



Opportunities and Enabling Technologies for 5G and Beyond-5G Spectrum Sharing

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Abstract

In this paper an overview is given of the current status of 5G industry standards, spectrum allocation, and use cases, followed by initial investigations of new opportunities for spectrum sharing in 5G and the underlying technologies to enable efficient sharing, considering both licensed and unlicensed scenarios and spectrum both below 6 GHz and in the millimeter-wave frequency range.

Keywords

5G NR · Millimeter wave · Spectrum · 3GPP · ITU · Cognitive radio · LLA · LSA · CBBS

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What Is 5G?

5G is the next generation of mobile communications technology and is being designed to provide (in comparison with 4G) greater capacity and faster data speeds and offer very low latency and very high reliability, enabling innovative new services across different industry sectors. The first wave of 5G commercial products is expected to be available in 2020 although some “pre-5G” deployments are already expected in 2018. 5G technology standards are currently under development and will include both an evolution of existing (4G) and new radio technologies (5G NR).

5G Use Cases

According to the International Telecommunication Union ITU [4] who has defined the vision and requirements of IMT2020 [1], potential 5G services and applications can be grouped into three different classes:

- **Enhanced Mobile Broadband.** Together with an evolution of the services already provided by 4G, 5G is expected to provide much faster and more reliable mobile broadband, offering a richer experience to consumers for application such a virtual reality (VR) and augmented reality (AR) as well as cloud-based services. The specific requirements are a minimum of 100 Mbps user-experience data rates and 20 Gbps peak data rate.
- **Massive Machine-Type Communications.** The Internet of Things (IoT) – where sensors, actuators, consumer electronics appliances, street lighting, etc. wirelessly connect to the Internet and each other. This is already happening on existing 4G networks, and the technology is being used in everything from smart homes to wearables. 5G should help the evolution of IoT services and applications and improve the interaction between different platforms as well as enable the vision of 50 billion devices becoming connected by 2030. Possible future applications could include real-time health monitoring of patients, optimization of street lighting to suit the weather or traffic, and environmental monitoring and smart agriculture. Data security and privacy issues will need to be considered given huge amounts of data could be transferred over a public network. We note that many IoT services are already being offered or will be offered in the next few years over existing and evolved 4G networks, e.g., using narrowband IoT (NB-IOT), LTE-M, or NB-LTE-M technologies. 5G, in this area, is likely to kick in by about 2025 where we expect to see through the explosion of new IoT services for which the evolution of LTE is unable to address the required scalability requirements.
- **Ultrareliable and low-latency communications.** This class is likely to rely on the new radio developments and includes services requiring a very high

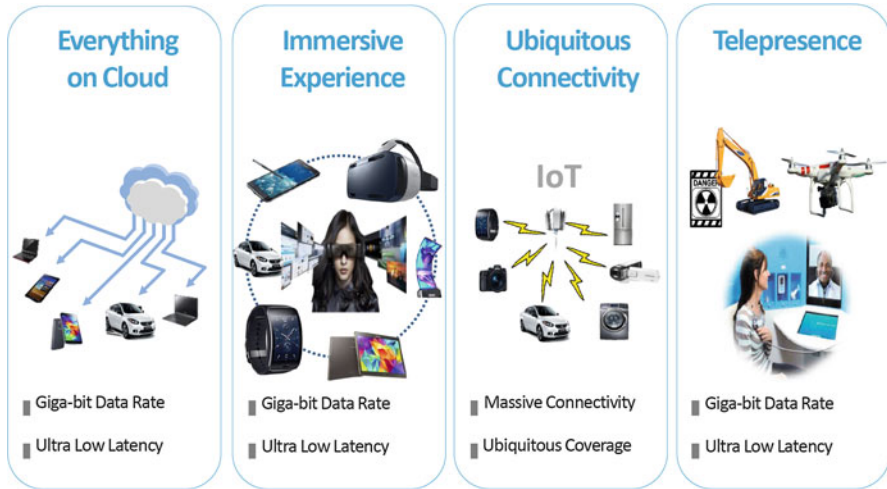


Fig. 1 Exemplar use cases of 5G and their requirements

reliability and/or a very low latency. Possible applications include connected and autonomous cars and aerial vehicles, remote control of robots in extreme conditions and hazardous situations and for industry automation (Industry 4.0), remote surgery, and the so-called tactile Internet as well as some of the applications in the context of smart grids.

These different services have different requirements in terms of speed, coverage, latency, and reliability, which will demand different network solutions (the evolution of existing network and potentially new networks) and different deployment models (including many small cells), an appropriate network infrastructure (which will include both fiber and wireless connectivity to the core network), and access to different spectrum bands. Therefore, the concept of network slicing is being put forward, where different slices of the overall 5G network infrastructure (including spectrum) may be allocated to different types of services to end users (Fig. 1).

We note that in addition to the above three categories of 5G use cases, perhaps surprising a new use case for 5G, the so-called fixed wireless access (FWA) or fiber-like wireless, has recently emerged [2,3]. FWA refers to the provision of high-data-rate (>100 Mbps) broadband wireless access to residential customers and enterprise premises using pre-5G/5G access technologies, including full-dimensional MIMO (FD-MIMO), massive MIMO, and millimeter-wave radio access technologies. The FWA concept has been around for quite a long time (being known also as wireless local loop), but only with 5G the techno-economic case for this use case has become a compelling alternative to wired solutions, such as next-generation cable, copper-based G-fast, and Fiber-to-the-Premises (FTTP) (Fig. 2).



Fig. 2 5G fixed wireless access architecture

Radio Access Technologies for 5G

Different from previous generations, where a new radio access technology replaced the old one, 5G will integrate different radio technologies. Some of these will be the evolution of already existing radio access technologies; some will be new. Different service classes could rely on different radio interfaces. Evolutions of the latest version of the 4G radio interface (LTE-Advanced Pro) are likely to be used to provide a coverage layer via macro cells. A new cellular radio interface (being developed in 3GPP under the name “New Radio” or “NR”) operating in frequencies up to 50 GHz will be used to provide very high data rates and ultralow latencies and to serve a very large number of devices via a large number of small cells. Low-cost, low-battery consumption IoT services are likely to be delivered initially using evolved 4G technologies, as described in the Introduction, with a gradual transition/phaseout to 5G by 2025. Wi-Fi evolutions will also play an important role for consumers, in particular to provide 5G services within homes or offices. In addition it is also expected that satellite technologies also play a role in 5G, in particular for wide area coverage in IoT application space (e.g., tracking of goods and vehicles) and also as a mechanism to off-load broadcast and multicast linear TV traffic from 5G cellular networks.

5G Standards Timelines

Figure 3 shows the latest (as of 25/06/2017) timeline of 3GPP (Third Generation Partnership Project), which is responsible for developing a global industry standard for 5G mobile communication technologies. As can be seen from this figure, 5G phase 1 standards, which are mainly focusing on enhanced mobile broadband (eMBB) with some element of ultralow latency included, are expected to be ready mid-2018, with an initial “non-stand-alone” version of the standard to be released already by the end of 2017. The second phase of 5G technology, which encompasses massive machine-type communications and ULL, is expected to be ready by the end

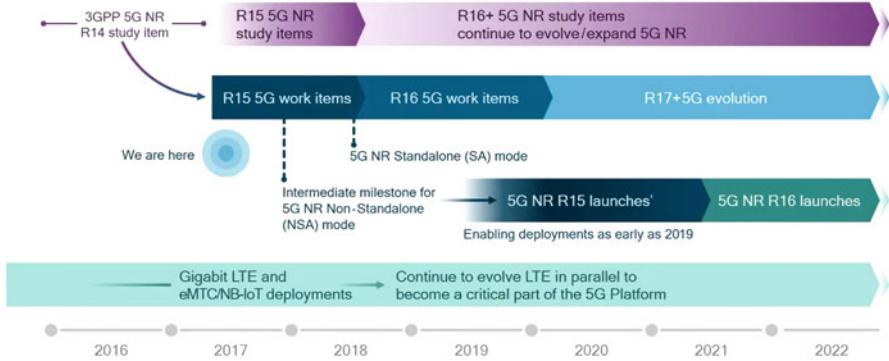


Fig. 3 5G standardization timeline according to 3GPP

of 2019, in time for the standard to be proposed to ITU as a candidate technology which fulfils the IMT 2020 requirements.

Spectrum for 5G

Spectrum is a critical component of wireless networks. It makes up the “airwaves” that underpin the communication services we use every day, such as mobile, Wi-Fi, and TV. The diverse set of 5G services and applications, described above, will require a diverse set of spectrum bands, with different characteristics, addressing different requirements and combining both low and high frequencies:

- Spectrum at lower frequencies, and in particular below 1 GHz, to enable 5G coverage to wide areas;
- Spectrum at higher frequencies with relatively large bandwidths below 6 GHz, to provide the necessary capacity to support a very high number of connected devices and to enable higher speeds to concurrently connected devices; and
- Spectrum at very high frequencies above 24 GHz (e.g., millimeter wave) with very large bandwidths, providing ultrahigh capacity and very low latency. Cells at these frequencies will have smaller coverage (between 50 and 200 m), and it is likely that build-out of 5G networks in millimeter wave bands will initially be focused on areas of high traffic demand or to specific locations or premises requiring services with very high capacity and/or peak data rates (Gbps) (Fig. 4).

5G Spectrum Allocation

The 2015 World Radio Congress (WRC-15) agreed on a WRC-19 agenda item (1.13) to consider the identification of frequency bands for the future development of International Mobile Telecommunications (IMT), including possible additional

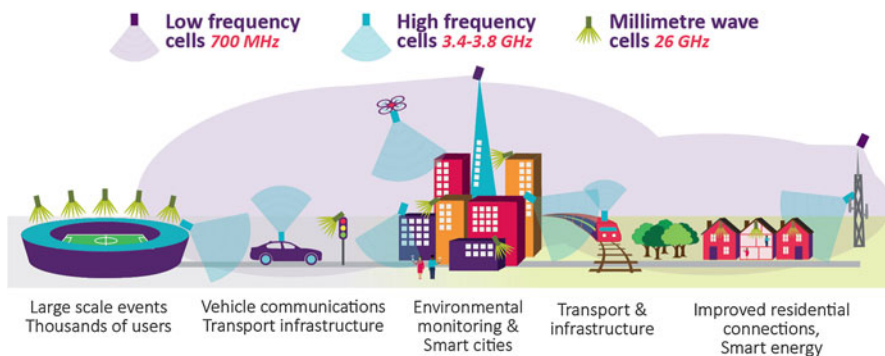


Fig. 4 Radio spectrum for 5G and its uses [Ofcom]

allocations to the mobile service on a primary basis, in accordance with Resolution 238 (WRC-15). This involves conducting and completing the appropriate sharing and compatibility studies for a number of bands between 24 and 86 GHz in time for WRC-19. The compatibility and sharing studies for these bands are being carried out in ITU-R Task Group 5/1 until 2018. This follows work in ITU-R on spectrum needs, deployment scenarios, sharing parameters, and propagation models which were completed in March 2017.

Candidate bands identified for further study in WRC-15 are shown in Fig. 5. It can be seen that there are regional differences, and in particular in the 20–30 GHz range, it can be expected that the 27.5–29.5 band will be only available in Americas, while other regions, including Europe, are likely to converge around the 24.25–27.5 range.

In parallel on the European level, Radio Spectrum Policy Group (RSPG) has developed in 2016 a strategic road map for 5G in Europe. In particular, the road map identified the following building blocks for 5G:

- Low-bandwidth spectrum at **700 MHz**; Medium-bandwidth spectrum at **3.4–3.8 GHz** as a “primary” band, which will provide capacity for new 5G services; and
- High-bandwidth spectrum at **24.25–27.5 GHz** as the “pioneer” millimeter wave band to give ultra-high capacity for innovative new services, enabling new business models and sectors of the economy to benefit from 5G. In addition, a European Commission Mandate to CEPT was approved by member states with regard to the development of harmonized technical conditions in two “pioneer” bands: 3.4–3.8 GHz and the 26 GHz band.

Frequency Ranges Below/Above 6 GHz of by Region (WRC-15)

| | Below 6GHz | | Above 6GHz/mm-Wave | | | | | | | |
|----------------------------|----------------------------|------------|--------------------|--|----------------------------|---|----------------|--------------------|---------|--------|
| | < 6GHz (MHz) | | 6-20 | 20-30 | 30-40 | 40-50 | 50-60 | 60-70 | 70-80 | 80-100 |
| APAC (APT) | 1427 - 1452 1492 - 1518 | | | 25.25 - 25.5 | 31.8 - 33.4 | 39 - 47 47.2 - 50.2 | 50.4 - 52.6 | 66 - 76 | 81 - 86 | |
| Europe (CEPT) | 1427 - 1518 3400 - 3800 | | | 24.5 - 27.5 | 31.8 - 33.4 | 40.5 - 43.5 45.5 - 48.9 | | 66 - 71 71 - 76 | 81 - 86 | |
| Americas (CITEL) | 1427 - 1515 3488 - 3600 | 10 - 10.45 | | 23.15 - 23.6 24.25 - 27.5 27.5 - 29.5 | 31.8 - 33 37 - 40.5 | 45.5 - 47 47.2 - 50.2 | 50.4 - 52.4 | 59.3 - 76 | | |
| Russia (RCC) | 5925 - 6425 | | | 25.5 - 27.5 | 31.8 - 33.4 39.5 - 40.5 | 40.5 - 41.5 45.5 - 47.5 48.5 - 50.2 | 50.4 - 52.4 | 66 - 71 71 - 76 | 81 - 86 | |
| Mid. East (ASMG) | 1452 - 1518 3400 - 3600 | | | | | | 31 - 100 | | | |

※ APT : Asia-Pacific Telecommunity (APT)
 CITEL : Inter-American Telecommunication Commission
 ASMG : Arab Spectrum Management Group
 CEPT : European Conference of Postal and Telecommunications Administrations
 RCC : Regional Commonwealth in the Field of Communications (Russia etc.)

Fig. 5 Candidate frequency bands for 5G as identified in WRC15

5G Spectrum Sharing

Sharing Below 6 GHz Spectrum

While above 6 GHz large chunks of spectrum are expected to become available for 5G systems, the amount of spectrum the sub-GHz and below 6 GHz range is far more limited. The sub-6GHz band is expected to support important applications of 5G, such as machine-type communications due to excellent propagation and indoor penetration characteristics, while the first wave of 5G mobile communication systems are expected to be deployed in 3.6 GHz frequency range, where in conjunction with the use of massive MIMO and full-dimensional MIMO (FD-MIMO) technologies 100Mbps+ data rates could be supported while also keeping cell sizes sufficiently large for viable deployment. It is, therefore, of great importance to explore options for the sharing of these very precious portions of 5G spectrum.

Due to quality of service requirement of 5G use cases that are expected to be supported, a very important option for the sharing of these bands is the evolution of Licensed Shared Access (LSA) [5]. In this approach licensed users, called LSA licensees, can access underutilized licensed spectrum on an exclusive basis, thus enjoying predictable QoS, when it is not being used by the incumbent, hence protecting it from harmful interference.

In 2017, the Federal Communications Commission (FCC) opened up 150 MHz of spectrum in the USA around 3.5 GHz that it named *Citizens Broadband Radio Service (CBRS)* [12]. Similar to the LSA approach, CBRS enables others to use the spectrum while it is still being used by existing incumbents, such as the military or satellite communication (see Fig. 6). However, in addition to sharing with incumbents – CBRS adds a “third tier” of general usage. In this third tier, anyone can use the spectrum when it is not used by the higher tiers (the incumbents or users that paid for a license) (see Fig. 2). Of course, if there are multiple third-tier users in the same area, then they will share the available spectrum with each other in a fair manner. The complexity of managing three tiers will require some additional control. To this effect, the FCC has defined a Spectrum Access System (SAS) – a type of database, in effect – and the *Wireless Innovation Forum* is helping to specify the details to ensure that it all works in accordance with the FCC rules.

CBRS can be used by existing mobile operators to offer Gigabit LTE in more places by making more spectrum available. One can also use this spectrum for small-cell deployments to extend coverage and add capacity indoors. Another foreseen



Fig. 6 CBRS spectrum sharing scenario in 3.5 GHz between an incumbent system (in this case Navy radar) and secondary users

use is the so-called neutral host, which is a LTE deployment that can be used by subscribers irrespective of their service provider.

Sharing mm-Wave Spectrum

Millimeter-wave (mm-wave) communications have emerged as a key disruptive technology for both cellular networks (5G and beyond) [6] and wireless local area networks (802.11ad and beyond). While spectrum availability is limited in traditional bands below 6 GHz, mm-wave frequencies offer order of magnitude greater bandwidths. In addition, mm-wave communication is typically characterized by transmissions with very narrow beams, enabling further gains from directional isolation between mobiles. This combination of massive bandwidth and spatial degrees of freedom may make it possible for mm wave to meet some of the boldest 5G requirements, including higher peak per user data rate, high traffic density, and very low latency. The use of mm-wave bands for 5G presents a number unique features not present at lower frequencies:

- **Beamforming as a mandatory requirement:** A common characteristic of all systems operating in mm-wave frequencies is that beamforming is mandatory to compensate for the significantly higher path loss in these frequencies. For example, the IEEE 802.11ad standard supports up to 4 transmitter antennas, 4 receiver antennas, and 128 sectors. Beamforming is mandatory in 802.11ad, and both transmitter-side and receiver-side beamforming are supported. Furthermore specification of beamforming for 5G is expected to be finalized by 3GPP, as part of 5G New Radio (NR) work item. Consequently, beams provide a common new dimension for the sharing of spectrum among multiple access technologies.
- **Potential for “infinite” spatial reuse:** Wireless communications systems already rely on spatial sharing of spectrum in two dimensions, and the entire concept of cellular communications relies on spatial reuse of radio spectrum. In mm-wave systems with the use of transmit-side and receive-side beamforming, spatial spectrum reuse can be pushed even further down close to one dimension, which the footprint of interference from each transmission link becoming very close to the line, rather than an area, in two dimensions. In the idealized case of ultra-narrow beams, this would allow infinite spatial reuse of spectrum.

Sharing with Satellite Services

FSS (Fixed Satellite Service) is the official classification for geostationary communications satellites that provide, for instance, broadcast feeds to television stations, radio stations, and broadcast networks. The FSS uplink (from FSS to satellite) is allocated in the band from 27.5 to 30 GHz, which is adjacent to the 24.25–27.5 GHz band identified for 5G. Therefore, there could be potential issues with the

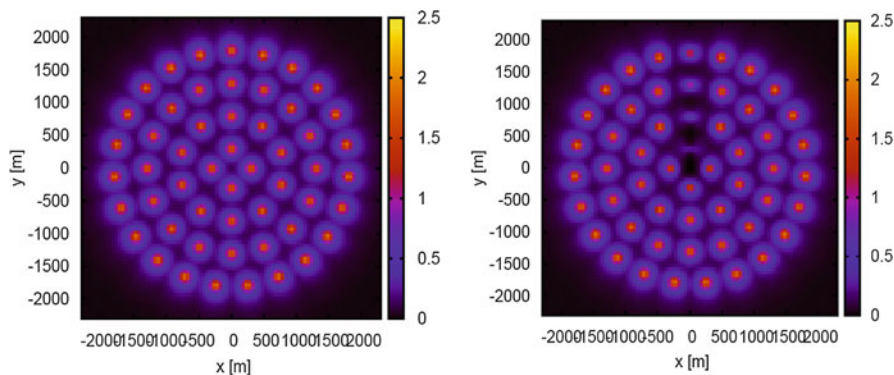


Fig. 7 Impact of FSS uplink transmission on the coverage of a mm-wave 5G network in the worst-case co-channel sharing of 28 GHz spectrum. Coverage maps are shown in the absence (left panel) and presence (right panel) of a FSS's highly directional transmitter positioned at the center of the area

sharing between 5G and FSS due to adjacent channel interference. Several cognitive techniques can be applied to mitigate and improve the 5G-FSS coexistence.

The coexistence between FSSs and mobile cellular BSs in the mm-wave bands has been the subject of only few, and mainly theoretical, studies. Important new parameters that need to be considered are how the interference levels could be reduced by exploiting multiple antenna configurations by 5G mm-wave systems as well as investigating the aggregate interference resulting from massive deployment of 5G systems on uplink FSS. The studies in [7, 8], performed in the worst-case scenario of co-channel sharing, have indicated that due to the use of a beamforming technology, combined with the relatively short range of communications in mm-wave frequencies, spatial sharing is much more feasible than in the case of IMT-advanced systems. In particular, even in this worst-case scenario, the required protection distance around FSS is much smaller (~1 km as opposed to hundreds of km) than those recommended previously. Furthermore, by using coordination among multiple 5G BS, further gains in spectrum sharing can be achieved. These studies also indicate that the presence of highly directional FSS transmission can cause outage in the coverage of 5G mm-wave network. However, due to the highly directional FSS transmission, the outage region is well-confined, and its impact could be mitigated using a combination of null forming at 5G UEs and cooperation by multiple BS to boost signal strengths at the victim UE (Fig. 7).

Sharing Between Access and Backhaul (Fixed) Links

The 26 GHz frequency range is used in many countries for 4G backhaul links, also known as fixed links (FL). Therefore it is of prominent importance to investigate the compatibility of using the 24.25–27.5 GHz for 5G access. A recent study of coexistence between FL and 5G access links has been performed by Ofcom [ofcom]. The study considered the deployment of 5G mm-wave base stations (BS) in London

overlaid on the existing FS deployment. It was assumed that, to avoid harmful interference to FS links, 5G BS can only operate if they are outside the denial area of FS links. Denial areas were assumed to be circular and were derived from interference analysis of a single 5G BS on a single FS link (Fig. 8).

The analysis shows that, in the non-LoS case, 5G BS would not be able to be rolled out within 0.5 km of a typical FL without a 20% probability of causing unacceptable levels of interference in all directions. This probability significantly increases in the pointing direction of the FL, while the distance at which a 20% probability of causing unacceptable levels of interference increases to 1.2 km. Therefore, to ensure that unacceptable interference was not caused to this incumbent FL, this area would have to be denied to IMT-2020 BSs. In fact, dependent on the requirements of the incumbent FL and what probability of interference they were willing to accept, this denial area may need to be significantly larger.

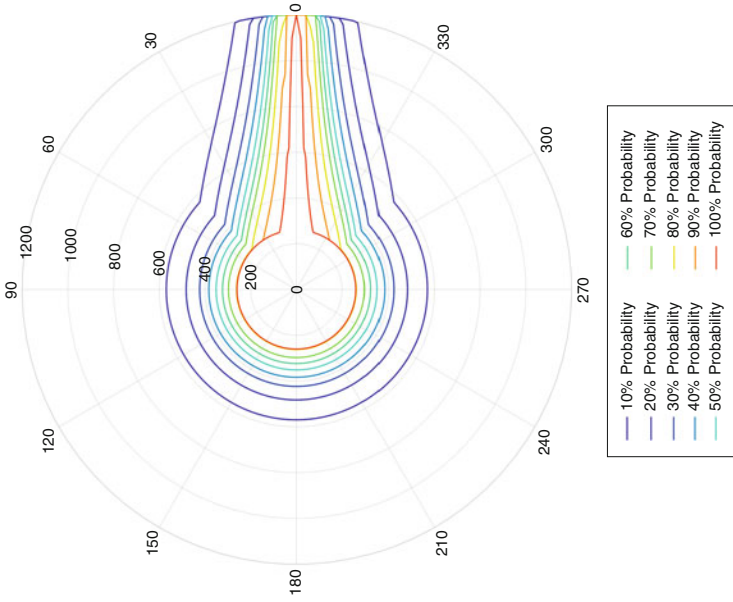
Figure 9 shows what impact this denial area would have on a mobile operator wanting to deploy 5G BSs in an urban conurbation, provided they were willing to ensure that their 5G BS did not have LoS to any FL. In this figure a denial area of 1.2 km is placed over all FLs in London which overlap with the block of 400 MHz of spectrum from 24.5 to 24.9 GHz (shown in red).

Sharing Unlicensed mm-Wave Spectrum

A recent trend in cellular communication is to utilize both the licensed and unlicensed spectrum simultaneously for extending available system bandwidth. In this context, LTE in unlicensed spectrum, referred to as LTE-U, is proposed to enable mobile operators to off-load data traffic onto unlicensed frequencies more efficiently and effectively and provides high performance and seamless user experience. Integration of unlicensed bands is also considered as one of the key enablers for 5G cellular systems. However, unlike the typical operation in licensed bands, where operating base stations (BS) have exclusive access to spectrum and therefore are able to coordinate by exchanging of signalling to mitigate mutual interference, such a multi-standard and multi-operator spectrum-sharing scenario (as shown in Fig. 4), this imposes significant challenges on coexistence in terms of interference mitigation. Licensed Assisted Access (LAA) with listen-before-talk (LBT) protocol has been proposed for the current coexistence mechanism of LTE-U. In case of mm-wave unlicensed sharing, a major issue is that the use of highly directional antennas as one of the key enablers for 5G networks becomes problematic for the current coexistence mechanisms where omnidirectional antennas were mostly assumed. For example, as shown in Fig. 10, transmission by a different nearby 5G BS or WiGig access point (AP) may not be detected due to the narrow beam that has been used, resulting in “beam collision” which can cause even more excessive interference than in conventional systems (Fig. 10).

We note that such beam-collision interference scenarios can also occur in exclusively used mm-wave spectrum as well. However in such scenarios, centralized resource allocation algorithms from 4G can be extended to include beam scheduling among multiple base stations to avoid such excessive interference scenarios. In the case of unlicensed sharing of mm-wave spectrum, centralized coordination is

Non-LoS - Probability of the IMT-2020 BS Causing Interference which exceeds the FL Interference Threshold Requirement - FL Gain = 36.6 dBi, FL BW = 2.5 deg, FL HAG = 15 m



LoS - Probability of the IMT-2020 BS Causing Interference which exceeds the FL Interference Threshold Requirement - FL Gain = 36.6 dBi, FL BW = 2.5 deg, FL HAG = 15 m

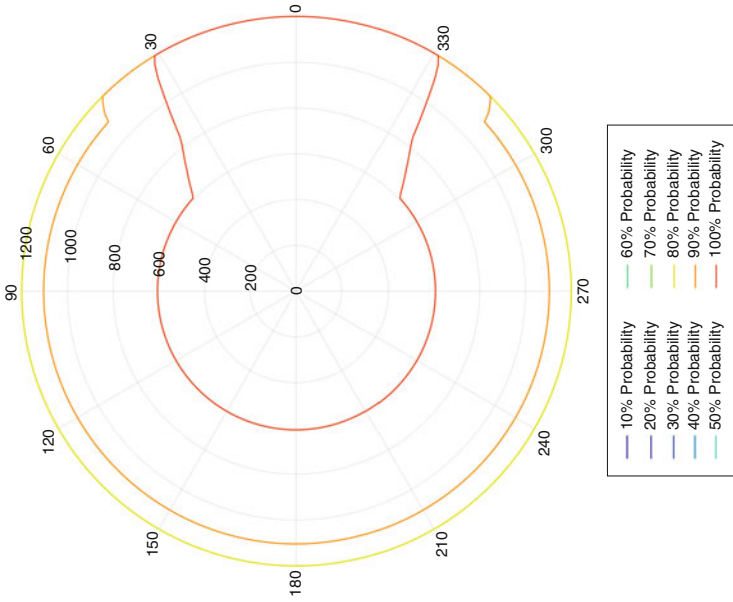


Fig. 8 Contour plots showing the probability of a 5G base station causing harmful interference to a fixed link operating in 26 GHz assuming line-of-sight (left panel) and non-line-of-sight (right panel) results [11]

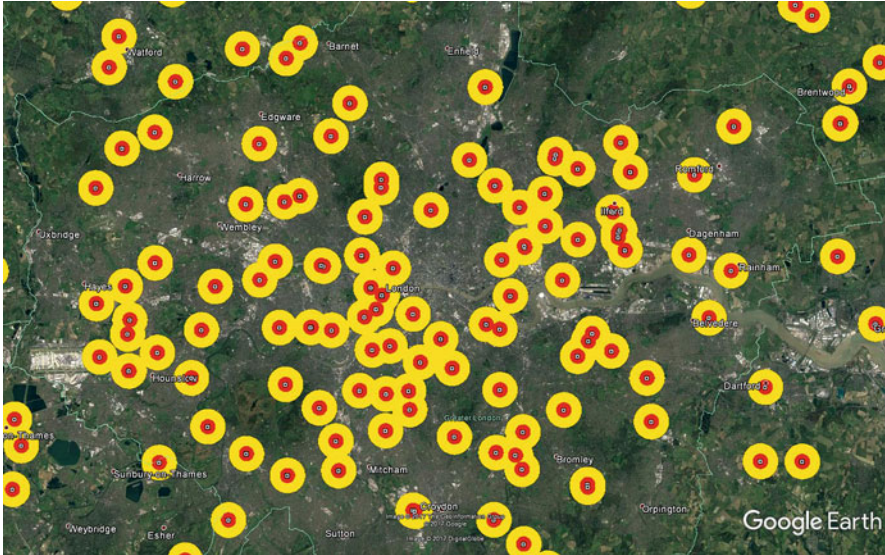
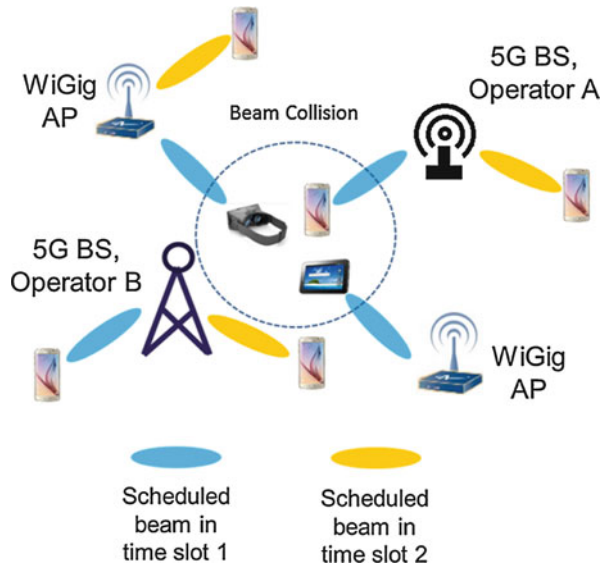


Fig. 9 Denial area within 1.2 km of all backhaul links in London operating in the 24.9 GHz [11]

Fig. 10 Multi-standard and multi-operator sharing of unlicensed mm-wave bands in future 5G systems, showing also a beam-collision interference scenario [9]



not possible, and novel mechanisms need to be developed. Work in this direction has only recently being started as part of a new study item in 3GPP 5G-NR which is expected to be completed in 2018 [10]. Various mechanisms for sharing are being proposed, including distributed and self-organized mechanism for beam coordination [9], and approaches based on spectrum pooling [13].

Conclusion

With industry standards for 5G cellular systems rapidly progressing and firming up, issues and challenges related to future sharing and coexistence of spectrum are starting to take a center stage. Furthermore, there is a strong desire from governments and regulators for efficient allocation and use of 5G spectrum. Therefore, given the maturity of technologies such as LSA, LLA, cognitive radio, and mm-wave communications, we can expect that spectrum sharing will be a very prominent area for innovation, standardization, and spectrum regulation in the next few years. Finally beyond 5G mm-wave frequencies, the World Radio Congress in 2019 is expected to consider new spectrum beyond 300 GHz [14], where new opportunities for spectrum sharing can be expected.

Cross-References

- ▶ [Cognitive Radio: The Need to Align Regulations with Technology](#)
- ▶ [Coexistence of Heterogeneous Cellular Networks](#)
- ▶ [Novel Regulatory Solutions for Cognitive Radio and Spectrum Sharing in the UK](#)
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