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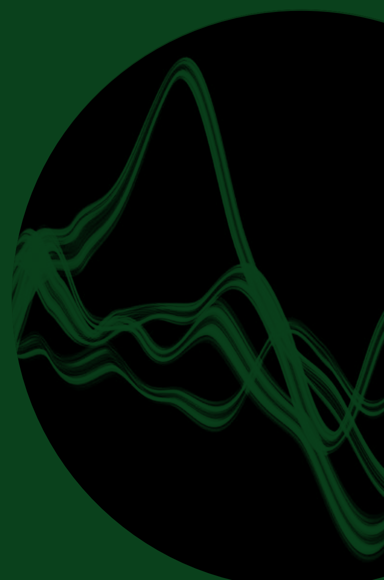
ERICSSON TECHNOLOGY Review



5G NR WITH LTE AT EXISTING SITES

ERICSSON

THE ADVANTAGES OF

Combining 5G NR with LTE

AT EXISTING SITES

5G at mid and high bands is well suited for deployment at existing site grids, especially when combined with low-band LTE. Adding new frequency bands to existing deployments is a future-proof and cost-efficient way to improve performance, meet the growing needs of mobile broadband subscribers and deliver new 5G-based services.

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The speed expectations and data consumption of mobile broadband (MBB) subscribers continue to grow rapidly. Already today, there are 4G networks in urban areas that are being densified with new sites (macro sites, small cells and indoor solutions, for example) as a result of spectrum exhaustion. Further, in regions such as western Europe and North America, the data demand per smartphone is projected to grow by 30-40 percent yearly [1], resulting in a four- to fivefold increase in five years. Adding new frequency bands at existing sites is a cost-efficient way to meet this demand and improve performance. The ability to achieve indoor coverage is particularly important, because the majority of the traffic is generated indoors [2].

■ Many people in the telecom industry tend to associate the deployment of high-frequency bands with poor coverage, which results in the need for new sites, which leads to high deployment costs. This is, however, not at all the case for 5G New Radio (NR) [3]. 5G NR is designed to make use of frequency bands above 3GHz and offers the possibility to introduce new frequency bands – typically above 3GHz – into existing 4G networks. Taking advantage of this possibility makes it easier to meet the increasing demands from MBB-based services, while simultaneously ensuring that site and backhaul infrastructure investments can be reused. 5G NR is also available for use in new bands below 1GHz and existing 3G/4G bands. Smooth migration from 4G to 5G in existing spectrum in a RAN can be done by means of spectrum sharing, where NR is introduced in parallel with LTE.

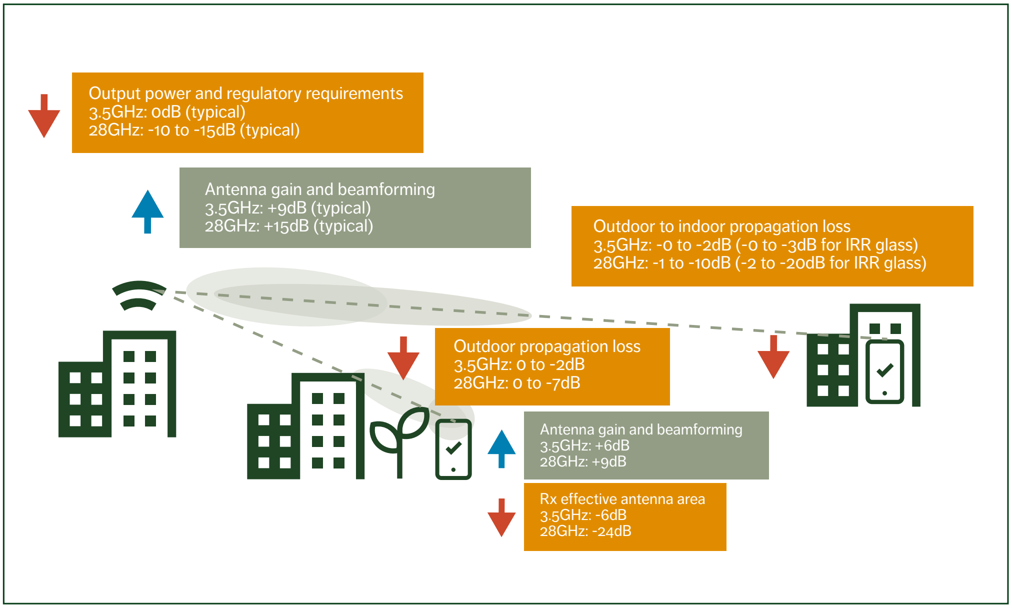

Figure 1 Schematic indication of antenna and propagation factors affecting downlink coverage positively (blue) or negatively (red) compared to coverage at a reference frequency of 1.8GHz. The numbers are indicative and may vary.

The main new NR frequency bands will typically be allocated as TDD in the mid (3-6GHz) and high (24-40GHz) bands. These bands present several interesting challenges and opportunities. By means of measurements and radio network simulations of coverage and capacity, we have demonstrated that it is feasible to deploy both mid and high (also known as millimeter Wave or mmWave) bands on existing sites.

Thanks to beamforming, a fundamental technique in NR, the need for site densification is much smaller than anticipated – particularly when interworking with LTE is applied. Beamforming and massive multiple-input, multiple-output (MIMO) techniques also provide higher capacity from existing 4G sites, which creates room for new 5G-based services and use cases in addition to MBB.

High-frequency challenges and opportunities

The use of mid and high bands for 5G makes it possible to utilize much higher bandwidths. However, the increased carrier frequency can also make it more challenging to provide coverage that is similar to existing low-band deployments. There are three primary reasons for this: (1) physical limits on the power reception capabilities of antennas; (2) radio frequency output power limitations; and (3) increased propagation losses, as shown in *Figure 1.*

> THANKS TO BEAMFORMING ... THE NEED FOR SITE DENSIFICATION IS MUCH SMALLER THAN ANTICIPATED

> THE HIGHER PROPAGATION LOSSES CAN BE MITIGATED BY USING HIGH-GAIN ANTENNAS

But the higher frequencies also allow higher antenna gains to be generated without increasing physical antenna size. 5G can utilize these increased antenna gains through beamforming both at the transmitter and at the receiver, which helps mitigate the impact on coverage at higher frequencies.

Additionally, increasing the frequency will allow the antennas to become smaller while maintaining the same antenna gain. It is important to note that any fixed-gain antenna in receiving mode actually captures 20dB less energy for each tenfold increase of the frequency. This is often misunderstood as a propagation loss, when in reality it is a result of a decreasing effective antenna area. If the physical antenna area of the antenna is maintained, its power capture capabilities become independent of frequency, while its antenna gain, for both reception and transmission, grows with the frequency at the same time as the beam width becomes smaller. Thus, at higher frequencies, there is a trade-off between reducing the antenna size and increasing the antenna gain. Coverage and implementation aspects determine the sweet spot.

The achievable output power at higher frequency bands such as mmWave frequencies can also be limited by power amplifier technology and by regulatory requirements [4]. Theoretically, the antenna gain of a fixed-size transmitting antenna would grow by 20dB per decade in frequency (dB/decade), but in practice the increase in EIRP (effective isotropic radiated power) may be smaller due to such constraints.

Electromagnetic wave propagation in cellular networks involves some processes that are strongly frequency-dependent, such as diffraction or transmission through, for example, walls or foliage, but also others such as free space propagation and reflection or scattering that show little to no difference over frequency. Effectively, the outdoor propagation loss is similar or increases slightly with increased frequency, as indicated in Figure 1.

Outdoor-to-indoor propagation losses can be challenging to overcome, especially for buildings equipped with thermally-efficient window glass, which can add up to 20-40dB of additional loss at a given frequency. When increasing the frequency, the outdoor to indoor losses also tend to increase, particularly for deep indoor locations. This increase is small to moderate for regular buildings but can be strong for thermally-efficient buildings, as shown in Figure 1.

The higher propagation losses can be mitigated by using high-gain antennas on both transmitters and receivers. These antennas become directive, forming beams with strong gain in certain directions, and low gain in other directions. The beams need to be set up and maintained to point in the right directions in order to support mobility. In NR, this is supported by beam management. Besides the benefit of amplifying the signal in the desired direction, beamforming also attenuates the signal in other directions, leading to less interference and better channel quality. This can be done to the extent that multiple users, using different beams, can communicate with a base station on the same frequency and time resource. This is known as multi-user MIMO (MU-MIMO), and it enables a significant capacity improvement.

Even with beamforming, using existing site grids, it can be difficult to reach full coverage on higher frequencies. But since a lower frequency band tends to be available, this is not a problem. Users out of coverage on the higher frequencies simply fall back to the lower frequency bands. This can be accomplished by interworking techniques such as dual connectivity or carrier aggregation. The result is a 'forgiving' situation, where a mid- or high-band deployment does not need to be dimensioned for 100 percent coverage. Instead, it simply takes care of the traffic that it covers.

To summarize, the numbers in Figure 1 illustrate that the use of today's technologies, power levels and beamforming gains on the mid band (3-6GHz) provides better downlink (DL) coverage than

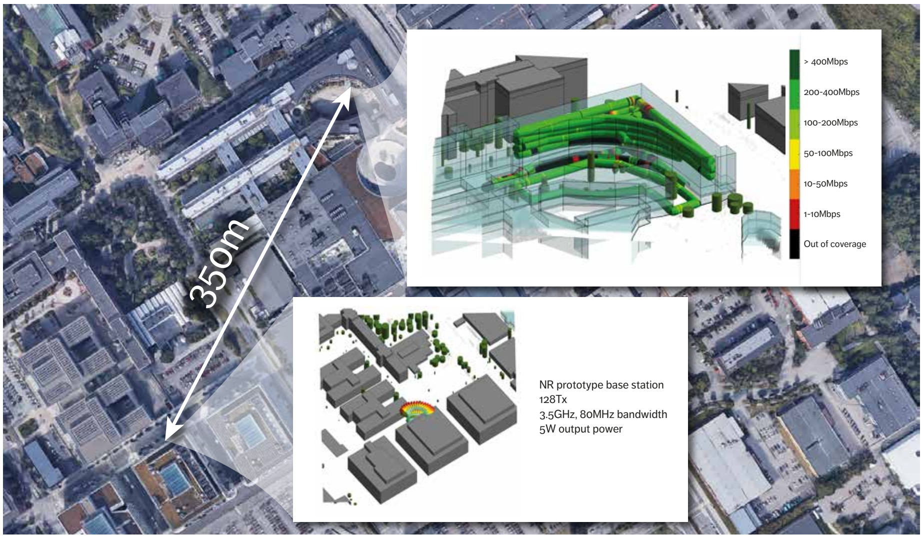

Figure 2 5G outdoor-in throughput measurement results from an NR 3.5GHz radio prototype

the 1.8GHz reference. Even so, users in the worst positions require the support of a lower frequency band, especially in the uplink (UL) direction.
For high bands (around 30GHz), the situation differs substantially from the reference. Very good outdoor coverage is achieved on existing grids. Outdoor-to-indoor coverage can be achieved by targeted deployments with line-of-sight to the buildings intended to be covered.

Measured beamforming performance and outdoor-in coverage

Early proof points of the 5G concept and its performance can be obtained from measurements in a radio network prototype. Ericsson has developed 5G prototypes for several 5G frequencies, including 3.5GHz and 28GHz. Initial trial deployments are typically set up with a few radio sites and one or a few mobile terminals, allowing for a controlled measurement environment. Test results on beamforming performance are reported in references [5], [6] and [7]. The results demonstrate that high antenna gains can indeed be realized through beamforming, and that the beamforming is able to track fast-moving users with sustained communication quality. Moreover, good indoor coverage can be achieved with 5G at 3.5GHz, proving the feasibility of deploying 5G at existing 4G sites. One example from our measurements is shown in ***Figure 2,*** where indoor throughput in a building at the cell edge reaches 200-400Mbps on an 80MHz carrier using conservative rank-2 MIMO transmission.

“THE MID BAND (3-6GHZ) PROVIDES BETTER DOWNLINK COVERAGE THAN THE 1.8GHZ REFERENCE”

BENEFITS OF OVERLAYING 5G NR 3.5GHZ AT EXISTING SITES

- Better user data speeds – 95 percent of indoor subscribers have more than 200Mbps with today's typical site grids.
- Higher capacity – adding NR 100MHz TDD (75 percent DL) on top of LTE with 2x50MHz paired spectrum provides an eight times higher DL capacity than using only LTE. Normalized with the 1.5 times higher spectrum usage, NR is thus five times more efficient.

Predicted urban mid-band coverage and capacity

To predict 5G coverage and capacity on a larger scale, we have performed radio network simulations. We chose a part of central London with an inter-site distance of approximately 400m, which is representative of many European urban areas. Similar studies of major cities in other parts of the world, including Asia and the US, indicate that the findings from this study are also applicable in those scenarios. Radio base station characteristics such as beamforming capabilities, power and sensitivity reflect the implementations of the first product generations, and terminals are modeled with expected typical smartphone characteristics for mid and high bands. Four and 32 receive antennas are assumed for terminals in mid and high bands, respectively. For maximal fidelity, a digital 3D map is used together with an accurate 3D site-specific propagation model, explicitly capturing relevant propagation phenomena along the propagation paths [8].

We have modeled LTE systems operating at 800MHz, 1.8GHz and 2.6GHz, as well as an NR system operating at 3.5GHz. This configuration is representative of the non-standalone version of NR that was developed in 3GPP Rel-15. The LTE system uses FDD, 2x10MHz at 800MHz and 2x20MHz at each of 1.8GHz and 2.6GHz adding up to 100MHz paired spectrum, and regular sector antennas. The NR system uses TDD, 100MHz of unpaired spectrum, and a 64T64R antenna array of 8x8 cross-polarized antennas. We applied user-specific digital beamforming, and MU-MIMO with multiplexing of up to four users is supported both in the DL and UL. When LTE and NR systems are evaluated together, carrier aggregation between LTE systems and dual connectivity between LTE and NR carriers are applied for the interworking. Although not considered in this evaluation, there are several interesting possibilities to evolve the LTE systems – with more advanced antennas, for example.

Figure 3 shows DL and UL coverage in terms of achievable data rates in an unloaded network without interference. Eighty percent of users are indoors, and they are shown only from middle floors. When existing LTE rooftop sites are reused with 3.5GHz, both indoor and outdoor users have very good coverage in the DL. The black line in the color bar indicates that 95 percent of the indoor subscribers have coverage for 200Mbps in the DL compared with 50Mbps when aggregating all LTE systems (not shown in the figure). In addition, 95 percent of outdoor users can exceed 500Mbps in the DL with NR 3.5GHz alone. The UL is much more limited with 3.5GHz alone. NR-LTE interworking improves, and many of the blank spots in the 3.5GHz band are covered. The remaining areas with poor coverage are concentrated to inside large buildings with high-loss outer walls. These buildings are suitable candidates for indoor deployments. Comparing the gains from adding 3.5GHz in the DL and UL, it is clear that the gains are larger in the DL. This is due to a DL-heavy TDD asymmetry (75 percent) at 3.5GHz, and the fact that the UL, because of the lower transmit power, is more power-limited and thus gains less from additional bandwidth.

When traffic load increases, more users are active simultaneously, sharing the base station capacity, causing increased interference levels, and leading to a reduction in user throughput compared with the unloaded case. These effects are mitigated by the

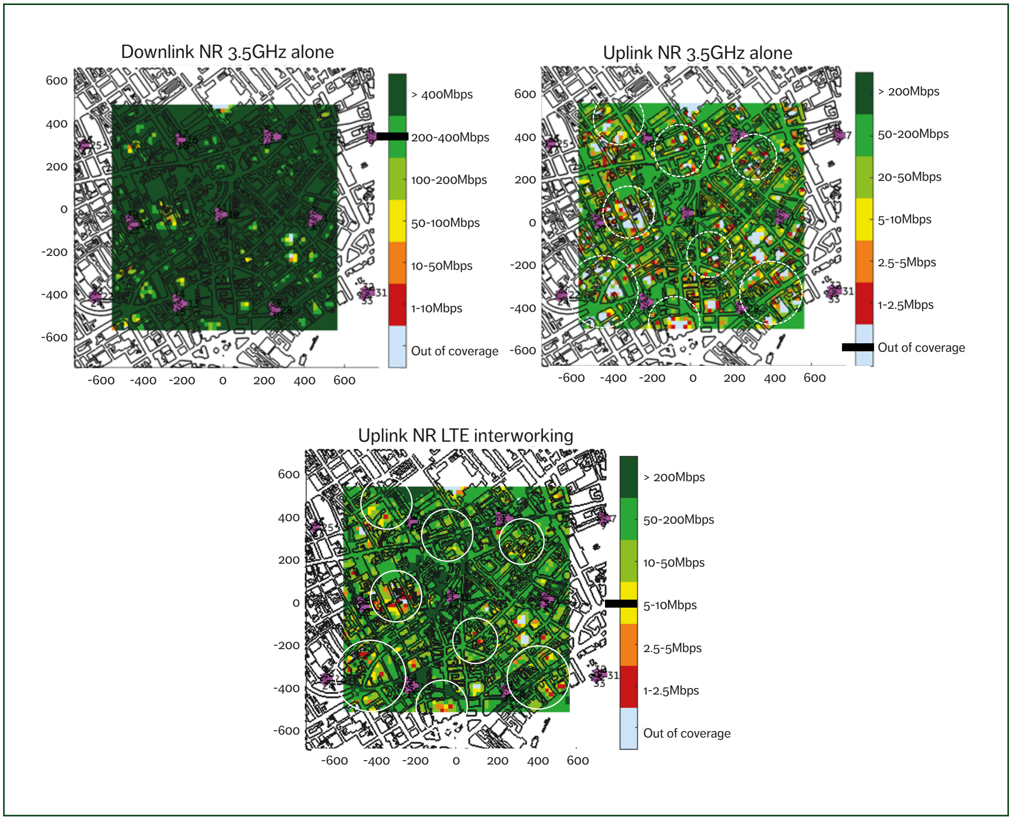

Figure 3 DL and UL coverage maps. The black line in the color legends represents the fifth percentile of an indoor user data rate, and the purple areas indicate antenna positions. The white circles mark indoor areas with limited coverage, improved by interworking.

NR system, using a wider bandwidth, beamforming and MU-MIMO. The ability to serve users in poor coverage areas on a lower band avoids the consumption of extensive resources on the 3.5GHz band, making it more efficient. To quantify the benefit of introducing NR, we measured the maximum traffic load for which (95 percent of) the users still achieve a user throughput exceeding 20Mbps. When adding NR in the DL direction, this maximum traffic load or 'capacity' increases by a factor of eight from 1Gbps/km² to 8Gbps/km² (corresponding to 135GB/subscriber/month, assuming 10,000 subscribers per km² and a busy hour traffic of 8 percent of the daily traffic). In the UL direction, the capacity gain is smaller than the DL due to TDD asymmetry (25 percent for the UL) and a lower transmit power. The capacity gains observed here are typical for a low-rise urban scenario with decent coverage. The gains are scenario-dependent and typically increase with improved coverage and increased vertical spread of users, and decrease with worse coverage and a smaller vertical spread.

> APPLYING MMWAVE SPECTRUM AT STREET-LEVEL SITES CAN ALSO BE A GOOD ALTERNATIVE

Predicted urban high-band coverage and capacity

The wide bandwidth available on mmWave spectrum can provide further increased data rates and additional capacity on top of the combined 3.5GHz mid-band NR and LTE system. Higher frequencies allow a higher gain of antenna array at the same physical area – both in a base station and at a user terminal side – so as to increase the maximum antenna gain.

Simulation studies in the central London scenario show that an NR 200MHz TDD system at 26GHz with the 256T256R antenna array of 16x16 cross-polarized antennas can provide very good DL coverage to outdoor users – for example, 50-60 percent approaching 1Gbps. With larger spectrum allocations such as 400MHz, it is possible to reach multi-Gbps speeds. When there is line-of-sight from the base station to a building and the building is a low-loss type, there is also a good chance that indoor users will be well covered.

Our results show that deploying the 3.5GHz and 26GHz band on existing macro sites can provide a capacity improvement of approximately 10 times compared with the LTE systems in low and mid bands. This additional gain is because 26GHz offloads the lower frequency bands by letting good-coverage users utilize an additional 200MHz, which thereby improves overall performance.

Applying mmWave spectrum at street-level sites can also be a good alternative. By placing antennas on lampposts, outer walls and the like, it is possible to avoid typical diffraction losses from rooftops and achieve shorter distances to users on outdoor hotspots or in targeted buildings. Our simulation studies in the London scenario indicate that the street-level radio deployment of an NR system with 64T64R antenna array provides good coverage both in nearby outdoor areas and for indoor users in low-loss buildings with line-of-sight to the base station.

Suburban and rural deployment considerations

Despite the typically larger cells in suburban and rural scenarios, it is possible to achieve similar results to those that we have seen in urban scenarios due to differences in the radio propagation. While the urban environment is characterized by relatively low antennas, frequent large obstacles and large, highly attenuating buildings, the suburban and rural environments have taller antennas, fewer obstacles and smaller sized buildings with wall types that are easier to penetrate. This compensates for the differences in cell range, and as a result it is typical to achieve very good performance in suburban and rural scenarios as well.

Indoor deployments

In-building deployments play a central role in providing good indoor performance in many parts of the world today. Large buildings with high building entry losses are an example of a coverage-driven in-building deployment, whereas a crowded public venue like a train station or a stadium would be a good example of a capacity-driven one. Passive distributed antenna systems (DASs) are currently the most common solution used for indoor deployments.

The hardware components of a passive DAS often have an operating frequency range that is limited to bands below 3GHz, which means that adding the new NR mid or high bands requires a new 5G indoor solution. A radio dot [9] solution at 3.5GHz provides good coverage and much higher speeds than current LTE bands at the same radio node density, as well as consuming less power than a DAS. For extreme demands in terms of user speeds or capacity, an indoor solution based on mmWave small cells might be the best choice. In this case, it is important to deploy a mid-band coverage complement.

Conclusion

The key benefits of deploying 5G New Radio with mid bands (3-6GHz) at existing 4G sites are that doing so results in a significant performance boost and allows for maximal reuse of site infrastructure investments. By adding NR with 100MHz unpaired spectrum, it is possible to achieve eight times higher downlink capacity relative to LTE (2x50MHz paired spectrum) along with improved downlink data rates – both outdoors and indoors – by means of massive MIMO techniques such as beamforming and multi-user MIMO. Uplink coverage deep indoors is maintained through interworking with LTE and/or NR on low bands using dual connectivity or carrier aggregation (new, refarmed or by using LTE/NR spectrum sharing). As a result of these possibilities in 5G NR, growing data demands can be met with limited site densification.

> “IT IS POSSIBLE TO ACHIEVE EIGHT TIMES HIGHER DOWNLINK CAPACITY RELATIVE TO LTE”

Further speed and capacity increases can be attained by deploying 5G NR at high bands (26-40GHz), also known as mmWaves. The high bands are particularly effective outdoors and inside buildings with line-of-sight from the deployed radio node and with low wall loss properties. Buildings that have or need dedicated indoor solutions due to high penetration loss and interior losses can be successfully upgraded with upcoming NR bands for higher speeds and capacity at similar radio node density to those used for LTE in-building deployments today.

Terms and abbreviations

DAS – Distributed Antenna System | **DL** – Downlink | **IRR** – Infrared Reflective | **MBB** – Mobile Broadband | **MIMO** – Multiple-input, Multiple-output | **mmWave** – Millimeter Wave | **MU-MIMO** – Multi-User Multiple-input, Multiple-output | **NR** – New Radio | **RAN** – Radio Access Network | **Rx** – Radio Receiver | **Tx** – Radio Transmitter | **UL** – Uplink

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Further reading

- **5G deployment considerations, available at:** *https://www.ericsson.com/en/networks/trending/insights-and-reports/5g-deployment-considerations*
- **Massive MIMO increasing capacity and spectral efficiency, available at:** *https://www.ericsson.com/en/networks/trending/hot-topics/5g-radio-access/massive-mimo*
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