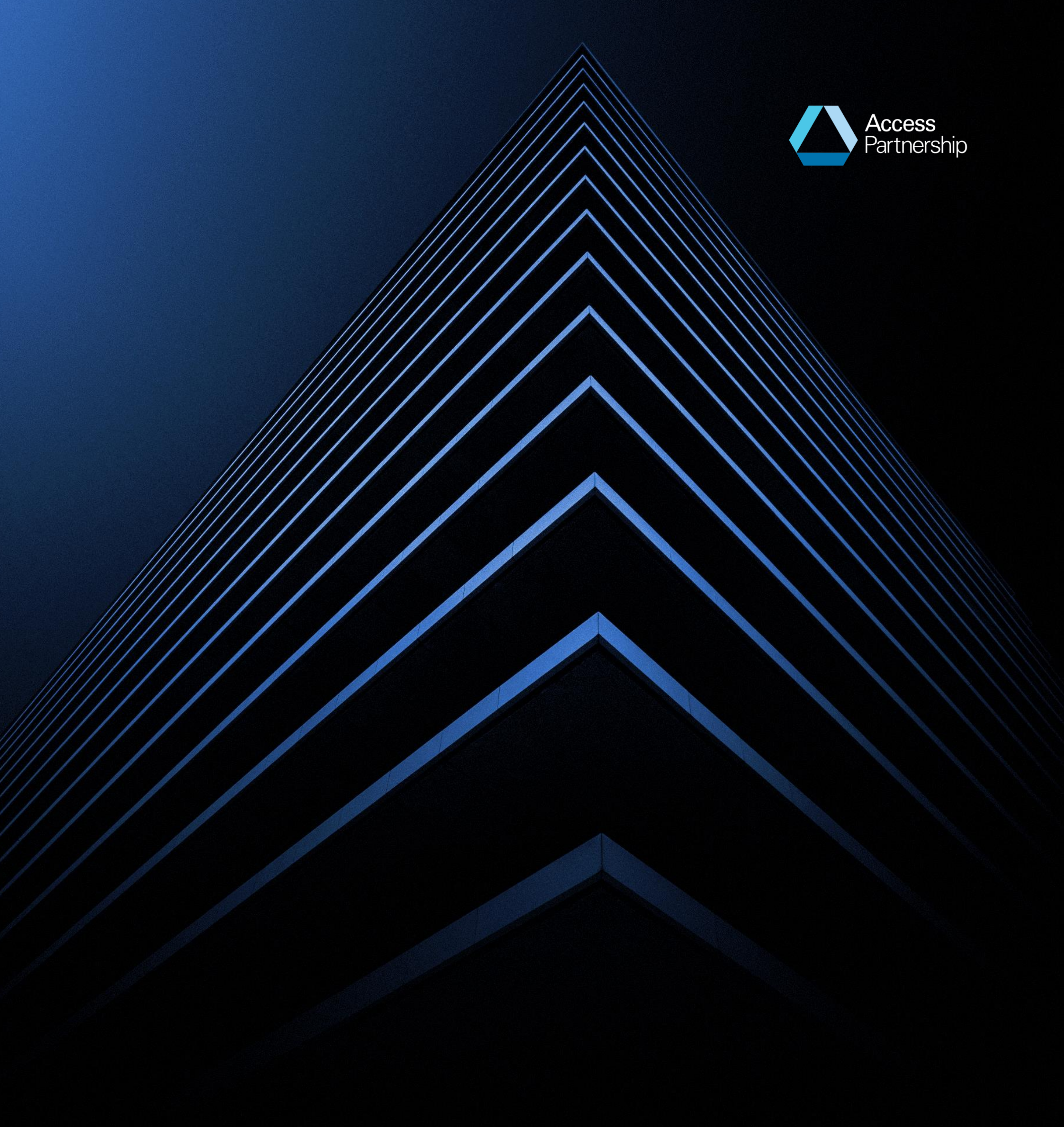
Access Partnership



The Future of Spectrum Sharing: From the Spreadsheet to the Algorithm

Contents

Introduction

With an increasing demand for high speed connectivity, wireless technologies have occupied wider bandwidths and taken up more spectrum than before. This has increased the pressure on regulatory agencies to allow spectrum sharing among multiple communication systems. As more bands are shared, interference scenarios become more complex and more sophisticated technologies are required to guarantee spectrum compatibility. This paper explores two technological developments which facilitate spectrum sharing: tiered spectrum access and advances in interference mitigation techniques. As an example of tiered spectrum access, the structure of the spectrum management systems proposed by CBRS is described followed by an overview of the research on the topic. This paper also describes how new technologies can reduce inter-system interference and allow sharing of new portions of spectrum. To that end, the 1755 – 1850 MHz band is used as an example. Annex 1 provides a complete frequency sharing study, developed by Access Partnership, between tactical radio relays and 4G/5G mobile networks in the 1755 – 1850 MHz band to illustrate how the development of communication technologies also has an impact on the possibility of spectrum sharing.

Contextualisation

Innovative applications and services continue to push the capacity of current wireless connectivity technologies to its limits, requiring increasingly higher data rates, lower latencies, and higher device densities from technologies which are currently deployed. Applications such as augmented and virtual reality, online gaming, machine to machine and ultra-reliable low-latency communications, drive growth in data traffic and, consequently, the need for spectrum. For this reason, estimations show that by 2022, mobile traffic per connection (including machine to machine and low power wide area technologies), will reach 6.3 gigabytes per month, with more than 12 billion mobile-connected devices globally.[1]

Figure 1: WiFi standards

Standard	Year released	Maximum Band width	Maximum Data rate
802.11	1997	20 MHz	2 Mbit/s
802.11b	1999	20 MHz	11 Mbit/s
802.11a	1999	20 MHz	54 Mbit/s
802.11g	2003	20 MHz	54 Mbit/s
802.11n	2009	40 MHz	450 Mbit/s
802.11ac	2013	160 MHz	1730 Mbit/s
802.11ax	2020	160 MHz	2400 Mbit/s

Technologies devised to meet this growth in demand, such as 5G[2], WiFi 6 and 6E[3] or Mega LEO constellations[4], utilize novel coding schemes, more aggressive modulations, advanced antenna designs and other strategies to increase spectrum efficiency and deliver more bits per second for each Hertz of available spectrum. However, it is common knowledge in communications engineering that occupying more spectrum is the simplest way to increase data rates, which is why most new generation communication standards allow for higher bandwidth transmissions than their predecessors.[5]

[1] Cisco (2020). *VNI Mobile Forecast Highlights Tool.* Available here.
[2] ITU (2019). *5G – Fifth generation of mobile technologies*. Available here.
[3] Wi-Fi Alliance (2020). *Wi-Fi Alliance® brings Wi-Fi 6 into 6 GHz*. Available here.
[4] Alessandro Guidotti et al (2018). *Integration of 5G technologies in LEO Mega-Constellations*. Available here.
[5] GSMA (2020). *5G Spectrum: GSMA Public Policy Position*. Available here.

The increasing demand for high speed, reliable connectivity has pushed regulators to make more spectrum available for cellular and local area network communications. For example, at the World Radiocommunication Conference 2019 (WRC-19), the International Telecommunications Union (ITU) identified a total of 17.25 GHz of spectrum for International Mobile Telecommunications (IMT).[6] Referred to by the ITU as IMT-2020, fifth generation mobile communications are a key component of the future network connectivity ecosystem. Another element is WiFi 6, which can utilize spectrum in the 6GHz band, previously unexplored by its predecessors, and channels of up to 160 MHz.[7] To accommodate WiFi 6 and other unlicensed applications, the US Federal Communications Commission has opened 1200 MHz of spectrum in the 5925 – 7125 MHz band.[8]

The pressure to make more spectrum available is also responsible for evolutions in spectrum sharing, with the use of new technologies and novel spectrum management techniques. On one hand, technologies are employing more directive radiation patterns that save energy and reduce the interference caused to other systems, that consequently facilitates spectrum sharing. At the same time, regulators are relying more on automatic frequency coordination and tiered spectrum access to automate and increase the density of spectrum sharing devices. One such initiative is the US Citizens Broadband Radio Service (CBRS), discussed in the next section.

The CBRS

In 2015, the FCC adopted rules for shared commercial use of the 3550 – 3700 MHz band (3.5 GHz band),[9] known as Citizens Broadband Radio Service (CBRS). Occupied by navy radar and other federal systems, the band was then shared with wireless carriers using CBRS to deploy 4G mobile networks without having to acquire spectrum licenses. The main form of interference mitigation is the division of 3.5 GHz band users into three tiers with different levels of priority and protection requirements: incumbents, priority, and general authorised access users.

At the lowest priority tier, CBRS has General Authorised Access (GAA) users. Permitted to use any portion of the 3.5 GHz not assigned to a higher priority tier and to operate opportunistically on unused channels. The GAA tier must not cause interference to and must accept interference from users in other tiers.. Applications such as local area networks for industry automation can take advantage of this tier's regulatory framework.

Next, the Priority Access tier consists of Priority Access Licenses (PALs), issued through a competitive bidding process.[10] Awarded in bands of 10 MHz for a renewable 10-year period, PALs must protect and accept interference from Incumbent Access users but receive protection from GAA users. Rural broadband connectivity is an example of an application that can be deployed in this tier.

[6] ITU (2019). *WRC-19 identifies additional frequency bands for 5G*. Available here.
[7] Evgeny Khorov et al (2018). *A Tutorial on IEEE 802.11ax High Efficiency WLANs*. Available here.
[8] Federal Communications Commission (2020). *Report and Order and Further Notice of Proposed Rulemaking*. Available here.
[9] Federal Communications Commission (2020). *3.5 GHz Band Overview*. Available here.
[10] Federal Communications Commission (2020). *Auction 105: 3.5 GHz*. Available here.

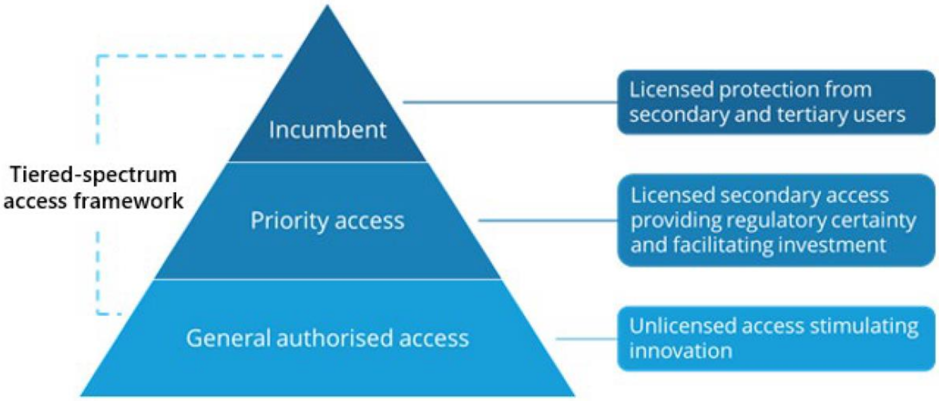


Figure 1: CBRS tiered spectrum access framework.[11]

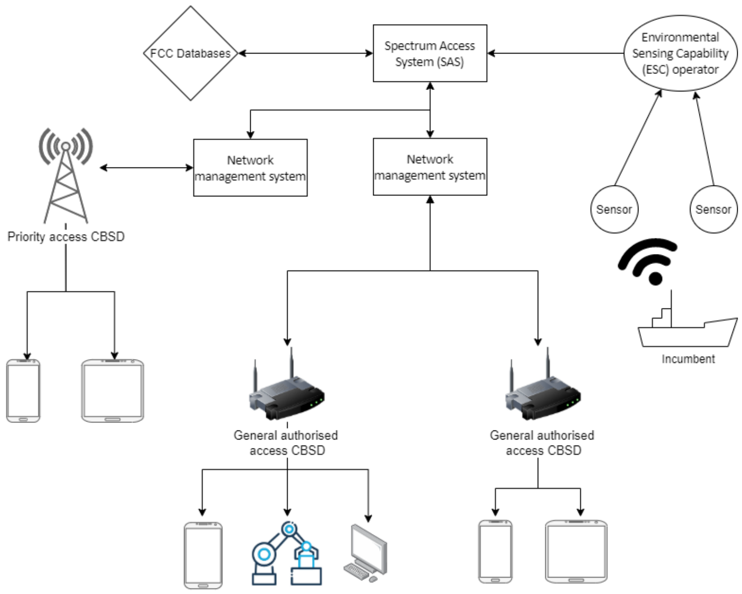


Figure 2: CBRS entities and their connections

The highest priority applications are the incumbent Federal systems, whose protection is the responsibility of all other systems utilizing the band. Some of these incumbents are satellite Earth stations,[12] but most are navy radar systems utilised by the US Department of Defence (DoD), which creates an extra level of complexity in the spectrum sharing scenario. The protection of radar systems on board of vessels depends on a reliable detection of the vessel's position and coordination of all other users to reduce emissions in the shared band when in the presence of an incumbent.

To address this, the CBRS created Spectrum Access Systems (SASs), to manage spectrum use requests at particular times and in certain areas, to ensure there is no interference between the three tiers. Data is collected from sensors based along the coast and at other strategical locations, to detect navy radar systems, which is managed and sold by the Environmental Sensing Capability (ESC) operators[13] to the SASs. The SASs are then able to dynamically coordinate the use of spectrum between the lower tier users. Furthermore, SASs also provide other services such as network planning tools, training, and certification.[14]

[11] Access Partnership (2020). *Spectrum Management: National Policies, Technology Advancements and Best Practices*. Available here.
[12] Federal Communications Commission (2020). *3.5 GHz Band – Protected Fixed Satellite Service (FSS) Earth Stations*. Available here.
[13] Fierce Wireless (2019). *Federal Wireless completes ESC network for CBRS*. Available here.
[14] Google (2020). *Spectrum Access Systems (SAS)*. Available here.

Figure 2 identifies the entities defined in CBRS. CBSD (CBRS Devices) are WiFi access points, LTE base stations, fixed wireless access station or any other type of equipment serving end users in the CBRS band. These are connected to network management systems (among other entities) which receive information on available frequency bands in their region from the Spectrum Access Systems. SASs take into consideration the positions of other CBSDs, location of incumbent services registered in FCC's databases and presence of incumbents, detected by ESC systems, when assigning frequency bands to CBSDs using algorithms defined in the standards.

The coordination between all these entities and networks requires agreed technical specifications and protocols. In 2015, members of the Wireless Innovation Forum[15] formed the Spectrum Sharing Committee to "facilitate the interpretation and implementation of FCC rulemaking to a level that allows industry and government to collaborate on the implementation of a common, well-functioning [CBRS] ecosystem."[16] The Committee, formed by approximately 300 engineers from 60 organisations, developed the 10 standards that form the basis for commercial operations within the 3.5 GHz band under CBRS. Besides specifications for PAL databases and CBSD testing, the standards also specify protocols for communication between SASs and CBSDs. All these developments have been supported by a growing body of research on the economic and technical aspects of tiered spectrum access, described in the next section.

Research

There is an extensive body of research investigating the performance, spectrum measurement markets and resource management algorithms of CBRS and tiered spectrum access. To analyse the performance of tiered spectrum networks, Chandrasekhar and Andrews[17] evaluated the QoS of macro-cell and femtocell networks when operating in a two-tier spectrum sharing scheme. By proposing a decentralised spectrum allocation policy, they demonstrate that "spatial reuse benefits […] result in nearly 50% spectrum reduction for meeting target per-tier data rates." Some publications study specific algorithms to optimise the performance of some applications over CBRS, such as adaptive video streaming,[18] while others consider how dynamic and static spectrum management can complement each other to increase the spectral efficiency of CBRS networks.[19] The extent or research covers a multitude of topics, from interference analysis between incumbents and lower tier services,[20] to the use of machine learning in tiered network spectrum access.[21]

Spectrum measurement markets for tiered spectrum access is also a significant research topic. As mentioned previously, CBRS allows for Environment Sensing Capability operators to gather and sell spectrum occupancy data to SASs who, in turn, use that data to coordinate spectrum sharing between the different tier networks. Some authors[22] have reviewed how the differences in the quality and price of

---

[15] Wireless Innovation Forum Webpage. Available here.
[16] Wireless Innovation Forum (2015). *Spectrum Sharing Committee Scope and Operations*. Available here.
[17] Vikram Chandrasekhar and Jeffrey G. Andrews (2008). *Spectrum Allocation in Two-Tier Networks*. Available here.
[18] Xiaoli Want et al (2015). *Adaptive video streaming over whitespace: SVC for 3-Tiered spectrum sharing*. Available here.
[19] Lukasz Kulacz et al (2019). *Coordinated Spectrum Allocation and Coexistence Management in CBRS-SAS Wireless Networks.* Available here.
[20] Neelakantan Krishnan et all (2017). *Coexistence of Radar and Communication Systems in CBRS Bands Through Downlink Power Control.* Available here.
[21] Matthew Tonnemacher. *Opportunistic Channel Access Using Reinforcement Learning in Tiered CBRS Networks*. Available here.
[22] Arnob Ghosh et al (2018). *Spectrum Measurement Markets for Tiered Spectrum Access*. Available here.

spectrum measurements impact the resulting market equilibrium between SASs. Studies have shown that "different qualities of measurements available to different SASs can lead to better economic welfare." Furthermore, results suggest that, for multiple firms to be sustained in the market, different quality measurements are necessary.

There is also a significant body of research on the resource managing algorithms and the protocols for communication between CBSDs and SASs. The importance of accurate, clutter-aware propagation models in the SAS resource managing algorithm was the topic of a presentation by Yi Hsuan at the Wireless Innovation Forum in 2018.[23] One of the conclusions presented was that, "without considering clutter, GAA coexistence function can create channel assignments that unnecessarily limit GAA spectrum available to CBSDs." Other papers[24] have studied the performance of the frequency allocation schemes proposed by the Wireless Innovation Forum, looking at the effects or propagation model, deployment density and different distribution of GAA power categories. An SAS end-to-end protocol is proposed by Kim et al[25] to activate dynamic exclusion zones for incumbent protection, manage primary/secondary devices and dynamically assign spectrum.

Developments in the frequency allocation algorithms and the communication protocols between networks and resource managers are key to increasing spectrum sharing and efficiency. Yet, interference mitigation techniques are just as important in reducing the impact that lower priority users will have on the incumbent services. Advancements in coding, spectrum sensing and antenna design allow for higher spectrum efficiency and robustness against interference, so much so that frequency bands previously deemed unsuitable for sharing, are now being occupied by more than one service.

The 1755 – 1850 MHz band

The 1755 – 1780 MHz band is an example of spectrum where sharing was initially considered infeasible before new technologies were developed to reduce the interference between different communication systems. Prior to the creation of CBRS, the US Department of Commerce studied multiple frequency bands[26] as potential spectrum for Wireless Broadband Systems. Among them, the 1755 – 1780 MHz band attracted particular interest from the industry. Corresponding to one of the LTE Extended Advanced Wireless Systems 3 (AWS-3) bands, the 1755 – 1850 MHz band is harmonised internationally for mobile operations. However, in the US it was allocated exclusively for Federal incumbents, such as fixed microwave communication systems, precision guided munitions, high-resolution video data links, TT&C for Federal Government space systems, data links for short range unmanned aerial vehicles, as well as land

---

[23] Yi Hsuan, Google (2018). *Impacts of Propagation Models on CBRS GAA Coexistence and Deployment Density*. Available here.

[24] Weichao Gao and Anirudha Sahoo. *Performance Study of a GAA-GAA Coexistence Scheme in the CBRS Band.* Available here.

[25] Chang Kim. *Design and Implementation of an End-to-End Architecture for 3.5 GHz Shared Spectrum*. Available here.

[26] US Department of Commerce (2010). *An Assessment of the Near-Term Viability of Accommodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, and 4200-4220 MHz, 4380-4400 MHz Bands*. Available here (last visited June 18 2020)

mobile robotic video functions, control inks for various land and water electric power management systems.

The possibility of allowing mobile services on the band had been studied previously in 2001,[27] and frequency sharing studies between 3G mobile communications and the incumbent systems were performed. However, the results suggested that "interference to both IMT-2000 and incumbent systems would preclude compatible operation in a large number of metropolitan areas and over large geographic areas of the country." For that reason, full-band sharing was not considered feasible. Figure 3 illustrates the interference scenario between the two systems.

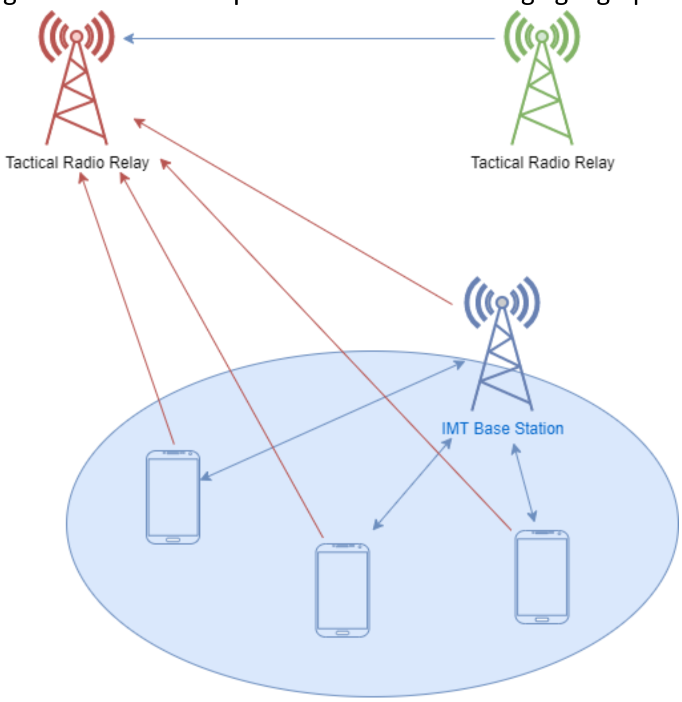


Figure 3: Interference from IMT stations into Tactical Radio Relays

Since 2001, new technologies have been developed and implemented with the introduction of fourth generation mobile communications (4G). Modern systems employ techniques to increase the spectral efficiency and intra and inter-system interference levels, such as beamforming. Instead of using a single sector antenna, that covers a wide area and cannot be steered, many 4G networks employ antenna arrays, which allow stations to electronically steer their emissions towards the stations to which they are connected. Figure 6 and Figure 7, in Annex 1, show examples of radiation patterns for sector antennas, taken from Recommendation ITU-R F.1336, and beamforming antenna arrays, taken from Recommendation ITU-R M.2101, respectively. Notice how the pattern shown in Figure 7 generates a much narrower beam than the one in Figure 6. That means that stations employing antenna arrays can concentrate most of their transmitted energy towards their serving or served stations and, thus, radiate less power towards victim stations of another system.

To illustrate the impact of these technologies, sharing between mobile networks and tactical radio relays (TRRs) in the 1755 – 1780 MHz band can be used as an example. Used by military entities to communicate crucial information during training and combat, tactical radio relays are fixed links dynamically deployed, as necessary. They utilise very wide beam antennas and, consequently, are highly sensitive to interference coming from multiple directions. For this reason, systems sharing spectrum with TRRs must maintain their emissions well confined into the geographical area which they serve, and that is exactly what beamforming does. The technical analysis described in Annex 1 shows that, by using beamforming, mobile networks can reduce the separation distance necessary to protect tactical radio relay stations from more than 150 km to about 20 km. In the study, parameters for 4G and 5G communication networks were used.

[27] US Department of Commerce (2001). *THE POTENTIAL FOR ACCOMMODATING THIRD GENERATION MOBILE SYSTEMS IN THE 1710–1850 MHZ BAND: Federal Operations, Relocation Costs, and Operational Impacts*. Available here (last visited June 18 2020)

Because of this, and other technological developments, on 29 January 2015, the FCC auctioned AWS licenses in several bands, including the 1755 – 1780 MHz band. Most of the federal systems originally utilising the band have been, or will be, transitioned to other portions of spectrum, but some will share the spectrum with non-federal users. TRR Systems in six locations across the US will operate on a co-equal, primary basis with AWS stations,[28] and the protection of the systems will be achieved through means of coordination. Given the fact that the studies performed in 2001 concluded that "co-channel sharing of TRR and IMT-2000 systems is not feasible based on the significant distance separations required to prevent interference", this is a huge step forward in the direction of increasing the social value of spectrum and illustrates the fact that new technologies are key to increasing spectrum reuse.

Future Trends

As systems that were initially incompatible evolve and start employing technologies that facilitate spectrum sharing, more and more administrations will be compelled to consider spectrum sharing. With the development of bigger and more efficient data bases and dynamic spectrum access techniques, efficient use of spectrum can increase worldwide and bring higher quality, more reliable services to customers. These improvements are not only probable, they are also necessary, as the demand for connectivity continues to grow and more users access wireless networks for increasingly complex applications.

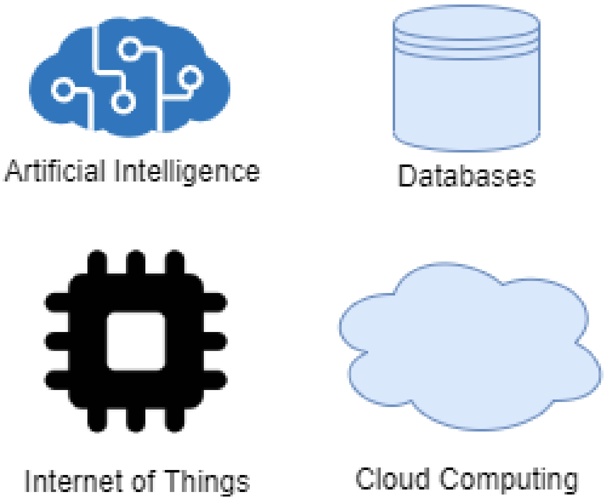


Figure 4: Drivers of innovation in spectrum sharing

Market analysis shows that CBRS and the shared bands can bring significant benefits to mobile service operators.[29] On 23 July 2020, the auction for Priority Access Licenses for CBRS began, resulting in 271 qualified bidders.[30] Only time will tell how successful CBRS will be in the long run, and the envisioned communication protocols and resource management techniques may require adjustments and revisions in the future. In the meantime, machine learning and cloud computing allow for faster and more efficient resource management algorithms, while IoT and licensing databases provide higher volumes of information. The future of spectrum engineering is not one of monolithic and single user allocations but one of intelligent spectrum sensing devices and automatic frequency coordination. Sectors and companies that do not find ways to be a part of this evolution face the risk of becoming obsolete and losing the chance to provide services and access markets currently unexplored, or even considered unexplorable.

[28] Federal Communications Commission. *US table of Frequency allocations, footnote US91.* Available here.

[29] Technicolor. *CBRS Use-Cases With focus on Localized Indoor Mobile Access (LIMA), Mobility and Service Continuity.* Available here.

[30] Verdict. *US CBRS spectrum auction draws diverse range of applicants.* Available here.

Annex 1

For this study, the SHARC simulator was used. Developed by the Brazilian National Telecommunications Agency (ANATEL) in partnership with academia and industry, the simulator has been used to study the coexistence between IMT, High-Altitude Platform Systems, Fixed Satellite Services, and many other telecommunication applications. The SHARC simulator is written in the Python programming language and the open source code is available online.[31] In this Annex, a frequency sharing study between IMT and TRR systems in the 1755 – 1850 MHz band is described.

SHARC performs simulations in atomic iterations, also called snapshots. Each iteration consists of the creation of the simulation scenario, the distribution of interferer and victim stations, connection of stations, application of load and traffic modelling and estimation of interference. The interference statistics is then collected, and a new snapshot is initiated, repeating the same steps with new randomised station positions and traffic distribution.

<u>Modelling</u>

IMT base stations (BSs) are distributed in a macro cell topology, as can be seen in Figure 5. Each base station covers three sectors where, at any given simulation snapshot, three user equipment (UE) stations are simultaneously active. UEs are distributed uniformly inside the IMT network, and an activity factor of 50% was considered for the individual sectors. That means that, at each iteration, each sector has a 50% probability of being active either in the downlink (BS to UE) or the uplink (UE to BS) direction. The activity factor is directly related to the expected load in the network and the traffic characteristics of the system since it models the overall spectrum use of the network.

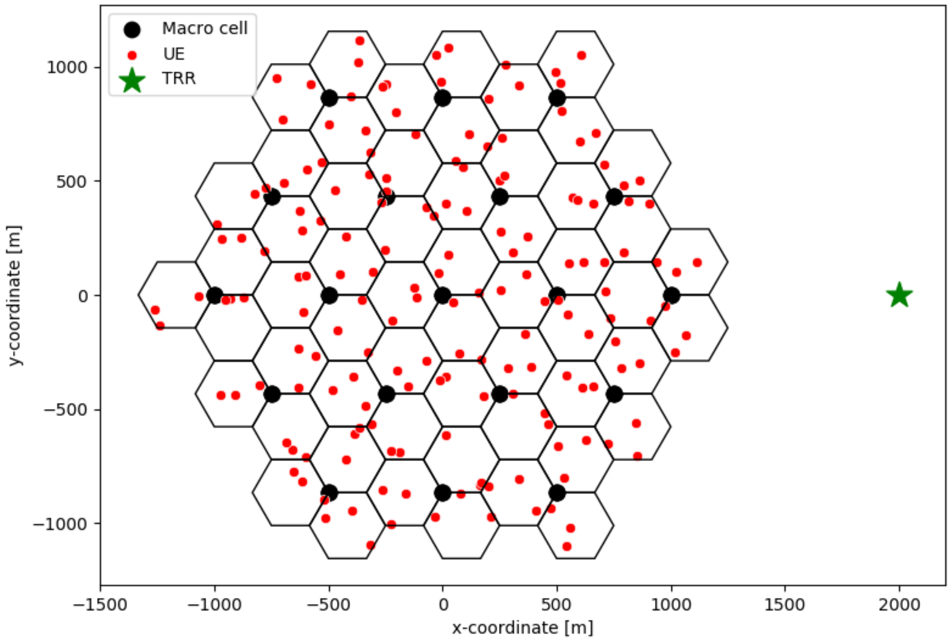


Figure 5: Simulation deployment scenario

[31] SHARC simulator code. Available here (last visited June 18 2020)

The band is divided equally among the active UEs in each active cell, and it is the transmission from these UEs, in the uplink direction, or the transmission from their serving BSs, in the downlink direction, that causes interference to the tactical radio relay station. While UEs utilise omnidirectional constant gain antennas, BSs can employ either sector or array antennas, using the radiation patterns shown in Figure 6 and Figure **7**. While the pattern corresponding to the sector antennas is fixed and cannot be steered, antenna arrays can use beamforming to electronically steer their transmitting or receiving beams. Consequently, base stations employing this type of antenna can track and concentrate emissions towards their served UEs. Figure 8 shows a beam steered at 30° azimuth.

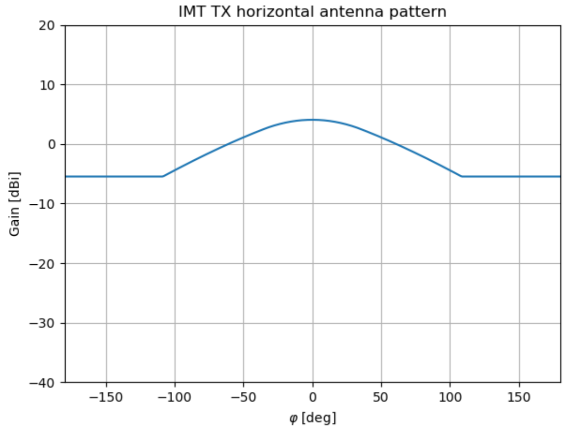


Figure 6: Sector antenna radiation diagram

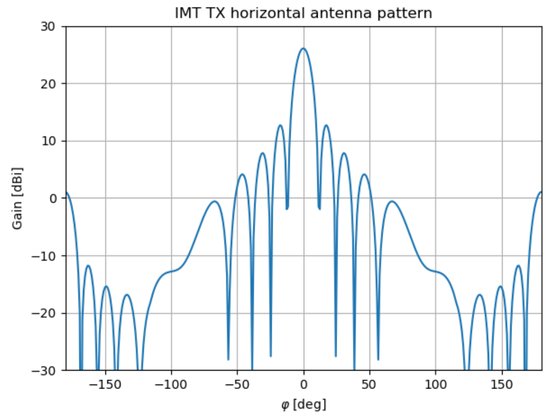


Figure 7: Antenna array beamforming radiation diagram

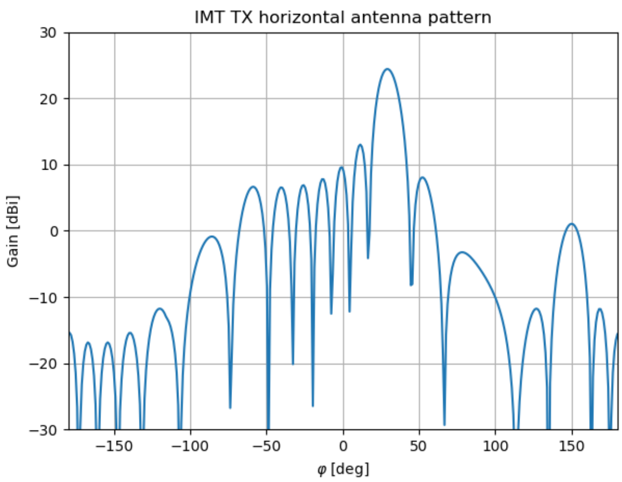


Figure 8: Antenna array beam steered at 30° azimuth

The Tactical Radio Relay systems simulated in this paper have a protection criterion which is given in terms of absolute interference power. If the interference caused by the IMT system is below -143 dBW, then it is considered harmful interference. Otherwise, the interference is considered acceptable.[27] In this analysis, the permitted time percentage below which the IMT systems may cause harmful interference to the tactical relay station is considered to be 1%. Additionally, the antenna pattern used for the tactical radio relay stations consists of a wide beam emissions envelope, shown in Figure 5.

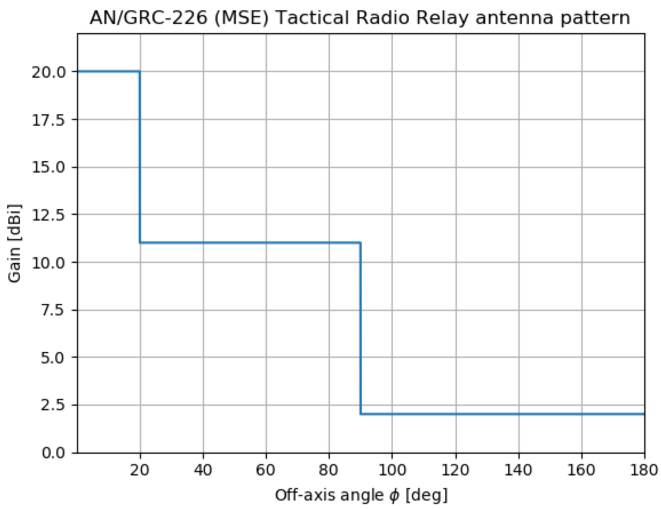


Figure 9: Tactical radio relay receive antenna pattern

Figure 5 shows the TRR station, which was always pointing towards the centre of the IMT network, and positioned at a given distance from the edge of the IMT cluster. This distance was varied to estimate the minimum separation distance required for the protection of the victim station. The propagation model used for the interference path from the IMT stations to the TRR victim station is described in Recommendation ITU-R P.452 and the specific propagation parameters used in this analysis are described in Table 1. Furthermore, a statistical clutter based on Recommendation ITU-R P.2108 was used in addition to building entry loss from Recommendation ITU-R P.2109 and a constant body loss of 4 dB for interference from user terminals.

Table 1: Propagation model parameters

Parameter	Value
Atmospheric pressure	935 hPa
Air temperature	300 K
Sea-level surface refractivity (N_0)	352.58 N-units
Average radio-refractive index lapse-rate (ΔN)	43.127 N-units/km
Distance over land to the coast	70 km
Polarization	Horizontal
Probability *p*	Randomized for each link

Parameters

The parameters used for the IMT system were taken from Report ITU-R M.2292 and from WP 5D document 5D/1120-E, while the parameters used for the TRR station were obtained from the technical studies performed by the US Department of Defense[27]. All parameters can be seen on the Tables below.

Table 2: IMT base station parameters

Parameter	Value
Centre frequency	1802.5 MHz
Bandwidth	20 MHz
Inter-site distance	500 m
Antenna height	25 m
Physical downtilt	10º
Frequency reuse	1
Network loading	50%
Ohmic losses	3 dB
Maximum eirp	59 dBm

Table 3: IMT user equipment parameters

Parameter	Value
Centre frequency	1802.5 MHz
Bandwidth	20 MHz
Active users per cell	3
Indoor users	70%
Maximum transmit power	23 dBm
Antenna diagram	Omni directional
Antenna gain	-3 dBi
Ohmic losses	3 dB

Table 4: IMT base stations' sector antenna parameters

Parameter	Value
Antenna pattern	ITU-R P.1336
Maximum gain	16 dBi
Horizontal beam width	65°
Vertical beam width	Calculated according to Rec. ITU-R P.1336

Table 5: IMT base stations' antenna array parameters

Parameter	Value
Number of elements	8x8
Antenna element maximum gain	8 dBi
Vertical element spacing	0,90 λ
Horizontal element spacing	0,60 λ
Beam width	80º horizontal / 65º vertical
Front-to-back ratio	25 dB

Table 6: Tactical radio relay parameters

Parameter	Value
Antenna gain	See Figure 9
Antenna height	30 m
Receiver bandwidth	0.85 MHz
Receiver noise figure	8 dB
Receiver noise power level	-137 dBW
Allowed interference power	-142 dBW

Results

Even though the 1755 – 1850 MHz AWS-3 band is destined for uplink transmission by 3G and 4G standards, the studies presented here also investigate the possibility of having base stations as transmitters on the band. This opens the possibility of using the band in a time duplex division mode, something that is also permitted by the standards. Figure 10 shows the cumulative distribution function for the interference measured at the Tactical Radio Relay station when the IMT network is operating in the uplink and downlink directions, with the base stations utilising sector antennas. Different separation distances were simulated, and the percentage of time at which the interference is above the protection criterion is shown in

Table **7**.

When the IMT system is operating in the downlink direction, the interferer – with regards to the TRR – is the base station, while the user equipment is the interferer when the system operates in the uplink direction. Since base stations are located at higher positions than user equipment, often above the clutter level and their transmit power is also higher, the downlink interference is higher than the uplink interference. The results show that, for an allowable time percentage of 1%, 10 km is already enough to protect the TRR station from interference from the UEs in the uplink direction. For downlink transmissions, however, 40 km is not enough to bring interference exceedance to a time percentage below 1%.

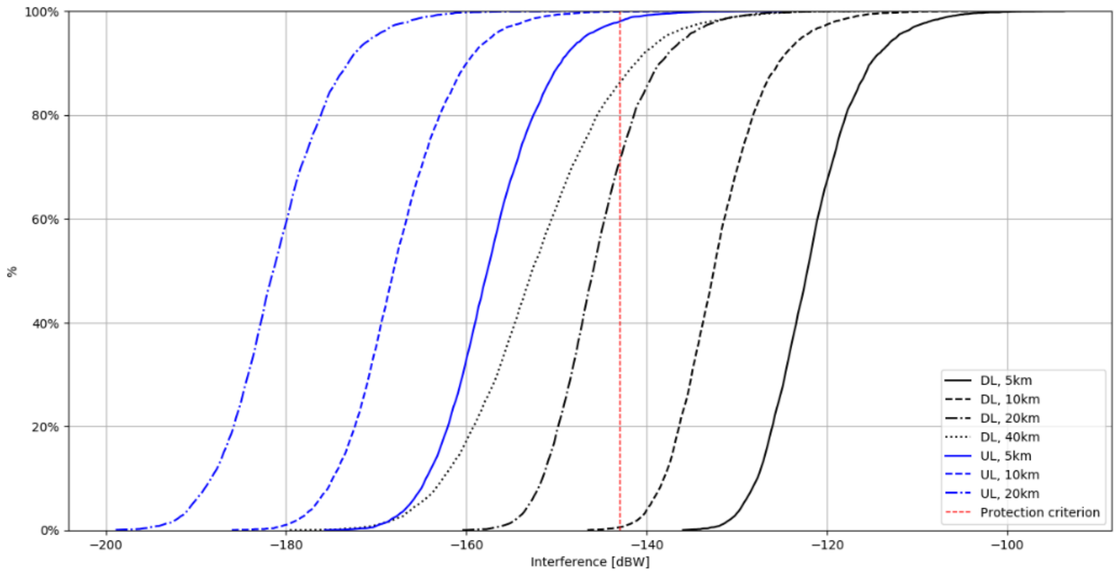


Figure 10: TRR cumulative distribution function of interference for IMT operating in the uplink and downlink directions

Table 7: Percentage of time at which interference is above the protection criterion

	5km	10km	20km	40km
DL	99.98%	99.42%	28.72%	13.42%
UL	1.88%	0.58%	0	---

To compute the gain obtained by the employment of beamforming, the downlink interference was estimated for base stations utilising both the sector antenna and the antenna array. The results can be seen in Figure 11 and Figure 12, while the exceedance time percentages are shown in Table 8 and Table 9. Based on the results, a separation distance of 160 km is necessary to reduce the exceedance time percentage to a value of 0.52% when the IMT base stations employ sector antennas. If the same base stations utilise antenna arrays with beamforming, the necessary separation distance can be reduced eight-fold to 20 km.

Table 8: Protection criterion exceedance time percentage for IMT using sector antennas

	20km	40km	80km	160km
Time exceedance	28.72%	13.42%	3.3%	0.52%

Table 9: Protection criterion exceedance time percentage for IMT using beamforming antenna arrays

	5km	10km	20km	40km
Time exceedance	70.86%	12.76%	0.52%	0.52%

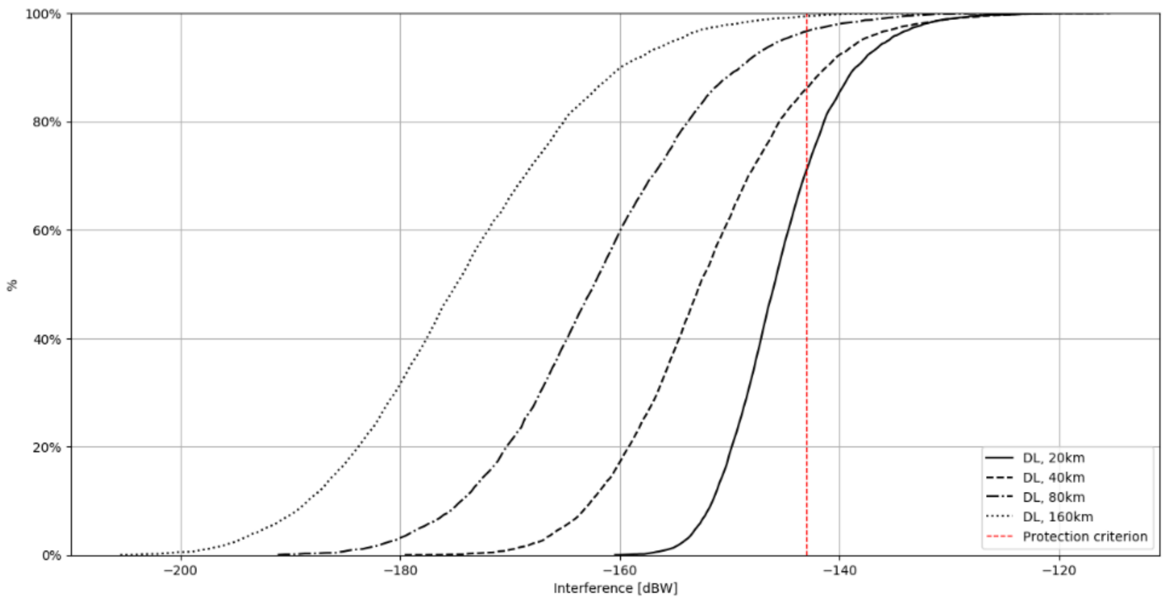


Figure 11: TRR cumulative distribution function of interference for IMT operating in the downlink direction using sector antennas

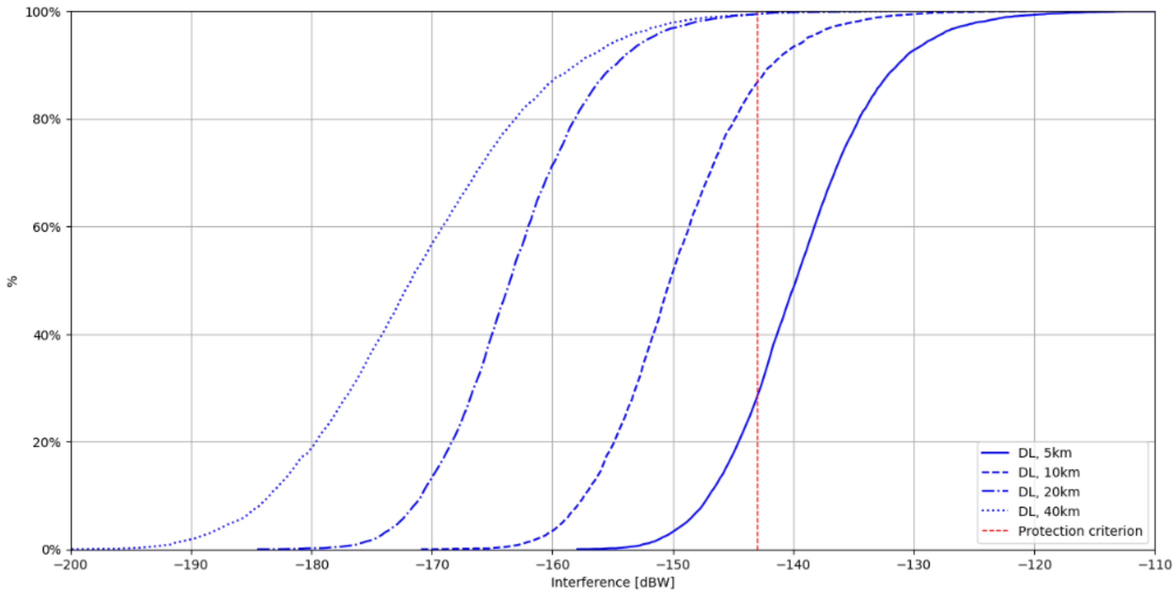
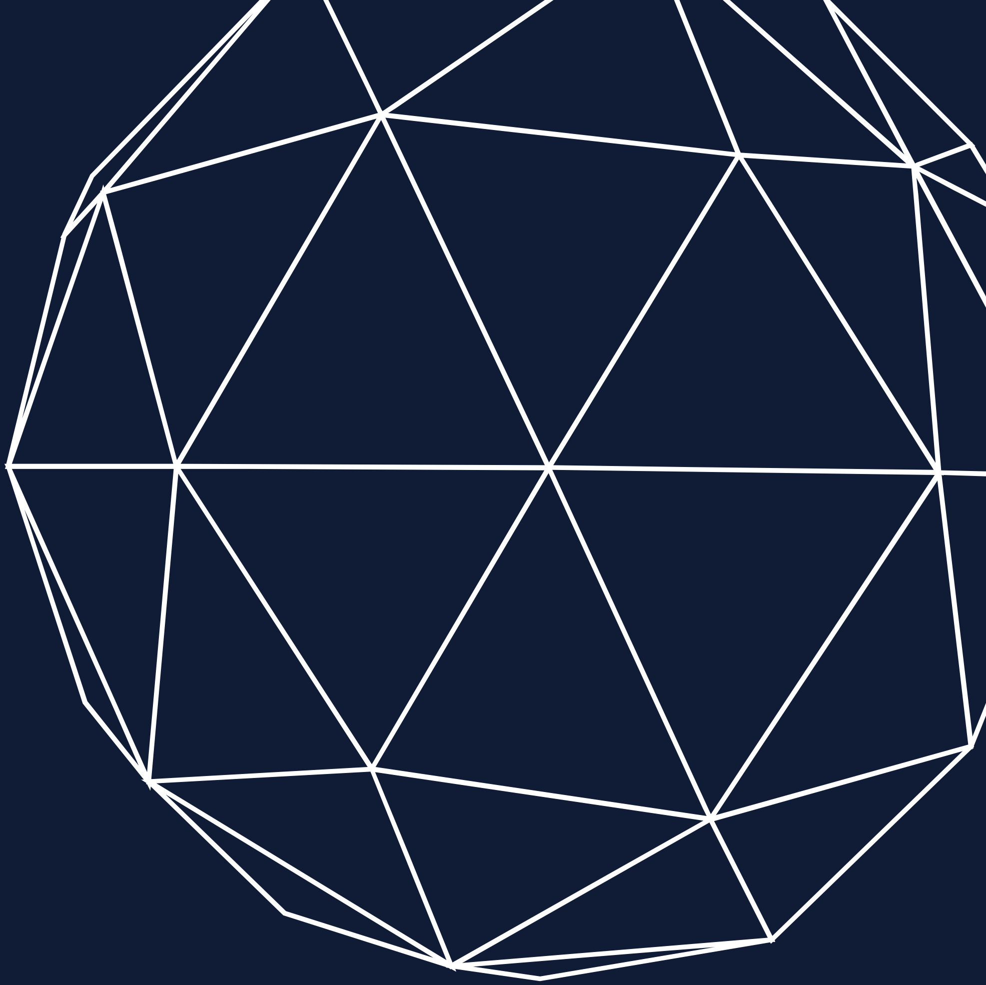


Figure 12: TRR cumulative distribution function of interference for IMT operating in the downlink direction using beamforming antenna arrays

The results highlight the importance of novel antenna design technologies for the mitigation of interference from mobile networks to other services. Developments in other areas, such as radio resource management, spectrum sensing and coding can also facilitate spectrum sharing between different communication systems. For that reason, the separation distances necessary to protect incumbents are expected to be reduced as new generations of wireless communications enter the market.



We lead countries to fair tech

Access Partnership is the world's leading public policy firm dedicated to opening markets for technology. We shape national, regional and international policies to ensure a fair, long-lasting environment for technology that drives growth. Our teams in six offices across the globe uniquely mix policy and technical expertise to drive outcomes for clients operating at the intersection of technology, data and connectivity.

9th Floor, Southside
105 Victoria Street
London SW1E 6QT
United Kingdom
Tel: +44 (0) 20 3143 4900
Fax: +44 (0) 20 8748 8572

www.accesspartnership.com

AccessAlerts

AccessPartnership