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Unlicensed Spectrum Bands for Cellular Mobile Networks-An Overview

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Resume of the Presenter

RONY KUMER SAHA received the B.Sc. degree in electrical and electronic engineering from the Khulna University of Engineering and Technology, KUET, in 2004, the M.Eng. degree in information and communications technologies from the Asian Institute of Technology (AIT), Thailand, in 2011, and the Ph.D. degree in electrical engineering from Chulalongkorn University, Thailand, in 2017. Since 2017, he has been working as a Postdoctoral Fellow/Research Engineer with the Radio and Spectrum Laboratory, KDDI Research, Inc., Japan.

He worked as a Lecturer and later promoted to an Assistant Professor with American International University-Bangladesh, Bangladesh, AIUB, from January 2005 to August 2013. From September 2013 to July 2014, he was with East West University, Bangladesh. His current research interests include 5G and beyond ultra-dense HetNets, spectrum sharing, policy, and management in multiple communication systems, and millimeter-wave communications. He has research experiences on mobile wireless communications in universities and industries for more than ten years. He has authored about 60 peer-reviewed, reputed, and highly recognized international journal and conference papers. He also filed an international patent.

Dr. Saha served as a member of the Fronthaul Working Group, xRAN Forum, USA. He also served as a TPC member of the 2020 ICSNC and 2018 IEEE Global Communications Conference Workshops. Furthermore, he also served as the Session Chair for two sessions, namely Radio Resource Management and Aerial Networks at 2019 IEEE VTC-Fall, Hawaii, USA, as well as the 2019 IEEE International Symposium on Dynamic Spectrum Access Networks Newark, NJ, USA, for the session Spectrum Sharing in 5G. Since early 2019, he has been serving as an Associate Editor of the Engineering Journal, Thailand. He served as a Reviewer of a number of recognized journals, including IEEE Transactions on Vehicular Technology, IEEE Access, Elsevier Physical Communication, Wiley International Journal of Communication Systems, MDPI Sensors Journal, MDPI Symmetry Journal, Hindawi Mobile Information Systems, and MDPI Sustainability Journal.

Topics of Research Interests

- Terahertz and millimeter wave communications
- 5G NR-U: 5G New Radio on Unlicensed Bands
- Dynamic spectrum sharing and policy for 5G and beyond mobile networks
- Cognitive radio networks and spectrum sensing techniques
- Co-channel interference analysis, mitigation, avoidance, and cancellation strategies
- In-building small cell network planning, design and deployment
- Planning, design and development of spectrum sharing algorithm for homogeneous (mobile networks) and heterogeneous networks (mobile networks and satellite networks)
- Radio resource allocation and scheduling policy and algorithm
- Mobile MAC layer and physical layer issues
- Proof-of-concept evaluation of virtualization and Slicing of 5G radio access network (RAN)
- Cloud RAN (CRAN) in 5G era
- Fronthaul design for CRAN

Presentation Outline

- Background and Problem Statement
- Related Study
- Overview of Unlicensed Spectrum Bands for Cellular Technologies
- Cellular Technologies in the Unlicensed Spectrum Band
- Benefits and Challenges
- Conclusion
- References

Background and Problem Statement (1)

Radio spectrum is limited and not allocated to a Mobile Network Operator (MNO) in proportionate with its traffic demand [1]. **To address the scarcity** of the available licensed spectrum, recently, the operations of the Third Generation Partnership Project (3GPP)-based cellular technologies in the unlicensed bands have been introduced.

Cellular technologies may operate in one or more unlicensed spectrum bands, including 2.4 GHz, 5 GHz, 6 GHz, and 60 GHz. Of these, 2.4 GHz, 5 GHz, and 60 GHz bands are available **worldwide** [4], whereas the 6 GHz band is currently available in Europe and the USA. In addition, cellular technologies, particularly, Fifth-Generation (5G) New Radio Unlicensed (NR-U) can also use shared bands, including 3.5 GHz and 37 GHz, only in the USA [5].

Note that, according to the 3GPP, 2.4 GHz, 3.5 GHz, 5 GHz, and 6 GHz are classified as **low-frequency bands below 7 GHz,** whereas 37 GHz and 60 GHz **high-frequency bands** are classified as millimeter-wave (mmWave) bands. These two unlicensed frequency ranges are **targeted for 5G NR-U operations** [6].

Background and Problem Statement (2)

Typically, **an unlicensed spectrum is** used by the Institute of Electrical and Electronics Engineers (IEEE) 802.11, also termed as Wireless Fidelity (WiFi) [7], technologies in addition to Bluetooth and ZigBee.

Hence, to **operate cellular technologies** in the same unlicensed band at the same place simultaneously, *a proper coexistence mechanism to manage Co-Channel Interference (CCI) between cellular and WiFi technologies is necessary.*

Coexistence mechanisms can be developed in two ways depending on whether or not modifications on the existing cellular networks are employed.

If modifications are employed, a cellular network is enabled with a carrier sensing mechanism, termed **as Listen-Before-Talk** (LBT).

Likewise, *numerous coexistence mechanisms without employing LBT* have been proposed to manage CCI such as channel selection, carrier sense adaptive transmission, fully blank subframe, and transmit power control.

Related Study

Numerous existing works addressed the operation of cellular standards such as Long-Term Evolution Unlicensed (LTE-U), Licensed Assisted Access (LAA), and NR-U on unlicensed bands from specific viewpoints, including coexistence mechanisms [9]-[19], unlicensed bands (e.g., 5 GHz [20]-[22], 6 GHz [23], and 60 GHz [24]), coexistence studies [25]-[26] and scenarios [27], fairness conditions [28]-[29], standardization efforts [30], challenges, and open problems [3] [31].

Different from these above existing studies, in this paper, we provide **a survey on unlicensed spectrum bands from a nonspecific viewpoint** that takes into account all available unlicensed spectrum bands in both the *sub-7 GHz, including 2.4 GHz, 5 GHz, and 6 GHz, as well as mmWave, including 60 GHz, for the cellular* networks.

Major aspects of each unlicensed band, including operational region, regulatory requirement, existing technology, available bandwidth, spectrum range, benefit, and challenge, are discussed.

A **comparative framework** of all these aspects is then developed, and major benefits and challenges regarding the operation of cellular networks on unlicensed bands are pointed out.

Overview of Unlicensed Spectrum Bands for Cellular Technologies

2.4 GHz band

The **2.4 GHz band** is the first unlicensed band released by the **Federal Communications Commission (FCC)** for commercial use and is currently the most utilized unlicensed shared band [8].

In the 2.4 GHz band, the bandwidth is divided into **14 channels** with a separation of 5 MHz from one channel to another.

- In the USA, operations on **channels 12 and 13** are allowed only under low power conditions [32].
- Likewise, in Canada, of **a total of 12 channels** (from channel 1 to channel 12) available to use.
- However, **most of the rest of the world can use 13 channels** (from channel 1 to channel 13) [32], and **channel 14** is available only in Japan.

5 GHz band

The use of **the 5 GHz band** depends on its requirement in a country [20].

- The **5.15-5.35 GHz** band is available in the USA, China, South Korea, Europe, Japan, and India;
- the **5.47-5.725 GHz** is available in the USA, South Korea, Europe, and Japan; and
- the **5.725-5.85 GHz** is available in the USA, China, South Korea, and India [7].
- the **5.35-5.47 GHz** and the 5.85-5.925 GHz unlicensed spectra are being considered to make available in the USA and Canada [3] [7] [8].
- European Commission (EC) also recently proposed to use the **5.725-5.85 GHz** spectrum band [8].

In general, due to the **clearer channel condition**, wider spectrum, and easier implementation [8], the 5 GHz band is considered favorable to other unlicensed bands.

Overview of Unlicensed Spectrum Bands for Cellular Technologies

6 GHz spectrum band

- The 6 GHz spectrum band is available **from 5.925 to 6.425 GHz** in Europe, whereas **from 5.925 to 7.125 GHz** in the USA [23].
- Recently, **5.925-6.425 GHz** [33] spectrum and **5.925 GHz-7.125 GHz** spectrum have been proposed, respectively, by the EC and the FCC under part 15 rules for the unlicensed access [34]-[35].

The amount of the unlicensed spectrum available in Europe **is 500 MHz** and in the USA is **1200 MHz**. Since much of the 6 GHz band is occupied by some licensed services, **Automatic Frequency Coordination** (AFC) is needed by unlicensed users.

60 GHz spectrum band

- The **60 GHz band** is considered for the NR-U to provide **directional communications** using beamforming to overcome propagation constraints [36]-[37]. The 60 GHz band ranges from **57 GHz to 71 GHz** [38].
- The bandwidth available in the unlicensed 60 GHz band is more than that of the aggregate bandwidth of all the other unlicensed bands [39].
- The minimum available bandwidth in a region is more than 3 GHz, and at least 7 GHz of bandwidth can be used in most regions in the 60 GHz band [39].
- Due to this reason, the 60 GHz band is suited for serving high data rate demand in magnitudes of Gbps over short distances.

Cellular Technologies in the Unlicensed Spectrum Band

- Long-Term Evolution (LTE) is the first cellular-based technology extended with a view to operating in the sub-7 GHz unlicensed spectrum bands in 2015, whereas *NR-U is the first cellular-based technology* that includes operations in the mmWave unlicensed bands [4]-[5].
- Hence, since cellular technologies in the previous generations, i.e., Fourth-Generation (4G) LTE, were not allowed to use mmWave bands, two standards of LTE working in the unlicensed bands, namely LTE-U and LAA, operate in the 5 GHz band.
- However, unlike LTE that operates only in the 5 GHz unlicensed spectrum, **NR-U can operate on multiple** spectrum bands, including mmWave bands, e.g., sub-7 GHz and 60 GHz [4].
- Moreover, like LTE, there are a number of variants of 5G NR-U, including 5G NR-U Standalone operating only in an unlicensed spectrum band (e.g., 60 GHz) and 5G NR-U Anchored operating in both the licensed spectrum and the 60 GHz unlicensed spectrum.
- Though existing IEEE and 3GPP-based technologies operate in the unlicensed bands on a competitive basis, such *competition results in convergence* to **use and develop similar features in the radio access in the latest releases and amendments** [4], e.g., the use of LBT to 3GPP technologies developed in line with Carrier-Sense Multiple Access with Collision Avoidance (CSMA/CA) inherent to the IEEE 802.11 technologies.

Cellular Technologies in the Unlicensed Spectrum Band

Table I shows comparisons in terms of numerous aspects **among 2.4 GHz, 5 GHz, 6 GHz, and 60 GHz** unlicensed spectrum bands.

- From Table I, it can be observed **that a total of about 2 GHz unlicensed bandwidth is available below 7 GHz for omnidirectional communications** at the 2.4 GHz, 5 GHz, and 6 GHz bands [34].
- Moreover, **a large amount of 9 GHz of spectrum in Europe and 14 GHz unlicensed spectrum in the USA is available in the 60 GHz** band for directional communications [41]-[42]

Table I: A comparative framework of unlicensed bands for cellular technologies.

Features	Unlicensed spectrum bands			
	2.4 GHz	5 GHz	6 GHz	60 GHz
Classification	Mid-bands (sub-7 GHz)	Mid-bands (sub-7 GHz)	Mid-bands (sub-7 GHz)	High-bands (mmWave)
Availability	Worldwide	Worldwide	Europe and the USA	Worldwide
Regulatory requirement	The maximum data rate, multiple access methods, digital modulation scheme, maximum coverage distance, and media access protocol [43]	The maximum in-band output power, out-of-band and spurious emissions, DFS, LBT, and Transmit Power Control (TPC) [44]	DFS, AFC, TPC, and indoor coverage [6]	Short-range communication, Equivalent Isotropic Radiated Power (EIRP), EIRP densities, maximum power, and antenna gains [45]-[46]
Existing technologies	802.11b/g	802.11a/n	Licensed microwave links, fixed satellite systems, and mobile services	802.11ad/ay
3GPP Releases	Release 16 (5G NR-U)	Release 10/11/12 (LTE-U), Release 13 (LAA), and Release 16 (5G NR-U)	Release 16 (5G NR-U)	Release 16 (5G NR-U)
Available bandwidth	About 100 MHz [47]	500 MHz [7]	500 MHz (Europe) and 1200 MHz (USA) [34]-[35]	9 GHz (Europe) and 14 GHz (the USA)
Spectrum range	2.40-2.50 GHz [47]	5.150-5.925 GHz [7]	5.925-7.125 GHz [5]	57-66 GHz [39]
Antenna pattern	Omnidirectional [34]	Omnidirectional [34]	Omnidirectional [34]	Directional [41]-[42]
Constraints	• Heavily congested • lower data rate	• Lower coverage • Higher penetration and path losses	• Lower coverage • Higher penetration and path losses	• Extremely high penetration and path losses • Blocking
Advantages	• Most utilized unlicensed shared band • Favorable signal propagation characteristics	• Availability of a large amount of spectrum bandwidth • The majority of IEEE 802.11-based technologies operate in this band	• No unlicensed devices now operate [23] • The high capacity demand of future mobile networks can be addressed	• Large spectrum bandwidth availability • High capacity and data rates at a short distance indoors

Benefits and Challenges

Benefits (to operate in the unlicensed bands)

By operating cellular networks such as LTE and NR in the unlicensed bands, significant benefits in several aspects can be achieved. A few noticeable benefits are discussed in the following.

High capacity, spectral efficiency, and data rates

Due to the addition of the unlicensed spectrum, the combined spectrum bandwidth of an MNO increases. Because the capacity is directly proportional to the available channel bandwidth, the use of the unlicensed spectrum in a cellular network helps increase its overall capacity, spectral efficiency, as well as data rates per user.

Data offloading

An MNO can configure its indoor small cells to offload all or a major portion of its user traffic over the unlicensed spectrum.

Cost-efficiency

As there is no cost from using an unlicensed spectrum, by operating an MNO in both the licensed and unlicensed spectrum bands, the demand for high capacity and data rates per user of the MNO can be served at a low average cost per bit transmission, resulting in improving its cost-efficiency.

Benefits and Challenges

Challenges (to operate in the unlicensed bands)

Several technical challenges remain unaddressed across different layers for the operation of cellular standards (i.e., LTE-U, LAA, and NR-U) and IEEE 802.11 standards (i.e., WiFi and WiGig) in the same unlicensed band. A few noticeable challenges are discussed in the following.

Efficient coexistence mechanism

The main challenge to operate cellular standards in the unlicensed band comes from *the design of an efficient coexistence mechanism* of cellular and IEEE 802.11 standards in the unlicensed band.

- *Major constraints* to designing an efficient coexistence mechanism include
- the lack of inter-Radio Access Technology (RAT) coordination,
- intercell interference management,
- independent resource allocations from one RAT to another, and
- different Medium Access Control (MAC) and Physical Layer (PHY) protocols [31].

Physical and MAC layer procedures of cellular and IEEE 802.11 technologies:

- The transmission power, Modulation and Coding Scheme (MCS), and error correction code, are different [48].
- Moreover, cellular standards use Radio Link Control Layer with Hybrid Automatic Repeat Request (**HARQ)**, whereas, WiFi, for example, uses Automatic Repeat Request (ARQ) mechanisms, for the recovery of packet losses.

- In the case of the MAC layer procedure, cellular technology is an allocation-based mechanism, whereas an IEEE 802.11 (e.g., WiFi) technology is a contention-based mechanism.
- Cellular technology uses continuous transmission of data in consecutive frames using a centralized scheduler. But, a WiFi technology uses opportunistic transmission using Distributed Coordination Function (DCF).
- DCF uses the CSMA/CA protocol to detect the energy level in order to get access to a channel.

Benefits and Challenges

Interference management

Since **no interference management exists between cellular** and IEEE 802.11 standards, and the current LBT does not allow neighboring cellular nodes to transmit simultaneously due to employing contention-based opportunistic scheduling, **no simultaneous transmission of cellular and IEEE 802.11 nodes are allowed, and hence no reuse** of the same unlicensed spectrum spatially is possible.

Transmission mode

Unlike licensed bands, transmissions in unlicensed bands are *discontinuous and opportunistic*, particularly, for cellular standards using LBT such as LAA and NR-U, which result in reduced efficiency and flexibility in Radio Resource Management (RRM).

Beam-based transmissions

Unlike LTE-U and LAA, since **NR-U operates as well in the 60 GHz mmWave** band using beam-based transmissions, LBT used in LAA with omnidirectional transmissions needs additional requirements to be addressed for the beam-based NR-U.

Conclusion

- This paper has presented an essential survey on unlicensed spectrum bands considered for the operation of cellular mobile networks. Particularly, both sub-7 GHz (i.e., 2.4 GHz, 5 GHz, and 6 GHz) bands and millimeter-wave bands (i.e., 60 GHz) proposed for the Fifth-Generation (5G) and beyond networks have been discussed.
- Each unlicensed band has been surveyed taking into account the classification, operational region, regulatory requirement, existing technology, available bandwidth, spectrum range, benefit, and challenge.
- A comparative framework in a tabular form has been developed for numerous aspects to compare one unlicensed band to another to find an appropriate unlicensed spectrum band corresponding to a particular aspect. Finally, we have pointed out major benefits and challenges to operate cellular networks in unlicensed bands.
- This paper can serve as a source of fundamental knowledge on unlicensed spectrum bands for cellular technologies and be useful for those who aim at working on the operation of cellular networks in the unlicensed spectrum bands.
- For more details, interested readers are recommended to refer to the existing works cited throughout the paper and given in the reference section.

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End of the Presentation

Thank You …