

5G deployment below 6 GHz

Ubiquitous coverage for critical communication
and massive IoT

White Paper

There has been much attention on the ability of new 5G radio to make use of high frequency spectrum, such as mmWave bands, as an effective way to provide huge amounts of capacity to meet rocketing demand. Yet the early phases of commercial 5G are more likely to be deployed on lower frequency spectrum, especially sub-6 GHz.

This Nokia paper explains the reasons and the benefits of deploying 5G on these low bands below 6 GHz, as well as describing the technology and practical solutions.

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1. Executive Summary

5G is the first radio system designed to support any spectrum between 400 MHz and 90 GHz. This wide range of spectral options provides the best combination of high capacity, high data rates, ubiquitous coverage and ultra-reliability.

The low bands below 6 GHz meet the needs of wide area coverage and data rates of up to a few Gbps. Reliable coverage is important for providing connectivity for Internet of Things (IoT) devices and for critical communications like remote control or automotive applications.

The main spectrum options for 5G in its early phases are around 3.5 GHz and 4.5 GHz and millimeter waves at 24-28 GHz and 39 GHz with Time Division Duplex (TDD) technology. The initial phase aims to use existing base station sites for 3.5/4.5 GHz to simplify 5G introduction. 5G at 3.5 GHz with massive MIMO (Multiple Input Multiple Output) beamforming antennas can match the coverage of existing 4G networks using the 2 GHz band with traditional passive antennas. Peak data rates up to 2 Gbps can be achieved with 5G by using 100 MHz of bandwidth, providing a capacity up to 10 times greater than 4G. Millimeter wave spectrum offers up to 1 GHz per operator to enable peak rates of up to 20 Gbps and very high hotspot capacity.

5G can also use sub-1 GHz Frequency Division Duplex (FDD) bands to provide wide area coverage, including deep indoor penetration. The low band spectrum can take advantage of the new 700 MHz allocation in Europe or 600 MHz allocation in USA, as well as the refarming of 850/900 MHz released by minimizing the use of legacy 2G/3G spectrum. The aggregation of the different spectrum bands from sub-1 GHz to millimeter waves provides the best combination of coverage, capacity and user data rates.

5G can also be deployed on shared spectrum, like the 3.5 GHz in USA, and in unlicensed spectrum, like 5 GHz. This approach opens new opportunities for enterprises and industries to benefit from 5G technology without the need for licensed spectrum.

Evolving 4G to 4.9G provides an excellent path to 5G. New 5G technologies will deliver even greater performance in terms of latency, spectral efficiency, massive MIMO optimization, energy efficiency and reliability, encouraging the refarming of existing spectrum to 5G.

The first phase of 3GPP 5G specifications will include the RF requirements for the new spectrum allocations and for refarming most current frequencies.

2. Spectrum below 6 GHz

Spectrum is the key asset for a communications service provider (CSP). The available spectrum has a major impact on how a network's maximum capacity and coverage are defined.

The mainstream spectrum will be 3.5 GHz with up to 400 MHz available from 3.4 to 3.8 GHz, including 3GPP bands 42 and 43. Additionally, China will use 3.3 to 3.4 GHz and Japan 4.4 to 4.9 GHz.

The spectrum around 3.5 GHz is attractive for 5G because it is available globally and offers a high amount of spectrum – potentially more than 100 MHz of contiguous spectrum per CSP. But with 3.5 GHz spectrum, the cell range is limited because radio propagation reduces as the frequency increases. Therefore, 3.5 GHz provides less coverage than the 2 GHz used by 4G networks. However, deploying massive MIMO beamforming antennas at 3.5 GHz can match the coverage of existing LTE1800/2100, effectively enabling full urban coverage with 5G.

5G can also use sub-1 GHz spectrum to provide deep indoor penetration, a reliable uplink and large coverage. Extensive coverage is important for new uses cases like IoT and critical communications. Low data rate IoT connectivity can be supported with wider coverage using various extension solutions.

The low band could make use of 700 MHz spectrum, which has been made available, or will soon become available, in various countries. Another option is 900 MHz, which is mainly occupied by 2G and 3G today. Most CSPs are likely to keep 2G and 3G running until 2020 but will minimize the allocation of spectrum for legacy radios in order to make room for 5G. Another option for the 5G low band in the USA is 600 MHz.

Typically, the early phases of 5G will use mmWaves to provide up to 20 Gbps, 3.5/4.5 GHz to offer up to 2 Gbps, and low bands for ubiquitous coverage running at more than 200 Mbps throughput.

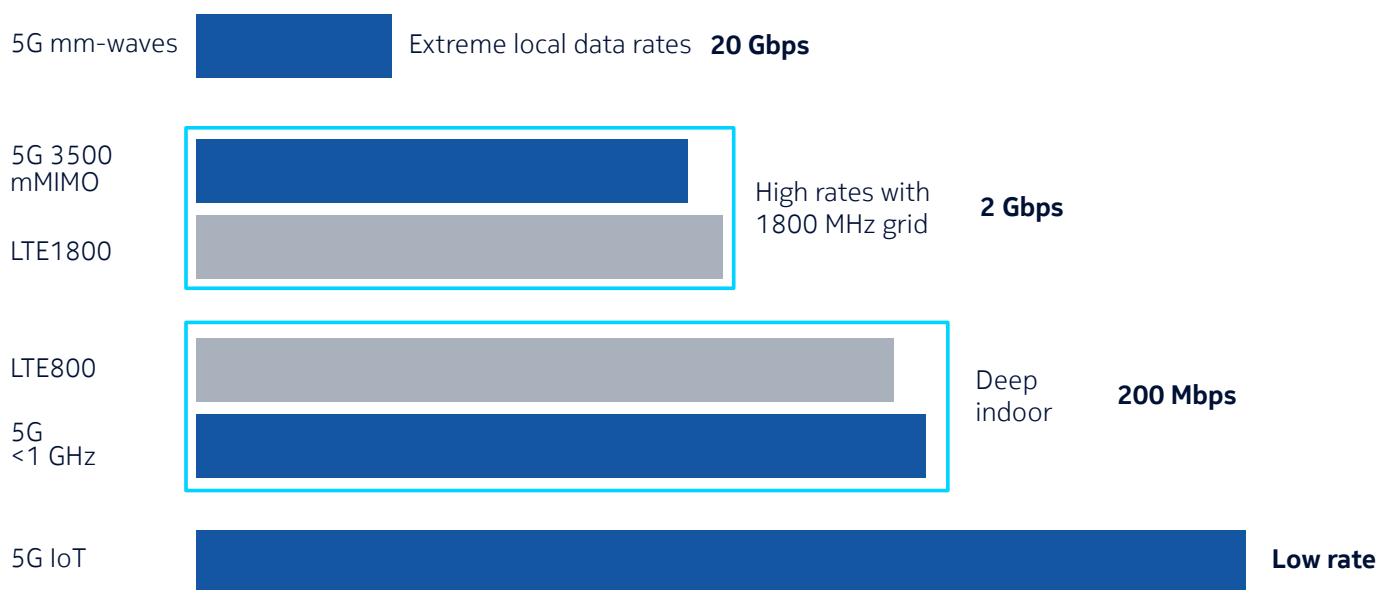


Figure 1. Typical 5G spectrum use in the early phases of 5G (mMIMO=massive MIMO).

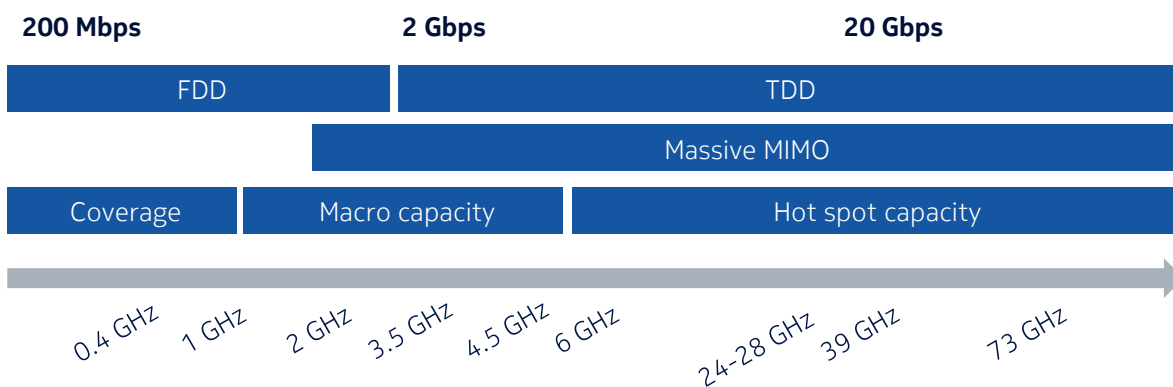


Figure 2. Overview of 5G spectrum options, the main technologies (FDD, TDD, antennas) and the main use area (coverage, capacity). The low bands are FDD-based and provide coverage, while the high bands are TDD-based and offer high capacity when used with massive MIMO.

2.1. Coverage and beamforming

Bands below 1 GHz provide excellent coverage with typical LTE antenna configurations known such as 2x2 MIMO. In addition, typical FDD designs in these low bands provide good coverage and long signal travel times, enabling tens of km of extended cell radii. The large wavelengths below 1 GHz, however, limit the option to use 5G features like massive MIMO. That’s because handheld devices are typically not large enough to accommodate more than two sub-1 GHz antennas, while size, weight, wind load and visual impact considerations limit the number of deployable antenna elements at base stations. This does mean, though, that sub-1 GHz 5G coverage can be implemented relatively easily and with minimal technological risk.

Coverage in and around the 3.5 GHz band can be enhanced by using beamforming antennas and lower frequency bands for the uplink. Figure 3 illustrates the relative outdoor coverage for the different frequencies compared to a 2100 MHz uplink. The calculation assumes the Okumura-Hata propagation model, a downlink that is 8 dB better than the uplink, and a massive MIMO (mMIMO) gain of 6 dB compared to 2x2MIMO. This calculation shows that 5G at 3500 MHz downlink with massive MIMO can exceed LTE1800 MHz 2x2MIMO coverage.

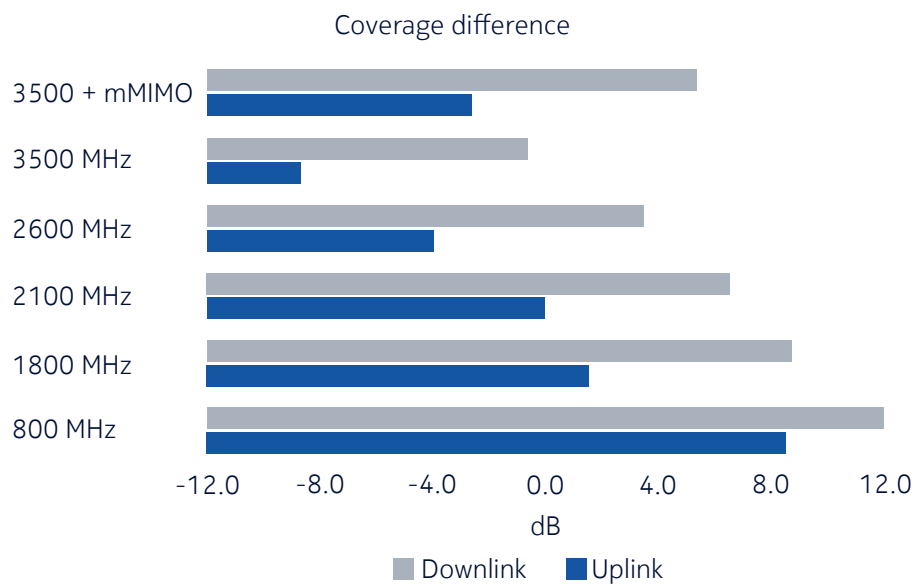


Figure 3. Outdoor coverage difference compared to 2100 MHz uplink.

Macro network coverage is uplink limited because the 0.2W maximum output power of devices is much lower than the base station power which can be in excess of 100W. Therefore, a 3500 MHz uplink falls short of LTE2100 or LTE1800 coverage.

One solution is to deploy 5G at low bands which are then aggregated with the 3.5 GHz band. Another option is to share the uplink frequency between 5G and LTE, for example, at 1800 MHz or 800 MHz. Figure 4 illustrates this latter configuration. Spectrum utilization on the uplink is generally lower than on the downlink because traffic is asymmetric with downlink traffic volume typically ten times higher than uplink traffic because of the use of video streaming. Therefore, it is feasible to also use part of the LTE uplink spectrum for 5G.

LTE and 5G sharing an uplink may restrict practical 5G deployment. The same antenna direction is required for LTE and 5G, while changes to the existing LTE equipment are likely to be needed. Using a dedicated low band for 5G would be a more flexible solution.

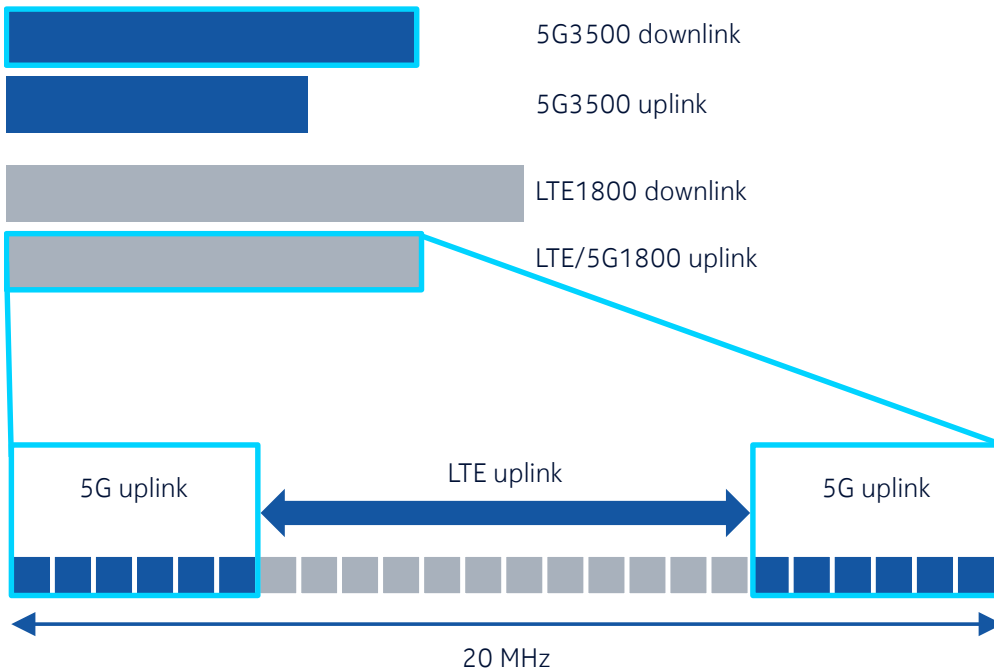


Figure 4. 5G uplink in lower band together with LTE.

2.2. Capacity below 6 GHz

Higher capacity can be provided by using more bandwidth and deploying more antennas. Combining these two measures boosts capacity substantially. Figure 5 illustrates a simplified view of cell capacity at 3.5 GHz compared to the existing 4G cell capacity. This assumes that the 3.5 GHz band has 100 MHz of bandwidth available while LTE1800 has 20 MHz. Massive MIMO can improve spectral efficiency by a factor of two to four. The new 3.5 GHz band is the most efficient way of increasing the capacity of existing cell sites, achieving an increase of 10-20x.

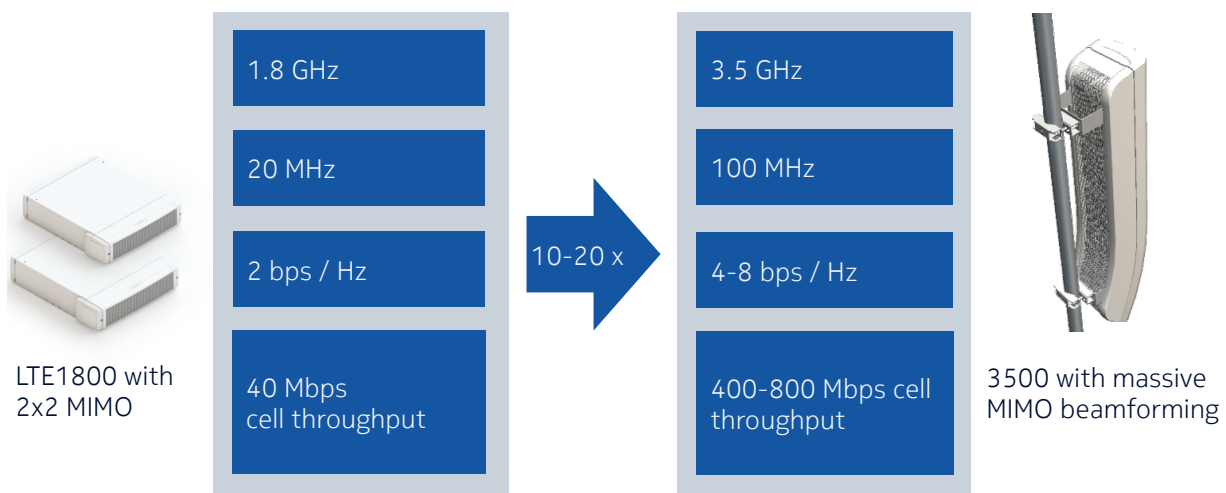


Figure 5. 5G versus 4G capacity per cell.

Sub-1 GHz capacity is limited by the comparatively narrow bandwidths available, typically 2x 10 MHz FDD, and the limited options for using advanced 5G antenna technology. However, this does not affect the performance of most of the new 5G services that require moderate data rates, but does enable them to benefit from the excellent coverage properties of these bands.

Future network deployments, especially high capacity sites, need to take into account Electromagnetic Field (EMF) limits in terms of maximum allowed Equivalent Isotropic Radiated Power (EIRP). These limits are country specific, which calls for flexibility in the way that solutions can be deployed. Nokia solutions achieve this flexibility by enabling dynamic power sharing in multiband RF units, minimizing average transmission power with lean carriers, and the seamless integration of small cells with the macro network.

Low bands become even more important where high power levels are not feasible to boost coverage.

3. The benefits of running 5G on low bands

5G will enable extreme mobile broadband, massive IoT connectivity and ultra-reliable critical communications. Ubiquitous coverage is the most important aspect of reliable connectivity, especially for massive IoT and critical communications, see Figure 6. Therefore, low bands are highly important for the success of 5G.

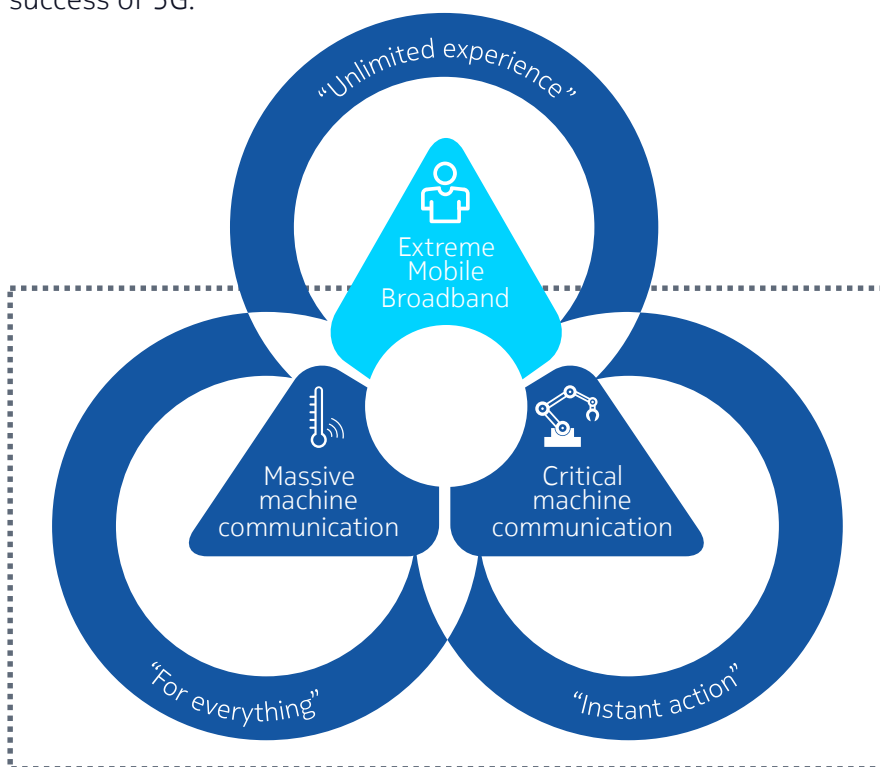


Figure 6. IoT and critical communication requires ubiquitous coverage.

5G radio can substantially improve network performance and efficiency, as summarized in Figure 7.

Yet some of these gains can also be obtained with 4.9G, which is an evolution of existing LTE networks. Nokia expects 5G to be able to provide lower latency, lower IoT power consumption, higher network energy efficiency and enhanced spectral efficiency. The values in Figure 7 are based on the following assumptions:

- The shortest transmission time in 5G is 0.125 ms, which enables a round trip time of 1 ms.
- IoT average power consumption of 7 mW with one transmission per minute
- Efficiency energy use is based on a 3-sector 100 MHz macro base station with a busy hour average throughput of 1 Gbps, 7 percent busy hour share, 200 W base station average power consumption, and 20 percent of base stations carrying 50 percent of traffic. These assumptions deliver an average base station utilization of less than 15 percent.

The five-fold efficiency improvement over LTE is obtained through power saving techniques used at low loads and with a wideband carrier of up to 100 MHz at 3.5 GHz. 5G technology has built-in components to minimize energy consumption compared to a similar LTE configuration, although the absolute power consumption per base station in 5G may be higher than in LTE because of high power massive MIMO transmission.

- A spectral efficiency of 10 bps/Hz/cell assumes the use of massive MIMO beamforming and four antenna devices. By comparison a typical LTE downlink efficiency is 2 bps/Hz/cell in live networks and 30-50 percent more with 4x4MIMO.

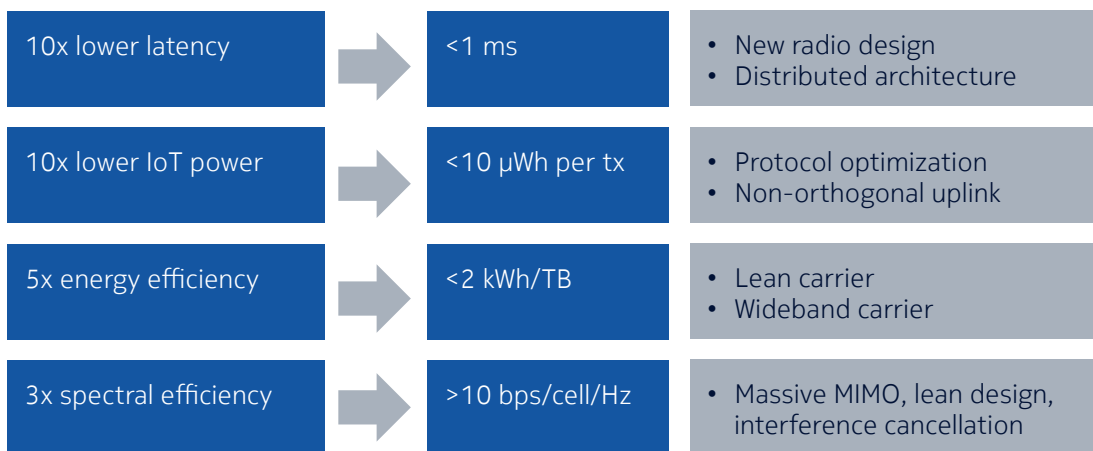


Figure 7. Summary of 5G technology capabilities compared to the existing LTE networks.

4. Example deployment in a large city

Let's now look at a potential deployment and spectrum utilization for early phase 5G implementation.

The scenario is located in a major European city as shown in Figure 8. The low band 700 MHz layer is used to provide wide area coverage and indoor penetration. The low band enables low latency communication for ultra-reliable use cases and for IoT connectivity.

Across the larger metropolitan area, new 5G applications, such as automated driving and smart grids, can benefit from 5G coverage.

The 700 MHz network can reuse existing 800/900 MHz base station sites. The dense urban coverage and high data rates are provided by the 3.4-3.8 GHz band which supports enhanced mobile broadband with much more capacity. Existing base station sites around 2 GHz can also be reused.

Extreme hotspot capacity and data rates are provided by 25 GHz mmWave bands. The millimeter wave coverage is focused on stadiums, airports and other areas with high usage density, as well as research and development centers to allow interested parties to develop, implement and test new 5G applications.

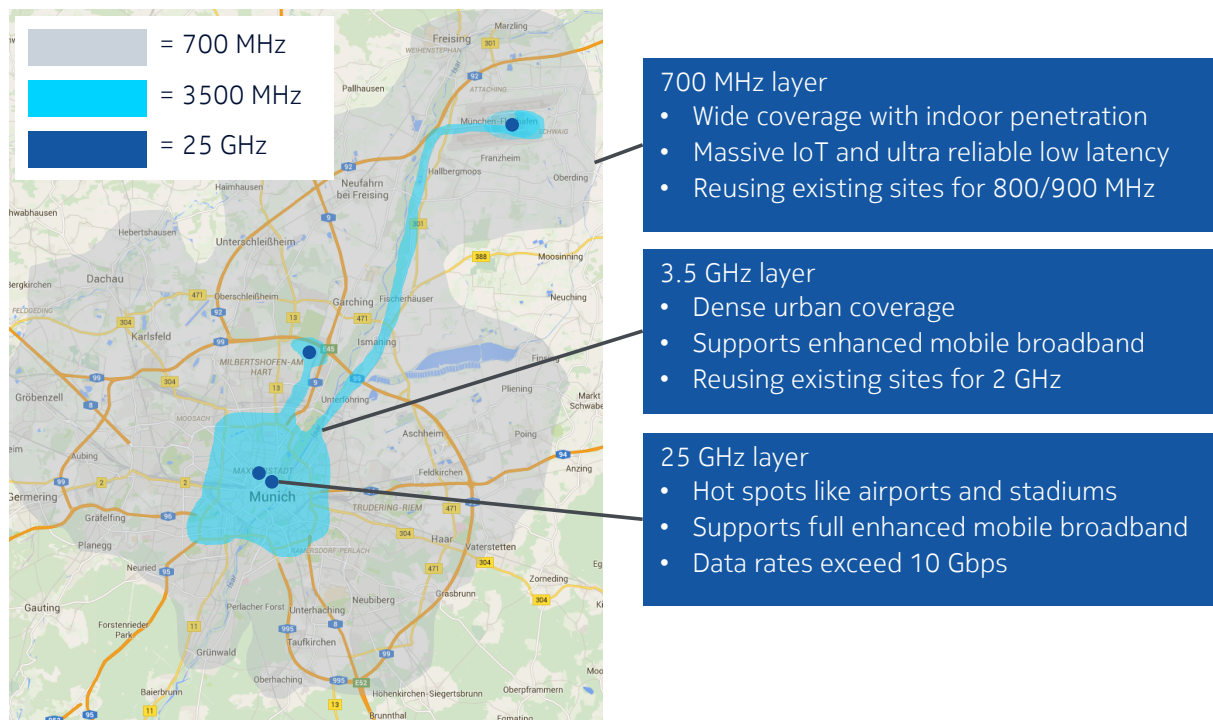


Figure 8. Example early phase 5G deployment in a European city.

5. Shared and unlicensed spectrum

3GPP technologies have traditionally been deployed only on licensed spectrum bands, but future deployments will be different. 5G is designed for licensed, unlicensed and shared spectrum. This opens up a wide range of possibilities for enterprises and industries to take advantage of reliable 5G connectivity without the need for a spectrum license.

The unlicensed band plans in 3GPP are shown in Figure 9. 5G can also be deployed on shared spectrum like 3.5 GHz in USA where 5G can access a large amount of spectrum without affecting incumbent services.

Large number of spectrum options considered	For example 5 GHz, 37 GHz and 60 GHz spectrum
Standalone unlicensed operation included	Standalone unlicensed and dual connectivity with licensed bands
Regulatory aspects and fairness considered	Listen-before-talk and other co-existence solutions

Figure 9. Unlicensed spectrum with 5G.

6. Conclusion

While the deployment of 5G on high frequency bands in the mmWave range will provide extreme capacity, the roll out of 5G in sub-6 GHz low bands will characterize early commercial phases, providing a capacity boost and wide coverage to support most applications.

A selection of technologies is available to help CSPs evolve smoothly to 5G and use existing and new spectrum to build capacity and ubiquitous coverage.

5G is most likely to be first deployed on newly available 3.5 GHz and 4.5 GHz spectrum, sub-1 GHz spectrum released by the digital switch-off, on spectrum made available by refarming 2G and 3G frequencies, and using new unlicensed spectrum. In addition, we will see 25-39 GHz mmWave spectrum being used to meet the needs of extreme hotspots like event stadiums.

This flexibility of 5G to be able to use a vast range of different spectral bands is an attractive benefit for CSPs and enterprises, one they have not enjoyed with any previous mobile radio standard.

Further reading

Nokia white paper: “5G Master Plan” <https://pages.nokia.com/5g-master-plan.html>

Nokia white paper: “5G for Mission Critical Communication” <https://pages.nokia.com/GC200007.html>

Nokia white paper: “Translating 5G use cases into viable business cases” <https://resources.ext.nokia.com/asset/201152>

Nokia white paper: “Dynamic end-to-end network slicing for 5G white paper” <https://pages.nokia.com/GC200339.html>

Nokia white paper: “5G System of Systems white paper” <https://pages.nokia.com/GC200012.html>

Abbreviations

EIRP	Equivalent Isotropic Radiated Power
EMF	Electromagnetic Field
FDD	Frequency Division Duplex
IoT	Internet of Things
LTE	Long Term Evolution
mMIMO	Massive MIMO
TDD	Time Division Duplex



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