broadband technologies adaptation for future terrestrial TV requirements, while using TV UHF band (470–694 MHz). The consensus is to be reached until WRC-23 conference.

3 Spectrum Toolbox

Increasing amount of the available spectrum bands, equipped with the range of spectrum access technologies, provides highly complex system to operate and coordinate the resource usage among radio access nodes. Figure 1 presents an example of Heterogeneous Network (HetNet) comprising of macro- and Small Cell (SC) layers, accompanied with various spectrum access techniques, including e.g. Carrier Aggregation (CA) and Dual Connectivity (DC), covering licensed and unlicensed frequency bands.

Spectrum Toolbox covers the available frequency bands, spectrum aggregation mechanisms, licensing and duplexing schemes, as well as spectrum sharing and refarming techniques. Table 2 presents an overview of the Spectrum Toolbox evolution over the LTE releases, while the following sections elaborate on individual areas presented therein.

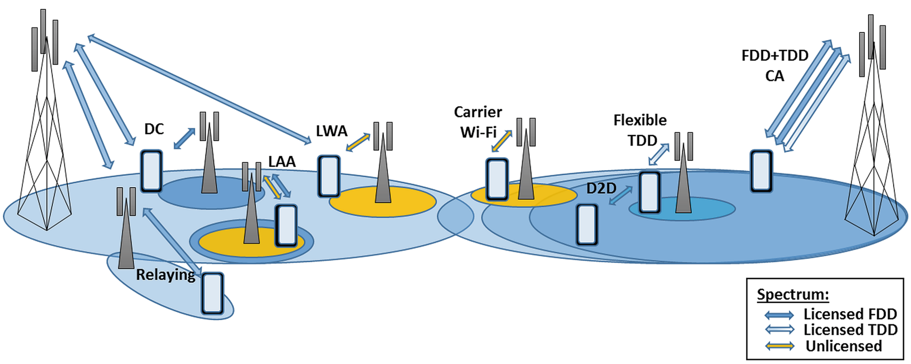

Fig. 1. Spectrum toolbox landscape in HetNet

Table 2. Spectrum Toolbox evolution across LTE releases: standardized solutions, ongoing Study Items, and future concepts for 5G discussions[a]

3GPP release	LTE: Rel-8, 9	LTE-A: Rel-10, 11, 12	LTE-A Pro: Rel-13, 14	5G phase I: Rel-15 5G phase II: Rel-16
Frequency bands [GHz][b]	0.7, 0.8, 1.8, 2.1, 2.3–2.4, 2.5–2.6 GHz	0.45 (Brasil), Digital Dividend, 1.5, 3.4–3.8 GHz	5 GHz ISM; WRC-15 bands	New bands below 6 GHz for 5G RAT; mmW: 6-100 GHz; WRC-15/19 bands
Spectrum aggregation	Single Carrier (1.4–20 MHz), symmetric DL/UL	Dual Connectivity, CA variants: -up to 5CC, -intra-/inter-band, -(non)-continuous, -FDD and/or TDD -Co-located, RRH; -asymmetric DL/UL	Massive CA (32CC), LAA (5 GHz), LWA, SDL for CA: 2.3–2.4 GHz	Multi-Connectivity with asymmetric DL/UL, SDL for CA: 700 MHz, 2.5–2.6 GHz, Lean carrier
Spectrum licensing schemes	Licensed spectrum only	Licensed, Carrier Wi-Fi	Licensed, Unlicensed, DL LAA, LWA, LSA	Co-existence of: exclusive licensed, shared license-exempt spectrum, enhanced LAA (DL + UL)
Duplexing schemes	Separate FDD, TDD	FDD and TDD (CA-based), eIMTA	FDD Flexible Duplex	Full Duplex, Additional DL-only TDD configurations
Sharing schemes (network, spectrum)	Static schemes (MOCN, MORAN)	Static schemes (MOCN, MORAN)	RSE, LSA	LSA (new bands), SC sharing, SCaaS, spectrum trading, Cognitive Radio
Spectrum refarming	Static	Static	Dynamic, DSA, MRAT Joint Coordination	Fully dynamic, opportunistic, Cognitive Radio

[a]Abbreviations in Table 2: CC – Component Carrier, DSA – Dynamic Spectrum Access, eIMTA – enhanced Interference Mitigation & Traffic Adaptation, LSA – License-Shared Access, LWA – LTE-WiFi Aggregation, MOCN – Multi-Operator Core Network, MORAN – Multi-Operator RAN, RRH – Remote Radio Head, RSE – RAN Sharing Enhancements, SCaaS – Small Cells as a Service, SDL – Supplemental Downlink

[b]3GPP introduces frequency bands and CA band combinations in a release independent manner. Per-release breakdown presented only to describe standard's evolution.

3.1 Frequency Bands

Below, the list of current 3GPP spectrum bands for E-UTRA is presented [5]. Due to the complex nature of the country-, and market-specific spectrum bands allocation, the following compilation is limited only to the presentation of general spectrum bands without detailed distinction:

- FDD [GHz]: 0.45, 0.7, 0.8, 0.9, 1.5, 1.8, 1.9, 2.1, 2.3, 2.6, 3.5
- TDD [GHz]: 0.7, 1.8, 1.9, 2.0, 2.6, 2.3-2.4, 2.5-2.7, 3.4-3.8

In case of spectrum bands for IEEE 802.11 access technologies, unlicensed frequency bands are identified and summarized in Table 3.

Table 3. IEEE802.11 spectrum bands breakdown for 802.11 protocol variants

Protocol	Release date	Frequency band [GHz]	Channel bandwidth [MHz]
802.11	1997.06	2.4	22
802.11 a	1999.09	3.7[a]; 5	20
802.11 b	1999.09	2.4	22
802.11 g	2003.06	2.4	20
802.11 n	2009.10	2.4/5	20, 40
802.11 ac	2013.12	5	20, 40, 80, 160
802.11 ad	2012.12	60	2160
802.11 ah	~2016	0.9	1, 2, 4, 8, 16
802.11 aj	~2016	45/60	540, 1080
802.11 ax	~2016	2.4/5	80, 160
802.11 ay	~2017	60	8000

[a]Licensed 3.7 GHz band; allowed by FCC in the USA.

3.2 Spectrum Aggregation Techniques

Baseline LTE standard (i.e. 3GPP Rel-8) was defined as an OFDMA[5] system supporting single carrier with various channel bandwidths (BW), defined in the range of 1.4–20 MHz. In Rel-10 LTE-Advanced, CA was introduced to aggregate multiple Component Carriers (CC) with the use of MAC layer scheduling. Up to 5CC were standardized and each individual CC was reusing Rel-8 numerology for the BW size to allow backward compatibility. Thus, the overall theoretical maximum aggregated bandwidth summed up to 100 MHz with intra-band consecutive, non-consecutive, or with inter-band spectrum aggregation options. Different component carrier allocation for UL and DL could reflect the expected traffic demand by the use of non-symmetrical configurations (e.g. 3DL CC, 1UL CC). CA introduced concepts of Primary Cell (PCell) and Secondary Cell (SCell), where the former is used for signalling and user data purposes, while the latter serves for user data only to increase the overall user's throughput.

[5] OFDMA used for LTE DL transmission. For LTE UL, Single Carrier FDMA is used.

Unpaired spectrum variant further improving inter-band FDD CA-based operation was provided with the SDL concept defined for L-band (i.e. 1452–1496 MHz, previously used for broadcasting services) [16]. SDL was also introduced for 717–728 MHz band, and the discussion continues to introduce the harmonized European SDL band in 738–758 MHz range, as well as to enable SDL in 2.6 GHz band [8, 9].

CA was standardized for either intra-site or inter-site[6] scenarios, based on ideal backhaul due to CA timing requirements on scheduling. Furthermore, in later stages CA allowed aggregation of TDD and FDD based component carriers.

Even though 5CC configuration was standardized in Rel-10 already, the highest CA combination being standardized for specific spectrum bands so far considers "only" up to 4 frequency bands and 4 CCs [1], e.g.:

- FDD only: 1900, 2100, 2300 + 700 SDL
- FDD + TDD: (2100, 1800, 800) FDD + 3500 TDD

Lately, work on 5CC Carrier Aggregation has been started within Rel-13 for 5DL/1UL configuration [24].

Significant change in the spectrum aggregation management was possible through the aggregation of different carriers with the use of Rel-12 Dual Connectivity feature. With DC, spectrum is aggregated in inter-site scenario, where a macro-cell serves as a mobility anchor (using so called Primary Cell Group, PCG) whereas the other radio link provided by Small Cell acts as local capacity booster (i.e. Secondary Cell Group, SCG). This feature implements Control Plane/User Plane (CP/UP) split, in order to reduce the signaling overhead, reduce the number of handovers, and to improve user experience for mobile users. CP/UP split operates by switching User Plane (UP) links among available SCs, whereas the user's CP context is maintained by the overlay macro-cell. In contrary to CA, DC scheme uses concept of the Split Bearer, where instead of aggregating MAC layer transport blocks, the PDCP Packet Data Units (PDUs) are combined, thus omitting the requirement for low latency and allowing non-ideal backhaul for SC connectivity.

Rel-13 extends spectrum aggregation mechanisms towards higher number of aggregated bands and towards the use of unlicensed spectrum for mobile networking. Massive CA enables up to 32CCs and thus theoretically provides up to 640 MHz of aggregated bandwidth for a single device, while still fulfilling backwards compatibility with LTE Rel-8 channel bandwidths. Furthermore, LAA and LTE-WiFi Aggregation (LWA)[7] are provided as features to utilize the unlicensed spectrum. LAA aggregates the licensed LTE carrier (serving as a mobility and signaling anchor - PCell) with SCell using the new LTE frame format over the unlicensed 5 GHz ISM band[8]. Similarly, in case of LWA scheme, the Carrier Wi-Fi is serving as capacity booster's counterpart, using radio level integration for uniform user experience provision over the Wi-Fi

6 Based on RRH deployments using fiber for ideal backhaul.

7 All spectrum access and spectrum aggregation schemes have deployment related limitations, which are not discussed in this paper, e.g. LWA and LAA applicable mostly for Small Cells.

8 Other LTE-based access schemes using ISM spectrum: LTE-U – downlink-only radio access with Carrier Sensing Adaptive Transmission (CSAT) for fairness assurance; MuLTEfire – LTE-based technology without licensed PCell anchor proposed by Nokia and Qualcomm.

radio. In LWA, UE is configured by the eNB to utilize radio resources of LTE and WLAN. Another LTE-WLAN interworking mode is RAN Controlled LTE WLAN Interworking (RCLWI), defining LTE-controlled bidirectional traffic steering between LTE and WLAN. In RCLWI, LTE may send steering command to UE in order to perform traffic offloading to WLAN. LWA and RCLWI are supported in collocated, as well as in non-collocated scenarios (ideal backhaul, or non-ideal backhaul between eNB and WLAN access point, respectively).

3.3 Spectrum Licensing Schemes

Licensed spectrum allocation per Mobile Network Operator (MNO) is the basic principle for mobile networks operation, requiring acquisition of the spectrum license. However, an unlicensed spectrum usage was considered already in 3GPP Rel-8, where the Access Network Discovery and Selection Function (ANDSF) was introduced for the traffic offload to e.g. Carrier Wi-Fi access nodes. This technique was not very popular, but traffic offloading techniques evolution was continued in the subsequent 3GPP releases.

As already mentioned in the previous section, 3GPP has introduced LAA unlicensed spectrum access schemes, which became hot topic among 3GPP, WFA and IEEE. ISM spectrum usage was also considered under the LWA or RCLWI scheme. To enhance the integration of unlicensed spectrum into mobile networks, the Unlicensed Spectrum Offloading System (USOS) work was agreed for Rel-14, to define service requirements allowing MNOs to empower the clarification for: spectrum usage over unlicensed access networks, network planning and charging purposes.

Furthermore, the new spectrum sharing scheme for 2.3–2.4 GHz band was introduced, based on ETSI RRS work [10], called License Shared Access (LSA, or Authorized Shared Access, ASA). LSA allows spectrum owners (i.e. incumbents) to share their radio resources with other market players (LSA Licensees), enabling QoS support within a shared band. QoS support is achieved by the use of protection measures such as geographical exclusion, or restriction zones, within which the incumbent's receivers will not be subject to interference caused by LSA Licensees. 3GPP studied LSA access in Rel-13 [12], looking into architectural aspects of ETSI's concept for global solution provisioning, covering required information flows for static and semi-static spectrum sharing scenarios. Two alternatives for OAM based spectrum usage reconfigurations are available within LSA architecture model to handle LSA Spectrum Resource Availability Information (LSRAI) exchange over LSA_1 interface (Fig. 2). LSA Repository (LR) entity stores information describing Incumbent's usage and protection requirements. LR allows National Regulatory Authority (NRA) to monitor LSA operation. LSA Controller (LC) is located within licensee's domain, allowing the licensee to obtain LSA spectrum availability information from the Repository. LC controller interacts with the licensee's mobile network to support mapping of the spectrum availability information into appropriate radio nodes configurations.

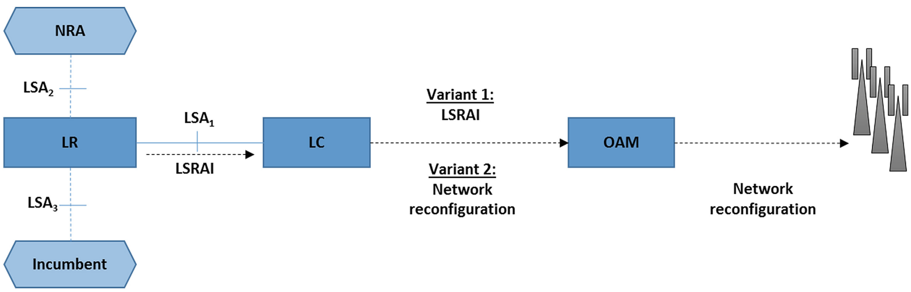

Fig. 2. Two variants for LTE RAN network elements reconfiguration under LSA scheme [11]

3.4 Duplexing Schemes

Duplexing schemes for LTE system correspond to either FDD or TDD, with pre-defined duplex-specific spectrum bands [1]. Initial Rel-8 TDD frame configurations included multiple settings for different UL and DL traffic ratios (i.e. ranging from UL heavy 2:2:6[9] up to DL heavy 8:1:1) within 10 ms radio frame, which were meant to be configured in a semi-static manner. However, TD-LTE frame setup modification requires careful inter-site coordination to avoid major interference problems, e.g. in case of inter-site configuration, where UL and DL transmission is present in the same subframe from the neighboring access nodes.

Based on TDD frame configurations described above, their dynamic adaptation for a HetNet scenario was introduced in Rel-12 with the introduction of enhanced Interference Management and Traffic Adaptation (eIMTA) feature. eIMTA enables on-the-fly changes of the TDD configuration based on instantaneous DL:UL traffic demand ratio in the particular cell. This feature was mainly foreseen for Small Cell deployments in 3.5 GHz band. In such scenario, DL-UL interference should not be an issue, since a SC with low transmit power, and operating on high frequency band is considered to be well isolated from the potential neighboring interferers (unless, dense deployment of SCs is considered), and it is not expected to deploy macro cells on such high frequency bands[10].

Furthermore, TDD frame configurations were discussed within Rel-13 to be further extended with additional DL-heavy and DL-only frames formats to support 9:1:0 and 10:0:0 options [25], but this study was left for standardization in future releases.

With the introduction of CA, TDD or FDD spectrum aggregation was possible. In case of FDD bands aggregation, it was possible to have a different number of the DL and UL CCs (e.g. refer to the SDL concept); in the case of TDD spectrum aggregation, number of carriers (and their bandwidths) obviously has to be the same for DL and UL due to the nature of TDD. Further evolution of CA configurations came with the aggregation of FDD and TDD component carriers, enabling greater flexibility in the

[9] DL:Sp:UL; Sp – Special subframe.

[10] However, 3.5 GHz based rooftop macro sites were considered in Japan, based on the inter-site coordination for interference management purposes.

spectrum arrangements for the operators having both, FDD and TDD spectrum licenses. In such scenario, PCell could be either FDD, or TDD (with the limit for the cross-carrier scheduling originating from the TDD PCell). One particular use case considers FDD based PCell, with the RRH based SCell using TDD.

Flexible duplex feature for FDD E-UTRA bands was also proposed during Rel-13 discussions [13]. It aimed to provide more efficient handling of the asymmetric traffic load between DL and UL, going beyond static resource allocation for both link directions, by permitting DL transmission to originate from the underutilized FDD UL frequency bands. However, based on negative feedback received from regulatory bodies, it seems that the option of flexible duplex for FDD bands will not be further considered at this stage of standardization.

3.5 Spectrum Sharing Schemes

According to the basic definition of spectrum sharing[11], some of the techniques described in the previous chapters could be considered as belonging to the spectrum sharing mechanisms, e.g. LAA spectrum access method, or LSA spectrum licensing method.

This section focuses on recent developments in the area of shared spectrum access improvements, in the form of Rel-13 RAN Sharing Enhancements (RSE) work [14]. RSE treats on RAN sharing, however it is closely related to the spectrum sharing. It improves the legacy inter-operator sharing schemes, where previously there was no knowledge on how much capacity the other participating operator is using. RSE improvements are addressing the following aspects:

- Allocation of the shared RAN resources based on the proportion of the assigned resource usage for each participating operator;
- Ability to monitor the usage of shared resources;
- Allows on-demand capacity negotiations;
- Load balancing while respecting the agreed shares of resources;
- Selective OAM access for the participating operators.

RSE is under the development for each of the following radio technologies: GSM, UTMS [15] and LTE. In terms of GSM, it is becoming an interesting improvement for some markets, where it is already expected, that there will be single shared GSM network for legacy devices support for all competing operators. At the same time, each MNO will own its individual 4G network using extra 2G spectrum resources by the means of dynamic refarming.

RSE functionality is expected to be particularly important in case of HetNets, including dense deployment of SCs for hotspots. In the authors' opinion, SC sharing will become an enabler for fruitful deployments of future networks in mature markets, where shortage of the access nodes' sites in dense environments will become a bottleneck.

[11] Spectrum sharing: simultaneous usage of the particular frequency band by the number of independent systems, or users.

3.6 Spectrum Refarming

Along the mobile networks evolution from 1G analogue systems up to today's LTE-A Pro cellular networks underlying spectrum regulations and standardization has been evolving to provide sufficient amount of market-, and RAT-specific frequency bands for the mobile operators. With new radio technologies becoming more spectrally efficient than the previous RAT generations and with ever increasing demand for the more licensed bands, the spectrum refarming comes as a natural solution to enable release of the legacy RAT bands. Static approach to the spectrum refarming, where reuse of 2G spectrum for the LTE services is allowed after 2G license expiration, is not too attractive, as market-specific spectrum licenses might have been granted for long periods (e.g. 20 years). Moreover, the static spectrum refarming has another drawback, i.e. the requirement of legacy RAT's devices lead-out consideration. Thus, the evolution in spectrum refarming domain already includes dynamic methods, and ultimately shifts towards Cognitive Radio based mechanisms.

So far, one promising method for dynamic spectrum refarming is being standardized under MRAT Joint Coordination framework [6, 17]. This concept utilizes Dynamic Spectrum Access (DSA) scheme[12], where the collocated LTE and GSM systems use dedicated bandwidth part whose size depends on the actual traffic demand in each radio network. This method is based on the temporal traffic statistics: e.g. when GSM load on Traffic Channel is low, LTE is allowed to use shared GSM/LTE part of the spectrum.

4 Future Evolution Directions

Considering the above solutions and the emerging standardization of 5G, the presented Spectrum Toolbox is expected to be further enhanced with new technology elements. Spectrum Toolbox will become even more complex, but it will also provide more flexibility in the spectrum allocation. Therefore, Spectrum Toolbox will have to be more adaptive and automated, evolving towards CR mechanisms, equipped with self-learning and self-optimization solutions. Some of the 3GPP study and work items considered for Rel-14 discussion are indicating future evolution directions, briefly covered below:

- Enhanced LAA (eLAA) proposal extends LAA scheme with UL consideration to enable full DC-like capabilities for unlicensed spectrum [19].
- SDL spectrum is extended by 2570–2620 MHz band for TDD or for unpaired DL within SDL framework.
- Flexible bandwidth study [20] targets the possibility to fully exploit non-standard channel bandwidths for LTE (i.e. extension of Rel-8 channel BWs) in spectrum, which is currently underutilized, e.g. in case of spectrum refarming, where the released 2G spectrum doesn't fit the Rel-8 channel bandwidths.

[12] Also studied in FP7 SEMAFOUR project [18].

- Lean carrier concept, after being initially rejected in Rel-12, is again brought to attention during Rel-14 discussion [21]. It is supposed to inherit from LAA radio frame, where most of the legacy PHY-layer information (including cell specific reference signals) is sent only when needed. By doing so, in the low/medium load conditions, the interference is decreased, and the eNB's power amplifiers can be switched to deep sleep mode to save energy. Furthermore, to enable easy integration with the existing system, it is proposed to provide the lean carrier with the possibility to be toggled to the legacy LTE frame when needed, e.g. serving as a legacy SCell when the PCell is overused by legacy users.
- Multi-connectivity [22] is expected to enhance DC, providing multiple links for a UE in the following two options:
  - Configuration of multiple radio links for UE, while only limited, selected set of them are active at any given moment;
  - All of the configured multiple links are active.

More advanced and novel areas of the "Towards 5G" RAN aspects include: adoption of high frequency bands, support for full duplex, and definition of the Unified Air Interface (UAI):

- New frequency bands in the range of mmWave bands have been considered for local capacity boosting and as dynamic backhaul/fronthaul solutions, where the standardization starts by studying the appropriate channel models.
- Full duplex provides the possibility to improve spectral efficiency by utilizing a single, un-paired band for simultaneous transmission and reception (i.e. without splitting the time slots onto DL and UL) possible through the use of advanced receivers.
- UAI should handle multiple different traffic types and incorporate their requirements into a single radio frame design utilizing different frame parts (e.g. in the frequency domain) with different waveform parameters and access schemes, e.g. small data packets transmitted by MTC devices can be sent in a contention-based manner, whereas MBB data is sent in synchronized scheduled manner [23].

All the above techniques provide a Spectrum Toolbox that includes a wide set of bands ranging from 450 MHz up to 100 GHz with licensed and unlicensed spectrum, covering different licensing options, as well as different access schemes, BW aggregation mechanisms, duplexing and RATs. On top of that, 5G requirements target tight integration of all these elements to unify the operation of the next generation mobile systems and to provide the possibility to adapt to different use cases and scenarios that will further complicate the overall landscape.

5 Summary and Conclusions

The aim of this paper was to present set of the available and currently discussed spectrum access techniques, considered as the enabler for the 5G pre-study discussions within 3GPP Rel-14. Based on the performed analysis, the authors are convinced that the ongoing 5G-related discussions should already address all the possible spectrum resources, while considering various licensing schemes. Unified approach to this complex problem of Radio Resources Management is an enabler for the spectrum-efficient future networks. This is due to the fact, that the unified approach to RRM is still considered to be a missing piece in the current multi-RAT mobile networks landscape. In order to enable efficient usage of new spectrum licensing schemes (like LSA), considering scenarios which are evolving towards Ultra Dense Networks (UDN), the radio resources coordination shall be addressed on multiple levels, namely inter-MNO, inter-RAT, inter-site, inter-layer, inter-band dimensions. To achieve this, it is already obvious that the high level flexibility in the RF domain will be required. Additionally, high level of "programmability" of the baseband units will be needed, relying on Software Defined Networking (SDN) techniques, leading to dynamic spectrum access. On top of that, the overall design of future networks should natively incorporate SON engines, to manage the network towards unified user experience provided across multiple converged radio access technologies.

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