# Chapter 2
# Requirements and Regulations in the 5 GHz Unlicensed Spectrum

**Abstract** License and fee are not required for operators to use the 5 GHz unlicensed spectrum. However, in order to avoid interference and to ensure a fair use of this resource, numerous requirements and regulations are imposed on this band by national and international organizations. The emerging U-LTE technology, therefore, needs to follow them as any other existing technologies, esp., IEEE 802/11 Wi-Fi, when deployed in this band. This chapter provides an overview on radio spectrum and related management/allocation concerns. It then summarizes a number of key requirements and regulations specified by the European Telecommunications Standards Institute (ETSI) and the Federal Communications Commission (FCC) on radio channels, operating channel selection, transmission power, and channel access rules. These technical details are the baselines to be followed when designing medium access control protocols for U-LTE and any other technologies operating in the 5 GHz unlicensed radio band.

## 2.1 An Overview on Radio Spectrum Management

The Radio Frequency (RF) spectrum is the part of the electromagnetic spectrum from 3 Hz to 3000 GHz (3 THz). Radio waves in this frequency range are widely used in modern technologies, especially in telecommunications. The radio spectrum is divided into different chunks or bands, each of which can be used by one or multiple technologies. Radio Frequency Interference (RFI) is the conduction or radiation of radio frequency energy that causes an electronic or electrical device to produce unwanted noise that typically interferes with functions of adjacent devices. In radio communications, RFI can disrupt and disturb the normal functioning of devices, and thus it is always important to avoid or keep the RFI within acceptable levels. For this, the generation and transmission of radio waves is strictly regulated by national laws, coordinated by international organizations, e.g., Federal Communications Commission (FCC), Inter-American Telecommunication Commission (CI-

TEL), International Telecommunication Union (ITU), European Telecommunications Standards Institute (ETSI), etc.

Most countries consider RF spectrum as a national resource. The process of regulating the use of this resource is spectrum management or allocation. Spectrum allocation varies by country and/or regulatory domain. In United States, for example, FCC regulates inter-state communications by radio, television, wire, satellite, and cable in all states and territories. From management perspectives, radio bands are categorized into *licensed* and *unlicensed*. Licensing is a way of ensuring that wireless operators do not interfere with each others by giving each of them an exclusive use of one or multiple bands in given geographical areas over a set period of time. Licensed bands are mainly sold/assigned to operators through spectrum auction precess. They are mostly used by television broadcasting, commercial radio and cellular voice and data. Operating in licensed bands, operators can avoid RFI and thus guarantee quality of services they deliver to their subscribers. However, licensing would be very impractical for certain use cases, like communications between cordless handsets and base units. Instead, such a kind of wireless technology transmits its radio signals in unlicensed frequency bands - usually the Industrial, Scientific and Medical (ISM) band defined by the ITU radio regulations and allocated in most countries for free use by anyone without any license and fee. Unlicensed bands enable numerous technologies and products, e.g., Wi-Fi, Bluetooth, and many other low-power short-range communications technologies. They are open sandboxes where users can operate without the high barriers to entry. The availability of unlicensed bands provides a platform for innovation, a greenfield space for technology start-ups and entrepreneurs, as well as established companies. Internet of Things (IoT) - the development and deployment of networking technologies that provide connectivity for everyday objects for many innovative applications - is essentially enabled by unlicensed spectrum.

Today, most people are within a few meters of consumer products (microwave ovens, Wi-Fi, Bluetooth, etc.) that use unlicensed bands. In other words, there is a great chance for RFI in these bands. As a result, even though no permission is required for the use of unlicensed bands, manufacturers and users must comply with numerous rules and regulations (related to transmission power, transmission time, etc.) in order to minimize the RFI to others as well as to ensure a fair sharing of the radio resource in these bands. IEEE 802.11/Wi-Fi is the most successful and popular technology operating in unlicensed spectrum. Wi-Fi manufacturers need to obtain compliance certifications from Wi-Fi Alliance whose certification program is designed following rules imposed by radio spectrum management organizations/authorities such as ETSI and FCC.

The two most widely-used unlicensed bands are 2.4 GHz and 5 GHz. These two bands have their own advantages and disadvantages in various perspectives. 5 GHz provides faster data rates at a shorter distance, whereas 2.4 GHz offers coverage for farther distances but support lower rates. New technologies, particularly unlicensed LTE variants including LTE-U, LAA, and MulteFire (as mentioned in Chapter 1), have been targeted to operate in the 5 GHz band alongside Wi-Fi. The selection of the 5 GHz band for U-LTE technologies (rather than the 2.4 GHz band) is mainly due to the following reasons:

- *More available channels:* In the 2.4 GHz band, only 14 channels, each of with provides 20 MHz of bandwidth, are defined. In U.S. (or Europe), only 11 (or 13) of those channels are legally available. However, those channels overlap excessively with one another. Due to this overlapping, the maximum possible number of parallel independent connections is limited to 3 channels (channels 1, 6, and 11). In the 5 GHz band, there are 21 non-overlapping 20 MHz channels (or 9 non-overlapping 40 MHz channels). Figs. 2.1(a) and (b) depict spectrum analyzer views of radio channels defined in 2.4 and 5 GHz bands, respectively.
- *Lower level of interference:* Since the 2.4 ISM band was released for Wi-Fi technology use more than fifteen years ago, this band is over-crowded with billions of existing Wi-Fi devices. There are also many consumer products use this band, including microwave ovens, cordless phones, baby monitors, garage door openers, etc. In contrast, the relatively recent release of the 5 GHz band for private use makes this band much less crowded and thus having a much lower level of RFI.
- *Higher performance:* The 5 GHz band operates on a larger spectrum and does not suffer the over-crowding. Therefore, compared to the 2.4 GHz band, each channel in the 2.4 GHz band allows for much better spectrum efficiency and therefore higher data rates.

As just mentioned, any technology operating in unlicensed bands needs to comply with unlicensed band rules and regulations in order to limit the RFI and to ensure that it does not unfairly grab a larger portion of the shared spectrum. Coexistence is one of the most notable concerns when U-LTE technology in introduced in the 5 GHz unlicensed band considering the fact that a sheer number of Wi-Fi devices/networks has been deployed in the same band for everyday applications in homes, offices, and buildings. Since the number of wireless devices using the 5GHz band has grown rapidly over the last few years, ETSI has updated its related regulations. For background knowledge necessary for developments of radio channel access protocols for U-LTE and Wi-Fi technologies in this band, the following sections summarize a number of key requirements/mechanisms presented in ETSI EN 301 893. Specifically, frequency channels, transmission power, and channel access mechanisms are focused.

## 2.2 Frequency Channels

The ETSI EN 301 893 V1.7.2 regulations [1] released in July 2014 defined three unlicensed frequency bands as follows:

- RLAN band 1: 5150 to 5350 MHz, divided into 2 sub-bands

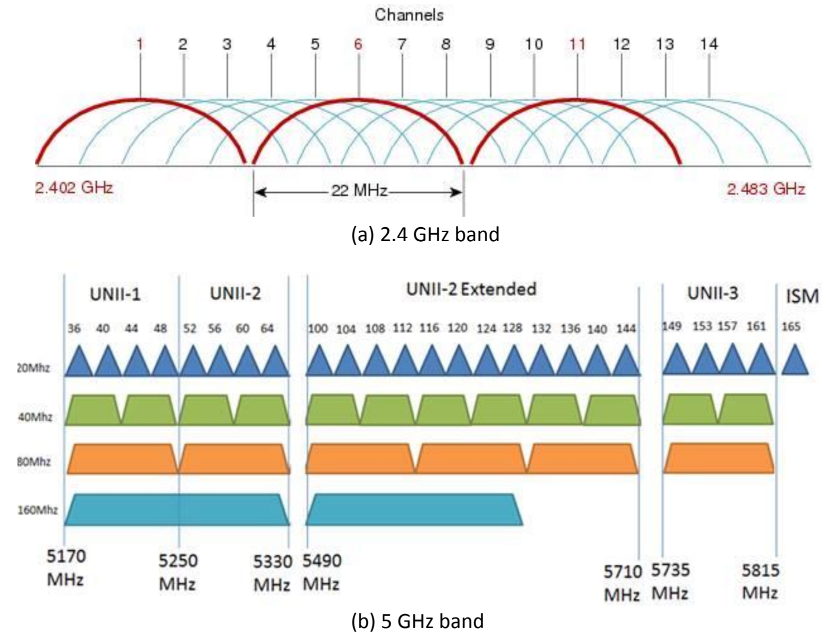


**Fig. 2.1** 2.4 GHz and 5 GHz Unlicensed Spectrums.

– Sub-band I: 5150 MHz - 5250 MHz. This sub-band is comparable to FCC U-NII-1.
– Sub-band II: 5250 MHz - 5350 MHz. This sub-band is comparable to FCC U-NII-2.
– RLAN band 2: 5470 MHz - 5725 MHz. This band comparable to FCC U-NII-2 extended (U-NII-2e).
– RLAN band 3, also known as Broadband Radio Access Networks (BRAN): 5725 5875 MHz. This sub-band is comparable to FCC U-NII-3 (5725 5825 MHz) band with a higher upper frequency range,.

Fig. 2.1(b) summarizes radio channels defined in the 5 GHz band by ETSI 301 893 standard (with a reference to FCC regulations). Technical details and the availability of each channel in four main regions (U.S., Europ, Japan, and China) are presented in Fig. 2.2.

## 2.3 Transmission Power

Each of the three bands defined by ETSI EN 301 893 V1.7.2 regulations [1] have different maximum allowable transmission power levels. Note that the RF output

| Channel Number | Center Frequency | U.S. | Europe | Japan | China |
|---|---|---|---|---|---|
| 36 | 5180 | Yes | Indoors | Yes | Yes |
| 38 | 5190 | No | No | Client Only | No |
| 40 | 5200 | Yes | Indoors | Yes | Yes |
| 42 | 5210 | No | No | Client Only | No |
| 44 | 5220 | Yes | Indoors | Yes | Yes |
| 46 | 5230 | No | No | Client Only | No |
| 48 | 5240 | Yes | Indoors | Yes | Yes |
| 52 | 5260 | DFS | Indoors/DFS/TPC | DFS/TPC | Yes |
| 56 | 5280 | DFS | Indoors/DFS/TPC | DFS/TPC | Yes |
| 60 | 5300 | DFS | Indoors/DFS/TPC | DFS/TPC | Yes |
| 64 | 5320 | DFS | DFS/TPC | DFS/TPC | Yes |
| 100 | 5500 | DFS | DFS/TPC | DFS/TPC | Yes |
| 104 | 5520 | DFS | DFS/TPC | DFS/TPC | Yes |
| 108 | 5540 | DFS | DFS/TPC | DFS/TPC | No |
| 112 | 5560 | DFS | DFS/TPC | DFS/TPC | No |
| 116 | 5580 | DFS | DFS/TPC | DFS/TPC | No |
| 120 | 5600 | No | DFS/TPC | DFS/TPC | No |
| 124 | 5620 | No | DFS/TPC | DFS/TPC | No |
| 128 | 5640 | No | DFS/TPC | DFS/TPC | No |
| 132 | 5660 | DFS | DFS/TPC | DFS/TPC | No |
| 136 | 5680 | DFS | DFS/TPC | DFS/TPC | No |
| 140 | 5700 | DFS | DFS/TPC | DFS/TPC | No |
| 149 | 5745 | Yes | SRD | No | Yes |
| 153 | 5765 | Yes | SRD | No | Yes |
| 157 | 5785 | Yes | SRD | No | Yes |
| 161 | 5805 | Yes | SRD | No | Yes |
| 165 | 5825 | Yes | SRD | No | Yes |

**Fig. 2.2** Details of 5 GHz Unlicensed Channels in Different Regions.

power is defined as the mean Equivalent Isotropic Radiated Power (EIRP) of the equipment during a transmission burst. In general, the limits are valid for the device with antenna gain and cable loss and not only the output power of WLAN module.

## *2.3.1 RLAN band 1 (5150 to 5350 MHz)*

### **2.3.1.1 Indoor only Sub-band I (5150 - 5250 MHz)**

The first RLAN sub-band includes the channels 36 to 48 and has an EIRP power limit to 23 dBm (200 mW). These channels are considered for indoor only usage and do not require any Dynamic Frequency Selection (DFS) or Transmit Power Control (TPC) features.

#### 2.3.1.2 Indoor only Sub-band II (5250 - 5350 MHz)

In the second sub-band of the RLAN band 1 with channels 52 to 64, the ETSI has set the EIRP power limit to 23 dBm (200 mW) for devices with TPC and 20 dBm (100 mW) for devices without TPC. For a device with TPC, the mean EIRP at the lowest power level of the TPC range must not exceed 17 dBm (50 mW). This band requires DFS support and

### *2.3.2 RLAN band 2 (5470 to 5725 MHz)*

Channels from 100 to 140 are part of the second RLAN band and have an EIRP power limit of 30 dBm (1000 mW) for TPC and 27 dBm (500 mW) for non-TPC devices or 20 dBm (100 mW) for devices without any TPC or DFS support. The mean EIRP power level for a slave device with TPC must not exceed 24 dBm at the the lowest TPC power level if the device is also capable of radar detection or 17 dBm otherwise.

### *2.3.3 BRAN (5725 to 5875 MHz)*

ETSI has defined the channels 155 to 171 (155, 159, 163, 167, 172) for Broadband Wireless Access (BWA) use only. The idea is to give internet access to locations without any wired access network available. The maximum EIRP output power has been set to 36 dBm (4000 mW) with the limitation of RF power into antenna of 304 dBm (1000 mW).

## 2.4 Transmission Power Control (TPC)

Dynamic adjustment of the transmission power is intended to reduce RFI. Dynamically adjusting the transmission power facilitates the shared use of the 5250-5350 MHz and 5470-5725 MHz frequency bands with satellite services. TPC should cause an average reduction in the transmission power by at least 3 dB compared with the maximum permitted transmission power. TPC determines the minimum transmission power necessary to maintain the connection with the partner (such as an access point).
If TPC is not used within these frequency bands, then the highest permissible average EIRP and the corresponding maximum EIRP density are reduced by 3 dB. This restriction does not apply to the frequency range of 5150-5350 MHz. Without DFS and TPC, a maximum of only 30 mW EIRP is permitted. When DFS and TPC are used, a maximum 1000 mW EIRP is permitted as the transmission

power (compared with 100 mW with 802.11 b/g, 2.4 GHz, DFS and TPC are not possible here). The higher maximum transmission power not only compensates for the higher attenuation of 5 GHz radio waves in air, it also makes noticeably longer ranges possible than in the 2.4 GHz range.

## 2.5 Dynamic Frequency Selection (DFS)

DFS was stipulated to (i) detect interference from radar systems (radar detection) and to avoid co-channel operation with these systems; and (ii) to provide on aggregate a near-uniform loading of the spectrum (Uniform Spreading). DFS is stipulated for the frequency ranges of 5250-5350 MHz and 5470-5725 MHz. It is optional for the frequency range of 5150-5250 MHz.
DFS initially assumes that no channel is available in the corresponding frequency band. The WLAN device selects an arbitrary channel at the start and performs what is known as a Channel Availability Check (CAC). Before sending to a channel for 60 seconds (Channel Observation Time, COT), a check is run to see if a different device is already working on this channel and the channel is therefore occupied. If this is the case, then a different channel is checked by the CAC. If not, then the WLAN device can perform the transmission operation. Even during operation, a check is run to see if a primary application such as a radar device is using this channel. This exploits the fact that radars frequently work according to the rotation method, whereby a tightly bundled directional transmission signal is transmitted by a rotating antenna. A remote receiver perceives the radar signal as a short pulse (radar peak). If a device receives such a radar peak, it pauses the transmission operation and monitors the channel for further pulses. If additional radar peaks occur during the COT, then a new channel is selected automatically. A check of this type is required to be carried out every 24 hours. This is why interrupting the data transmission for 60 seconds is unavoidable.

## 2.6 Channel Access Mechanisms

In order to avoid channel collisions when two or more than two devices transmit the signal in the same channel at the same time, Listen Before Talk (BLT) strategy is employed. ETSI EN 301 893 V1.7.2 [1] describes two mechanisms that require an equipment or a device to apply CCA before using the channel. The first mechanism is Frame Based Equipment (FBE) which defines a fixed (not directly demand-driven) timing frame for channel access. The second mechanism is Load Based Equipment (LBE) which defines demand-driven timing frame.

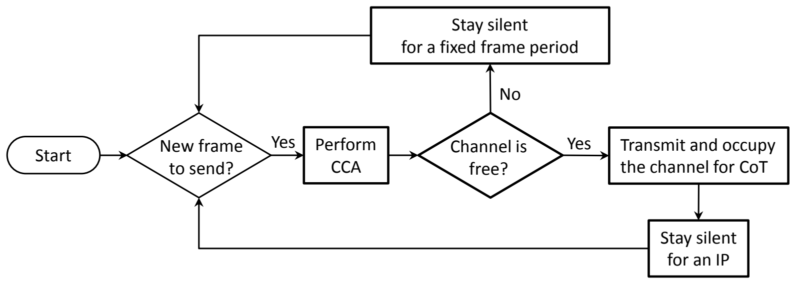


**Fig. 2.3** Simplified flowchart of FBE.

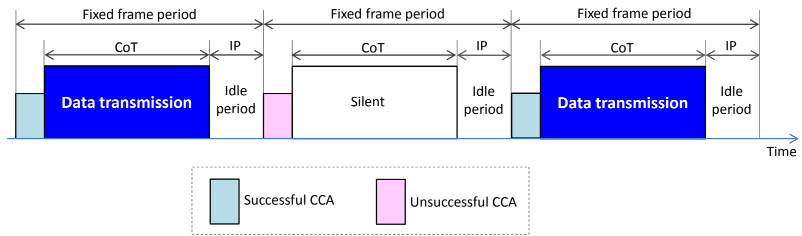


**Fig. 2.4** An illustrative example of FBE.

### *2.6.1 FBE-based Mechanism*

FBE shall comply with the following requirements:

- *R1:* Before starting transmissions on an operating channel, the equipment shall perform a CCA check using Energy Detect (ED). The equipment shall observe the channel for the duration of the *CCA observation time*. The operating channel shall be considered occupied if the energy level in the channel exceeds the *threshold* corresponding to the power level.
- *R2:* If the CCA procedure finds the channel clear, the equipment may transmit immediately and occupy the channel for a *fixed time period*.
- *R3:* If the CCA procedure finds the channel occupied, the equipment shall not transmit on that channel during the next fixed frame period.
- *R4:* The total time during which an equipment has transmissions on a given channel without re-evaluating the availability of that channel is defined as the *Channel Occupancy Time* (CoT).
- *R5:* After occupying the channel for CoT, the equipment keeps silent and waits for a short time, namely *Idle Period* (IP).
- *R6:* Towards the end of the idle period, the equipment shall perform a new CCA procedure as described in R1 above.
- *R7:* The equipment, upon correct reception of a packet which was intended for this equipment, can skip CCA and immediately proceed with the transmission

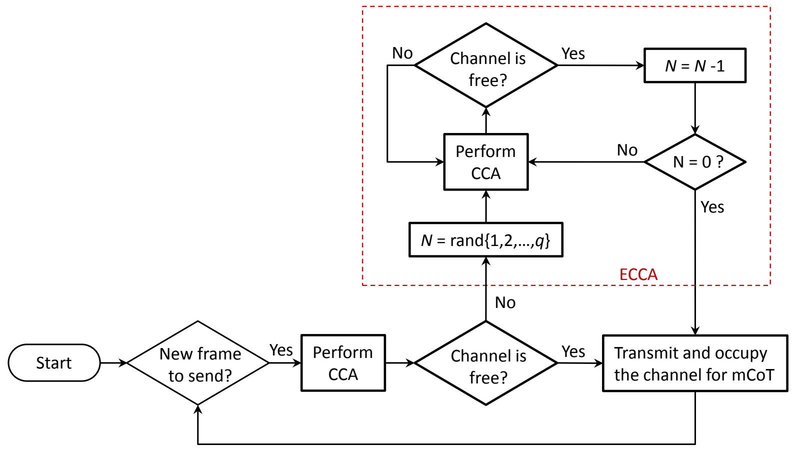


**Fig. 2.5** Simplified flowchart of LBE.

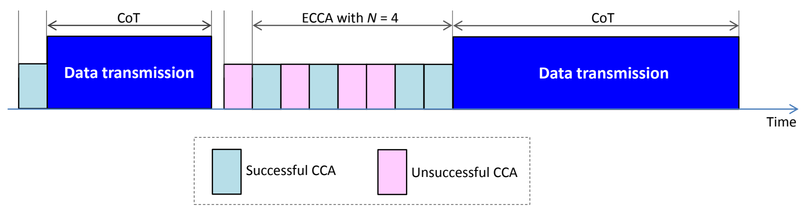


**Fig. 2.6** An illustrative example of LBE.

of management and control frames, e.g., acknowledgment (ACK) and block ACK frames.
- *R8:* A consecutive sequence of such transmissions by the equipment, without it performing a new CCA, shall not exceed the maximum CoT.
- *R9:* CCA observation time shall be not less than 20 $\mu$s.
- *R10:* CoT shall be in the range from 1 ms to 10 ms.
- *R11:* The minimum IP shall be at least 5% of CoT used by the equipment for the current fixed frame period.

A simplified flowchart and an illustrative of FBE are given in Figs. 2.3 and 2.4, respectively.

### *2.6.2 LBE-based Mechanism*

LBE shall comply with the following requirements:

- *R1:* Before starting transmissions on an operating channel, the equipment shall perform a CCA check using ED. The equipment shall observe the channel for the duration of the *CCA observation time*. The operating channel shall be considered occupied if the energy level in the channel exceeds the threshold corresponding to the power level.
- *R2:* If the CCA procedure finds the channel clear, the equipment may transmit immediately on that channel.
- *R3:* If the CCA procedure finds the channel occupied, it shall not transmit in that channel. The equipment shall perform an Extended CCA (ECCA) procedure in which the channel is observed for a random duration.
- *R4:* If the ECCA procedure has determined the channel to be clear, the equipment may start transmissions on this channel.
- *R5:* The total time that an equipment makes use of the channel (without performing CCA) is the *maximum Channel Occupancy Time* (mCoT), after which the device shall perform a new CCA procedure as described in R1 above.
- *R6:* The equipment, upon correct reception of a packet which was intended for this equipment, can skip CCA and immediately proceed with the transmission of management and control frames, e.g., ACK and block ACK frames.
- *R7:* A consecutive sequence of transmissions by the equipment, without it performing a new CCA, shall not exceed mCoT.
- *R8:* CCA observation time shall be not less than 20 $\mu$s.
- *R9:* The random duration in an ECCA procedure is $N\times$ (CCA observation time), where $N$ is randomly selected in the range $\{1,2,...,q\}$, $q \in \{4,5,...,32\}$ (declared by the manufacturer).
- *R10:* mCoT should be less than $(13/32) \times q$ ms (mCoT is in the range from 1.625 to 13 ms).

A simplified flowchart and an illustrative of LBE are given in Figs. 2.5 and 2.6, respectively.

## References

1. *ETSI EN 301 893 V1.7.2 (2014-07): Broadband Radio Access Networks (BRAN); 5 GHz high performance RLAN; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive*, European Telecommunications Standards Institute Std., 2014.