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HEAVY READING WHITE PAPER

# Shared Spectrum for 5G New Radio

*A Heavy Reading white paper produced for Qualcomm Inc.*

QUALCOMM®

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# 5G NEW RADIO & SHARED SPECTRUM

5G New Radio (NR) is the name for the new air interface being developed by the wireless industry to offer next-generation mobile services that meet strict latency, throughput and reliability performance targets. As with any mobile wireless system, spectrum is critical to 5G NR. Frequencies, channel widths and their licensing terms are very influential on technology development and, therefore, on end-user services. Spectrum will, in effect, shape the 5G system design and deployment model.

5G NR is widely expected to operate across very diverse spectrum, from low-band, to mid-band, to high-band (mmWave) frequencies. Licensed exclusive use spectrum is preferred by mobile operators because it provides greater certainty of performance and reduced risk of interference. This will remain the case in 5G.

There are, however, tremendous opportunities for shared spectrum in 5G, both as a complement to exclusive-use licensed spectrum and as a way for non-operator organizations to deploy private networks – for example, in public venues, workplaces or industrial facilities. Enabling these users to operate 5G networks will unlock opportunities for innovative deployment models.

This white paper investigates the role of shared spectrum in 5G. It discusses how shared-use can unlock lightly-used spectrum, how it can increase spectrum utilization and why it is vital to have effective and reliable mechanisms to optimize sharing in high-performance systems, such as 5G NR. It will argue that there are many advantages to shared spectrum and that support for shared spectrum operation should be embedded in the NR air interface standards.

## Shared Spectrum for 5G NR

The three types of spectrum available for 5G are shown in **Figure 1**. Exclusive use licensed spectrum is not only desired by mobile operators, but is also important for a range of critical services, and it will remain vital in 5G. Shared spectrum and unlicensed spectrum (which is inherently shared) are both also very promising.

**Figure 1: Types of Spectrum Available for 5G**

| Licensed | Shared | Unlicensed |
|---|---|---|
| Exclusive use by license holder | Many possible sharing schemes | Open use within regulatory limit |
| Foundation of public mobile networks (<6 GHz today) | Increase availability of spectrum and efficiency of spectrum use | Extensive adoption by professional and amateur users |
| Also critical to satellite, government & military | Established regulatory frameworks to build on | Enabler of "permission-less innovation" |

*Source: Heavy Reading*

There is already shared spectrum allocated globally, often for mobile use. In the unlicensed bands, there is significant spectrum available, although this varies by national jurisdiction. In particular, in the U.S. there is around 500 MHz available at 5 GHz, which is used for WiFi today and, in the near future, by LTE in the form of LTE in unlicensed spectrum (LTE-U), License-Assisted Access (LAA) or MulteFire (an LTE technology).

At 60 GHz (known as the V-Band) there is 7 GHz of unlicensed spectrum available between 57-64 GHz. This is used for WiGig local-area networks and point-to-point outdoor wireless transport links today. In the U.S. there is also a proposal to extend the license-exempt allocation to an additional 7 GHz between 64-71 GHz, to create a massive 14 GHz of unlicensed V-Band spectrum that could be used for 5G in the future.

There is also precedent for shared licensed spectrum. The E-Band (71-76 GHz and 81-86 GHz) is already lightly licensed and available for use for fixed point-to-point links, such as backhaul and enterprise access. In the near future, the 3.5 GHz Citizens Broadband Radio Service (CBRS) will be released in the U.S. under shared spectrum scheme, as will the 2.3 GHz Licensed Shared Access (LSA) in parts of Europe. It is generally easy to gain permission to operate in these bands via a fast and simple licensing process. This type of spectrum offers promise as a complement to the existing licensed spectrum holdings of mobile network operators (MNOs), as well as to non-MNO organizations.

These bands are not specifically linked to 5G today; however, they are an effective precedent that help to demonstrate the value of shared spectrum for mobile use and will help accelerate the development of regulatory frameworks that can also be applied to 5G. One important difference between todays' shared spectrum, which is heavily restricted on power output and therefore mainly suitable for small cells, will be new capabilities in 5G to enable coordinated systems to be deployed that can achieve better coverage from higher radiated power in new spectrum bands – for example, using beam-forming, higher transmit power, or both.

## Value of Shared Spectrum for 5G

Spectrum sharing has several advantages that will, in principle, also apply to 5G. The three most important benefits are the ability to:

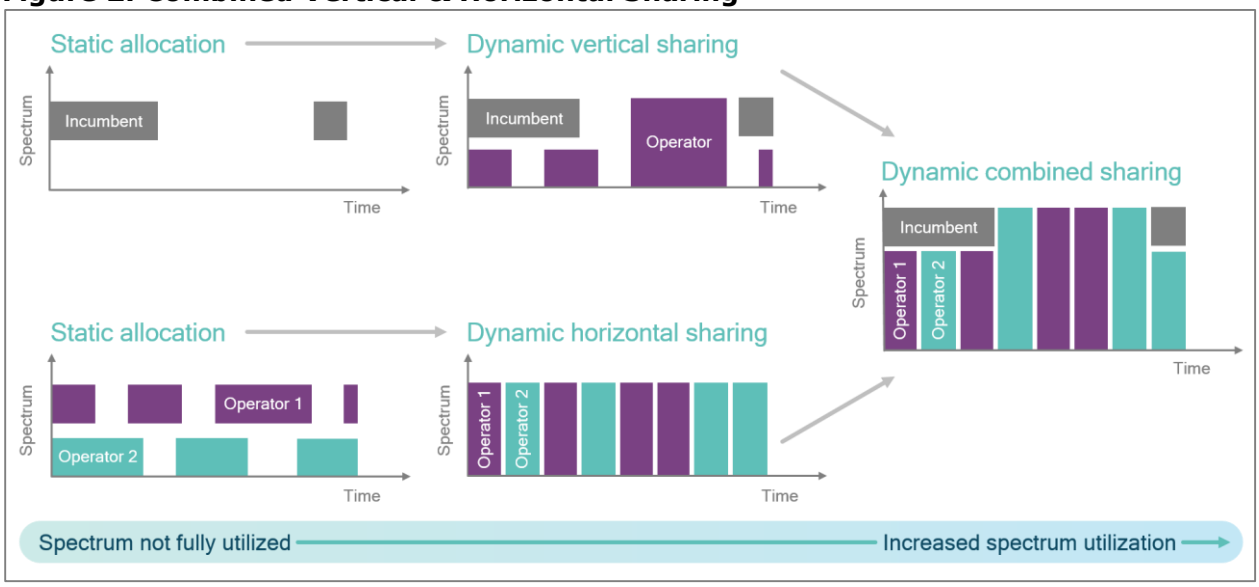
- **Unlock spectrum that is lightly used by incumbents.** Where a user makes only infrequent use of an allocated spectrum band, there is an opportunity to permit secondary (and even tertiary) users without comprising the primacy of the incumbent user. This is especially relevant for government, military, scientific and other specialist agencies that need dedicated spectrum at specific times or locations, but do not use the band heavily most of the time in many locations. Today's examples are LSA and CBRS, where spectrum is shared with incumbents.
- **Increase spectrum utilization**. Multiple users in a band should increase utilization of spectrum (and, therefore, the associated economic gain) relative to a single user. This is most useful in areas where demand is spread across multiple service providers. Where demand from a single operator saturates the spectrum the opportunity for gain is eliminated; however, even in these cases there may be opportunities to time-shift demand to quieter periods.
- **Attract new providers and enable new service models.** More so than efficacy gain, "permissionless innovation" is probably the key benefit of easier access to spectrum. Allowing different users into a band to exploit it for their own purposes opens the market to entrepreneurs, risk-takers and innovators. This will be particularly important to 5G, where industry verticals want to deploy their own networks – for example, a factory floor automation solution based on 5G NR need not necessarily require the involvement of a licensed mobile operator.

# PRINCIPLES OF SHARED SPECTRUM

## Horizontal & Vertical Sharing

Spectrum can be shared in several different ways: horizontal sharing, vertical sharing and a combination of both. These options are shown in **Figure 2**. As a new technology, 5G should support dynamic, combined sharing, which is the most efficient arrangement, although more challenging to implement.

**Figure 2: Combined Vertical & Horizontal Sharing**




*Source: Qualcomm*

### *Horizontal Sharing*

Horizontal sharing is the most common sharing method today, and is used in most license-exempt bands, such as 2.4 GHz, 5 GHz and the E-Band. There are both static and dynamic sharing models. In the E-Band, for example, fixed wireless links are licensed for dedicated use of the channel at a specific location. Multiple links can be licensed that are adjacent in frequency and location, but which do not overlap. This is a static allocation of shared spectrum. In dynamic, horizontal sharing, different operators occupy the same spectrum at different times, with occupancy of spectrum determined according to fair-usage criteria set by the regulator (for example, listen-before-talk). This is a form of dynamic sharing and is used for WiFi.

### *Vertical Sharing*

Vertical sharing is applicable to shared spectrum with priority users – for example, an incumbent user, such as a government entity, may already exist in the band, but during fallow periods secondary and tertiary users may be permitted. This model is being pursued for the LSA scheme in parts of Europe and for the CBRS in the U.S. It includes static sharing and dynamic sharing that is time dependent, with the resource controlled by the incumbent user, according to regulatory agreement.

### *Dynamic Combined Sharing*

Dynamic sharing that combines both vertical and horizontal sharing offers the most opportunity for efficiency gain and greater utilization, as shown in **Figure 2**. This will likely be the target model for sharing in 5G radio networks. It requires more sophisticated regulation and sharing mechanisms to be effective. The closest thing today is the 3.5 GHz CBRS band, which will prioritize incumbent users and allow two classes of licensee to access spectrum in fallow periods. CBRS, however, is less dynamic than 5G NR sharing is expected to be.

## Activity to Date – Examples From LTE

Spectrum sharing is already coming to LTE systems, even though this technology was designed for exclusive use licensed spectrum. From a 5G perspective, these LTE initiatives are valuable in two ways: to show how sharing mechanisms work in practice, and to show how non-MNO organizations can deploy networks suitable to their specific location or need, e.g., in enterprises or campuses. **Figure 3** shows some example of LTE in shared spectrum.

**Figure 3: LTE Spectrum Sharing Examples**

| | Sharing Model | Frequency | Commercial Launch |
|---|---|---|---|
| LTE-U | Duty-cycle sharing with licensed anchor | 5 GHz | Possibly 2017; may be upgraded to LTE-LAA in time |
| LTE-LAA | Horizontal sharing with listen-before-talk and licensed anchor | 5 GHz | Expected in 2017 |
| MulteFire | Horizontal sharing with listen-before-talk | 5 GHz & 3.5 GHz | Expected in 2018 |
| LSA | Two-tier sharing with incumbent priority | 2.3 GHz | Not known; currently in trial phase |
| CBRS | Three-tier vertical sharing with incumbent priority | 3.5 GHz (150 MHz of spectrum between 3550-3700 MHz) | Expected late 2017 or 2018 |

*Source: Heavy Reading*

From a 5G point of view, the LSA and CBRS schemes are both interesting. LSA is a two-tier model, and the simpler of the two. It has quite a bit of regulatory support from international bodies such as the ITU-R, the European Conference of Postal and Telecommunications Administrations (CEPT) and the European Commission's Radio Spectrum Policy Group. France is the most progressive country in terms of both regulation and trial activity.

CBRS is, for now, a U.S.-only initiative. Such is the influence of the U.S. market, however, the importance of CBRS as proving ground for granular shared access is significant. It also benefits from an emerging global device ecosystem at 3.5 GHz, which should accelerate the availability of CBRS-compliant devices in the market. Japanese carriers, for example, are already using 3.5 GHz for licensed LTE.

Notably, CBRS should help demonstrate the extent to which database-driven spectrum access systems are practical at scale. In general, sensing-based mechanisms, such as those used on WiFi or LAA, are finer-grained and more efficient, but less effective at guaranteeing that a secondary or tertiary user gives way to a priority Tier 1 user (such as incumbent military). A combination of sensing and database-driven sharing is likely to give the best results in 5G.

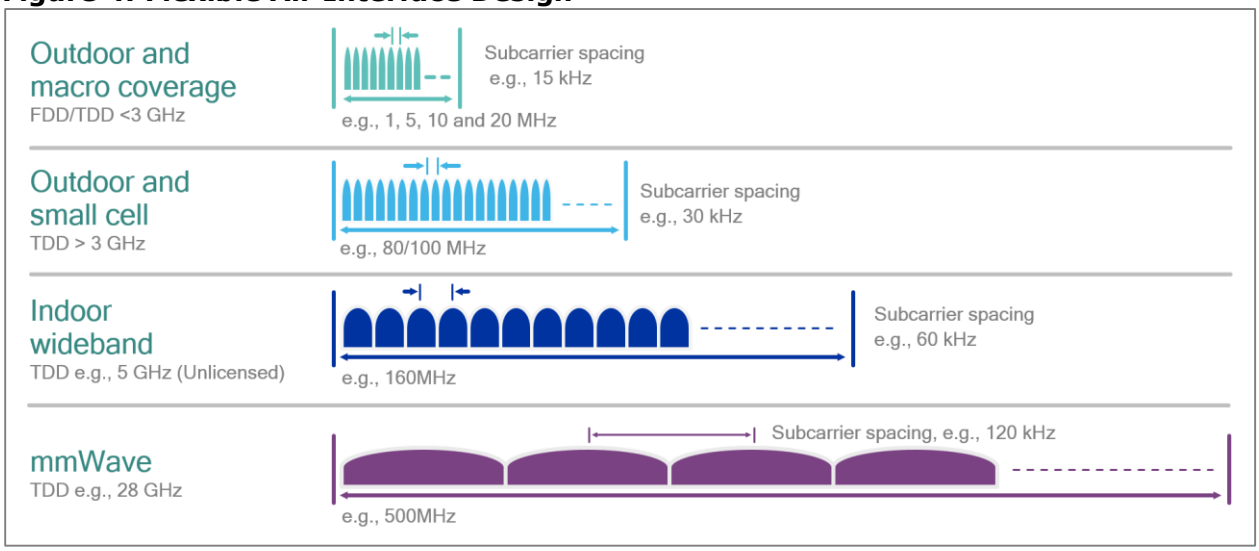
# DESIGN & IMPLEMENTATION IN 5G NR

To optimize the performance of 5G radio in shared spectrum requires a very flexible air interface with specific sharing-related capabilities that will allow the radio to adapt to adjacent and overlapping users. The first part – flexible design – is fundamental to 5G NR. The second part – sharing-specific extensions – is supported by the forward-compatibility features of the proposed NR sub-frame design.

## Flexible NR Design

5G radio is in development and standardization is underway in 3GPP. There is common agreement that the radio will be OFDM based with flexible numerology that will allow the radio to be configured to operate in different deployment scenarios. For example, in a low-band outdoor macro network with a 10 MHz channel, the radio would operate with 15 kHz sub-carrier spacing and an appropriately long cyclic prefix. A mmWave indoor deployment in, say, a 500 MHz channel would use a much wider subcarrier (to reduce processing load on the device modem) and a commensurately shorter cyclic prefix. This flexible numerology is shown in **Figure 4**.

**Figure 4: Flexible Air Interface Design**




*Source: Qualcomm*

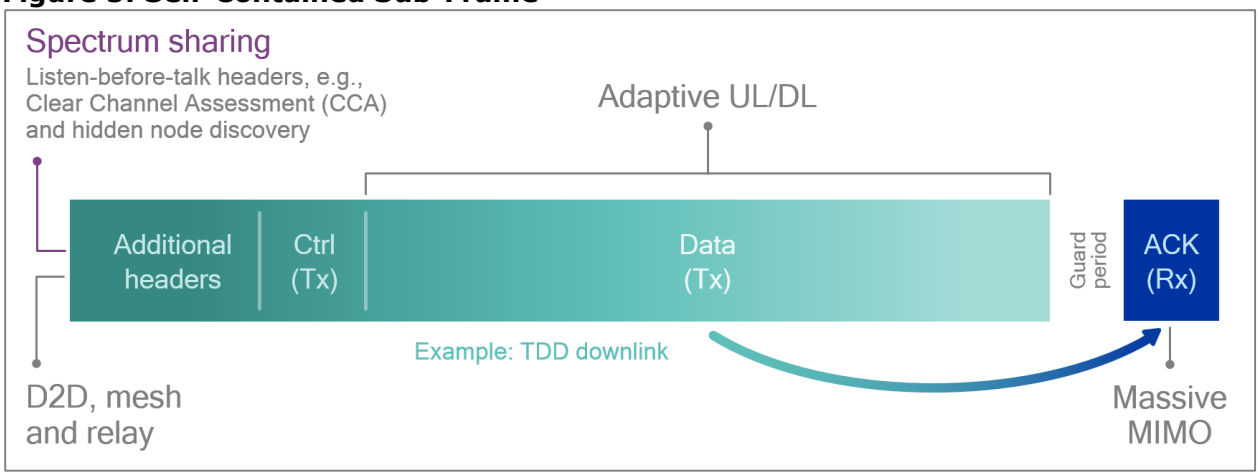
This flexibility helps NR adapt to different spectrum bands and given that unlicensed spectrum incorporates a range of band plans, the ability to scale up or down in channel size can help operators to exploit more of this resource.

A second aspect of NR that has direct bearing on shared spectrum is the frame structure. The proposed new "self-contained integrated sub-frame" has advantages in general terms (lower latency, for example) and specifically as relates to shared spectrum. Dynamic uplink and downlink configuration, for example, can adapt traffic flows according to the prevailing load in the radio environment, which might typically be more variable in shared spectrum.

The (proposed) ability to add headers to the packet is perhaps even more important. This allows system designers and operators to reconfigure how the radio performs and to add

new header information that can aid operation in shared spectrum – for example, special preambles can be added to resource grant requests to indicate if listen-before-talk is required. This is relevant even post-specification, because the header fields do not need to be known at the design phase – they are purposefully extensible. This is an example of the forward-compatibility that will allow NR to evolve to meet the use cases (and related performance requirements) that may emerge as important in the future.

**Figure 5: Self-Contained Sub-Frame**




*Source: Qualcomm*

## Unlicensed & Shared Spectrum Operation

A basic requirement for NR comes from the ability to operate within regulatory guidelines for shared spectrum. The opportunity for dynamic sharing between different operators, technologies, priority tiers, etc., will be partially determined by regulatory conditions, even in unlicensed bands – for example, LTE-LAA must support listen-before-talk. There are several features of 5G system design that will help NR operate in non-exclusive spectrum.

### *Dual Connectivity With Licensed Anchor*

Dual connectivity was introduced in Release 12 to support HetNet deployments. The idea is that a primary serving cell provides control signaling and user-plane services, while a secondary non-collocated cell provides additional user-plane throughput. This model can be applied to 5G NR in several ways:

- Coexistence of 5G NR and LTE, where LTE provides a simultaneous coverage anchor to expanding 5G NR deployments
- Simultaneous attachment to a sub-6 GHz and a non-collocated mmWave 5G radio
- Attachment to unlicensed spectrum secondary cells, aggregated with a licensed spectrum anchor

Note that collocated 5G NR sub-6 GHz and mmWave radios will use carrier aggregation rather than dual connectivity.

It is widely expected that 5G will be a multi-radio access technology (RAT) network, particularly in the deployment phases, where 5G coverage may be patchy and 4G is required for

mobility – for instance, as fallback to local-area mmWave 5G. Essential to this are devices with multi-connectivity support – which is an extension of dual connectivity – including NR, LTE and WiFi.

Note, however, that while dual connectivity and carrier aggregation is clearly useful – particularly for wide-area public network operators – it isn't required to run NR in unlicensed spectrum. 5G NR should also be deployable in stand-alone mode in unlicensed spectrum by any type of operator. This enables non-MNO organizations, such as enterprise or industrial verticals or even fixed line operators, to deploy networks for their particular use case.

### *Enhanced Spatial Techniques With mmWave*

The high-band mmWave spectrum being pursued for 5G is well suited to shared operation. The primary reason is that there is a lot of spectrum, and beam widths at higher frequencies are relatively narrow, making it more feasible for multiple operators to be deployed side-by-side without unduly interfering with each other. This is the experience with E-Band wireless links, where operators have successfully installed unlicensed links in close proximity.

Massive MIMO and advances in antenna processing will also help considerably for mmWave. The beam-steering techniques that are required to support robust mobility in mmWave coverage areas can also be used to adapt power transmission, according to the prevailing interference, and to focus power on the required area to reduce spillover to adjacent users. These same beam-forming, beam-steering and beam-tracking techniques are also useful in sub-6 GHz bands, as already being demonstrated in LTE-Advanced Pro networks.

Some high-band spectrum will be allocated to licensed users – for example, the 28 GHz band – because this is important to deliver reliable public network services. However, a relatively large amount of high-band spectrum will be made available under licensed exempt terms. Given the sheer amount of high-band shared spectrum, it is important that 5G NR is designed to operate in such environments.

## Coordinated Sharing

5G NR brings several improvements to the physical link. To make the most efficient use of shared spectrum will also require new approaches to media access control (MAC) that allow user transmissions to be scheduled according to the prevailing conditions. In some cases, the MAC will need to support priority users with guaranteed access, while also allowing opportunistic use of unused time slots.

The existing unlicensed bands, such as 5 GHz, already have well-established regulatory parameters on their use (e.g., power output limits or a requirement to use listen-before-talk). If 5G NR is to be deployed in these bands, it will have to respect the exiting regulation – in the same way that MulteFire does in 5 GHz, for example. There are ways to optimize performance within these constraints, but fundamentally contention overhead becomes a problem in very busy shared networks and performance starts to degrade, sometimes to the point where a wide, shared band becomes worse than a fixed, but narrow, allocation.

There is, evidently, a need to balance being dynamic with being robust. Where this balancing point lies depends on the type of spectrum, operator and services in question. The tipping point on this tradeoff can be made more favorable with coordinated sharing, particularly in new shared spectrum, which is less bound by legacy regulation (and by the installed base of

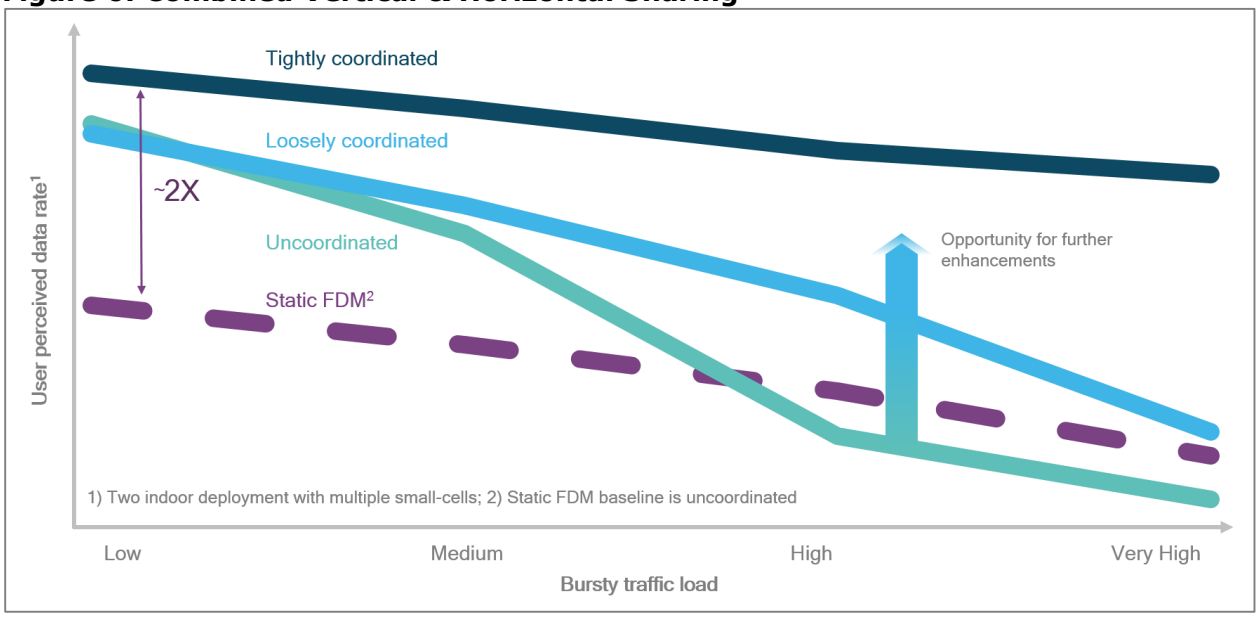
devices). This is where 5G NR can make a major contribution, if support for sharing is included in the MAC design.

**Figure 6** shows the results of modeling by Qualcomm into different types of spectrum allocation and sharing schemes, plotted against load and user-perceived data rate with a bursty traffic profile. The baseline is the dotted purple line, which uses frequency-division duplex (FDD) – i.e., a static allocation of spectrum for each deployment. In this case, performance declines more or less linearly with load. This is representative of today's licensed systems.

Uncoordinated shared spectrum (i.e., 2.4 GHz or 5 GHz used for WiFi, Bluetooth, etc.) is shown in green. End-user data rate can be superior to the FDM allocation in low load conditions (because more spectrum is accessible), but declines quite rapidly as demand increases. At a certain point the overhead associated with contention for resources can cause the user data rate to drop below the fixed spectrum allocation. Finding ways to improve on that situation results in the blue line ("loosely coordinated") which extends the point at which dramatic loss of performance is perceived by end users.

The dark grey line ("tightly coordinated") shows the best performance in this model, with consistently better performance across load conditions, particularly in very busy conditions. This requires advanced sharing to be incorporated into the radio interface itself to be effective; by extension, this means new spectrum, with the appropriate rules, is also needed.

**Figure 6: Combined Vertical & Horizontal Sharing**




*Source: Qualcomm*

Coordinated sharing has very significant promise and could be a very powerful way to introduce 5G to many new deployment models and operator types. However, it is still early days for 5G NR design overall, and shared spectrum requirements are not yet assured to be prioritized in the work plan. To some extent, that is OK because the forward-compatible nature of the design provides scope to add capability in the future, and near-term attention is inevitably focused on more pressing issues related to getting the base NR interface specified. However, it would be a missed opportunity to not take spectrum-sharing requirements seriously from the outset.

## ABOUT QUALCOMM

Qualcomm Incorporated (NASDAQ: QCOM) is a world leader in 3G, 4G and next-generation wireless technologies and chipsets. For more than 30 years, Qualcomm ideas and inventions have driven the evolution of digital communications, linking people everywhere more closely to information, entertainment and each other.

Qualcomm has been investing in 5G research and development for many years. At Mobile World Congress in February 2016, Qualcomm did a live demonstration of their 5G mmWave prototype, operating at 28 GHz. The demonstration showcased adaptive beamforming and beam-tracking techniques to enable robust and sustained broadband communications under line-of-sight (LOS) and non-line-of-sight (NLOS) RF channel conditions and device mobility.

In addition, Qualcomm has been able to use the technologies it has developed and is developing for WiFi and 4G LTE as a starting point for its work in 5G. For example, the company has a 60 GHz WiFi (802.11ad) device chipset with a 32 antenna element array suitable for mobile form factors.