Most 5G deployments are expected to use the 3.5 GHz band across the globe. With acquisition of new sites being challenging, using existing LTE sites would be the best solution. However, LTE is mainly based on the 1.8 GHz band, while 5G’s 3.5 GHz has a much higher attenuation. This would require further cells to ensure the necessary coverage.

This paper demonstrates how to use an existing LTE 1.8 GHz grid for efficient 5G deployment in 3.5 GHz, using techniques such as beamforming, low band 5G deployment and dual connectivity.
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Executive Summary

Initial deployment of 5G is expected to be in the 3.5 GHz band in most areas of the world, with the exception of the United States, where early deployments will occur in either high-band (>24 GHz) or low-band (<2.6 GHz). One of the most difficult challenges in deploying a radio network is site acquisition and construction. Operators try to make maximum use of their existing sites to minimize both site expenses and time-to-market.

LTE networks have been typically deployed using the 0.7 – 2.6 GHz frequency bands. Since higher frequency signals attenuate more quickly, a 3.5 GHz 5G cell will have a significantly shorter range compared to a typical LTE cell - this is a particular challenge for uplink coverage. Shorter cell ranges will necessitate further cell densification to provide coverage of comparable quality, leading to higher costs and slower deployment. There is a critical need for improved coverage at 3.5 GHz so that existing LTE cell-sites can be used for 5G deployment to minimize the adverse effects of the higher frequency band for 5G.

In most of the world, LTE was initially deployed in the 1.8 GHz frequency band and the corresponding grid still represent the most common inter-site distances. Using those cell-sites for 3.5 GHz 5G deployment will be the ideal solution. However, path loss measurements indicate that the attenuation at 3.5 GHz is approximately 10 dB higher compared to 1.8 GHz, resulting in much poorer coverage and requiring new techniques to compensate for this loss. A massive MIMO antenna with beam forming at 3.5 GHz can provide 6-7 dB higher gain compared to a typical passive antenna at 1.8 GHz. The remaining 3-4 dB gap can be addressed using either low-band deployment or dual connectivity with LTE.

Low band 5G deployment improves 5G coverage in the uplink and downlink. The low band carrier can be either dedicated for 5G or shared with LTE. Dual connectivity is a solution where LTE is used for the user plane in the uplink, while 5G is used for the user plane in the downlink and for control plane in the uplink. All 5G devices in the early phase are expected to support dual connectivity and thus this solution is expected to be practical right from the introduction of 5G.

It is not practical to allocate all uplink traffic on the low bands because these have just 10-20 MHz spectrum, while 3.5 GHz typically has up to 100 MHz. Therefore, a 5G uplink solution must change the way it uses the different uplink bands depending on the loading and the coverage.

This paper demonstrates how to use an existing LTE 1.8 GHz grid for efficient 5G deployment in 3.5 GHz. The main solutions are summarized in Figure 1.

Figure 1. Solutions for boosting 5G coverage

- Massive MIMO beamforming
- 6-7 dBi higher antenna gain compared to passive antenna
- Low band uplink
- LTE uplink with dual connectivity, or 5G uplink with carrier aggregation
Signal Propagation at 3.5 GHz Band

Higher frequency transmissions lead to higher signal attenuation and shorter propagation distances. Simple propagation models show that the expected path loss difference between 3.5 GHz and 1.8 GHz is 6-10 dB outdoors.

To further improve the estimates, Nokia has conducted propagation measurements in a European city. The results in non-line of sight cases are summarized in Figure 2. The difference in outdoor propagation between 3.5 GHz and 1.8 GHz is 6 dB. There is an additional 3-5 dB indoor penetration loss, which makes the total path loss difference 9-11 dB. The indoor penetration loss is higher in modern buildings, such as office buildings with thick walls and aluminium framed windows, than in old buildings with thinner external walls and wood framed windows. We can conclude that there is approximately 10 dB propagation difference between 3.5 GHz and 1.8 GHz in indoor conditions.

Figure 2. Nokia propagation measurements 3.5 GHz compared to 1.8 GHz

Since users consume most of their data indoors, it is important to compensate for the entire 10 dB difference. In order to make full use of the LTE 1.8 GHz grid, we need solutions to improve 3.5 GHz 5G coverage by 10 dB. The rest of the paper deals with various solutions.
Massive MIMO Antenna Gain

For the sake of antenna gain, the required separation between antenna elements is directly proportional to the wavelength, or equivalently, inversely proportional to the frequency. Thus, the antenna panel can be made smaller when the frequency increases. A typical antenna for 1.8 GHz deployment is significantly smaller than an antenna of comparable gain for 0.7 GHz deployment, as shown in Figure 3. A typical 3-sector 4-port passive antenna at 700-900 MHz (i.e. <1 GHz) band and at 1.8 GHz (i.e., approximately 2 GHz) bands yield 15 dBi and 18 dBi gains with frontal areas of 0.4-0.56 square meters.

Furthermore, antenna gain can be improved by increasing the number of antenna elements. Thus, for a given form factor, it is possible to pack more antenna elements at higher frequencies and provide higher antenna gain compared to a lower frequency antenna with fewer antenna elements. As shown in Figure 3, a 3.5 GHz Massive MIMO antenna can provide 24-25 dBi gain, while a typical passive 1.8 GHz provides only 18 dBi antenna gain for a similar form factor (<0.5 square meter frontal area). A massive MIMO antenna assumes 192 antenna elements - 8 columns, 12 rows and cross polarization.

Figure 3. Antenna gain with massive MIMO beamforming

<table>
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<th>Sub-1 GHz</th>
<th>2 GHz</th>
<th>3.5 GHz</th>
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<tr>
<td>38 cm</td>
<td>32 cm</td>
<td>&lt;50 cm</td>
</tr>
<tr>
<td>1.5m</td>
<td>1.3m</td>
<td>&lt;1m</td>
</tr>
<tr>
<td>0.6 m²</td>
<td>0.4 m²</td>
<td>&lt;0.5 m²</td>
</tr>
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Antenna gain
15 – 18 dBi

Antenna gain
24 dBi

Passive 4-port antenna

Massive MIMO antenna
Coverage implications of Massive MIMO antennas

Cell range and thus the required number of cells, is strictly driven by coverage. For a given performance target, a 3 dB higher coverage results in a 20 percent extension in cell range and a 40-50 percent extension in cell area. For a coverage driven design, this difference can produce a major benefit by reducing the number of required cell sites correspondingly.

The relative link budgets on different frequencies are shown in Figure 4. The Okumura-Hata propagation model is applied to obtain the relative path loss values on different frequencies. The gain from massive MIMO at 3.5 GHz is assumed to be 24 dB. The difference between downlink and uplink is assumed to be 8 dB. These link budgets are calculated for the user plane connection.

The results show that 3.5 GHz with massive MIMO has a similar or better downlink coverage to that of a 1.8 GHz uplink. However, 3.5 GHz uplink coverage, even with massive MIMO, is 4 dB shorter than a 1.8 GHz uplink. Therefore, there is a clear need to improve uplink coverage by innovative receiver algorithms such as interference rejection combining or multi-cell reception. There are also further solutions for improving uplink coverage. Those solutions are presented in the next sections. Similar conclusions can be drawn for the North American frequencies currently at 1.7 and 1.9 GHz, as well as the upcoming 3.7-4.2 GHz allocation.

Figure 4. Relative link budgets on different frequencies
Uplink Coverage Solutions

Uplink coverage can be improved by using a lower band, either a lower band 5G frequency or in dual connectivity mode with LTE as shown in Figure 5. The solutions are discussed in more detail in the following subsections.

Figure 5. Main solutions for extending 5G coverage at 3.5 GHz

- **Low band 5G at 700-2600 MHz**
  - Carrier aggregation with high band 5G
  - Optionally dynamic refarming with LTE

- **Dual connectivity**
  - LTE user plane in uplink
  - 5G control plane in uplink

**Low Band 5G deployment**

Low band usage for 5G is one alternative to make 5G coverage better in both uplink and downlink. Low band 5G can be deployed together with LTE on the same band. Spectrum sharing can be realized in either the frequency or time domain, as illustrated in Figure 6.

Figure 6. Options for low band 5G usage
The rapid time and frequency domain sharing is a new capability called Dynamic Spectrum Sharing (DSS). Both LTE and 5G can use the full frequency band while the resources are shared. DSS brings benefits because it allows to frequency allocation to be changed instantaneously between LTE and 5G. On the other hand, co-existence has lower spectral efficiency due to overhead. Common channels and reference symbols are needed for both systems, which imposes an additional overhead compared to LTE-only and 5G-only cases. Figure 7 shows channel structure in the time and frequency domains for a shared LTE-5G carrier. 5G capacity is affected by LTE Cell Reference Signals (CRS) and Physical Downlink Control Channel (PDCCH) overheads. DSS will also affect latency when LTE and 5G resources are shared in the time domain.

Figure 7. LTE and 5G sharing in time domain

Dual Connectivity with Low-band LTE
Dual connectivity allows the combination of two radios, LTE and 5G. Furthermore, dual connectivity allows inter-site operation, where 5G and LTE connections use different sites, as shown in Figure 8. This capability can be highly useful in the early phase of 5G deployment where the number of 5G base stations is low and a single 5G site can cover multiple LTE sites. Inter-site dual connection allows one 5G cell to collect traffic from many LTE cells, helping to maintain connectivity.

Figure 8. Inter-site dual connectivity concept
The dual connectivity solution to improve uplink coverage is available when 5G is first deployed. The first 5G devices are based on non-standalone architecture (NSA) and support simultaneous LTE and 5G radio connections. With a split bearer in Dual Connectivity, the uplink can be mapped to either of the two systems. The idea is that 5G is configured as the primary entity in the split bearer case and 5G radio is used for data transmission as much as possible. If the 5G uplink connection becomes weak and the throughput low, the data volume in the uplink transmission buffer increases and the UE uses LTE for uplink data transmission. The high-level concept is shown in Figure 9. LTE1800 is shown in this example but other LTE bands can also be used.

Figure 9. Spectrum and technology usage in dual connectivity in good and weak signals

Layer 1 and 2 control planes must be running in both LTE and 5G radios for dual connectivity. When 5G is used for the downlink data transmission, rapid layer 1 and 2 feedback is needed in the 5G uplink, even if the uplink user plane runs in LTE radio.

The 5G uplink includes Radio Link Control (RLC) Acknowledgement (ACK/NACK) on Physical Uplink Shared Channel (PUSCH), as well as Sounding Reference Signals (SRS) and Physical Uplink Control Channel (PUCCH) for L1 (HARQ) ACK/NACK. SRS in the uplink can be used by the base station to optimize the downlink beamforming in Time Division Duplex (TDD) systems. An overview of the user and control plane locations is shown in Figure 10.
Link budget analysis shows that it is feasible to use LTE for the user plane while continuing to run the control plane in 5G. With dual connectivity, 5G control channels have good enough coverage to use low band LTE for the uplink user plane. The reason is that the control channel data rate is very low, allowing the use of robust channel coding to provide extensive coverage. However, 5G SRS may be a bottleneck for uplink coverage if SRS is used for downlink user specific beamforming.

SRS can be implemented as either wideband or narrowband. Wideband SRS is needed for good beamforming performance, while narrowband SRS is a necessity for good coverage. Narrowband SRS refers to the transmission of SRS only on part of the bandwidth, which provides partial channel information for beamforming. It will take more time to scan the whole bandwidth with narrowband SRS, reducing downlink beamforming performance. Therefore, SRS bandwidth optimization is important in order to strike a balance between 5G coverage and beamforming performance.
**Supplemental Uplink**

One more option for improving uplink coverage is to use the Supplemental Uplink (SUL) solution, where an additional low band carrier is used in the uplink direction on top of the allocated 5G mid-band carrier. This low band uplink carrier is typically carved out of the spectrum used for LTE. It may be noted that even though a part of the LTE uplink spectrum is allocated to 5G, downlink LTE spectrum continues to be fully dedicated to LTE service.

This arrangement is possible because today’s LTE data traffic is quite asymmetric, with the downlink carrying 8-10 times more traffic than the uplink. Therefore, FDD uplink spectrum utilization is lower than downlink utilization, and it is feasible to allocate part of the LTE uplink spectrum for 5G.

In Release 15, uplink sharing from a network point of view is the only supported mechanism. This means that, when using dual connectivity and supplemental uplink on the same band, the anchor LTE eNodeB is required to control the sharing between LTE and the 5G uplink. We should note, however, that Uplink Sharing from UE Perspective (ULSUP) is not mandatory for Release 15 devices. ULSUP refers to the case where Supplemental Uplink is used together with dual connectivity in the same band. For example, if LTE uses 1800 MHz in dual connectivity, then 5G can use 1800 MHz for supplemental uplink only with network explicit resource sharing co-ordination. If there is no coordination, then LTE must use another band, like LTE800. The concept is illustrated in Figure 11.

Figure 11. Supplemental uplink without and with 5G – LTE coordination

![SUL at 1800 MHz without 5G – LTE coordination](#)

![SUL at 1800 MHz with 5G – LTE coordination](#)

We can summarize that low band 5G and dual connectivity are both attractive solutions in practice for uplink coverage. Low band 5G also brings enhanced downlink coverage and enables carrier aggregation between low and high bands.
Evolution of 5G Coverage Enhancements

Even though low band 5G is a simple and elegant solution, spectrum constraints in many countries may not allow such implementation in initial deployments.

Dual connectivity is the expected first solution to make uplink coverage better because the first 5G devices will support dual connectivity. Dual connectivity will slightly increase user latency, since uplink connection uses LTE instead of 5G. Dual connectivity has additional benefits in that it is also feasible in multi-vendor LTE-5G cases as well as inter-site cases.

Low band 5G is a useful solution, particularly for new 5G use cases requiring low latency. A 5G FDD solution can provide the lowest latency because FDD has continuous uplink and downlink transmission. Since low-band spectrum is available mostly in FDD mode, a low band 5G solution becomes relevant, in particular with 5G standalone architecture and a 5G core network. Low band 5G can be aggregated with 3.5 GHz for high capacity and data rates. An example evolution of 5G coverage enhancements with low band is illustrated in Figure 12.

Conclusion

Maximizing 5G network coverage is critical to gain full benefit from the network technology but traditional deployment at 3.5 GHz will need significant cell densification, leading to high deployment costs and long time to market. Using existing LTE sites for initial deployment is thus imperative where it is important to match the coverage of 5G in 3.5 GHz with LTE in 1.8 GHz as closely as practicable.

Several solutions can be used to enhance 5G coverage, including beamforming antenna and low bands. Studies indicate that the combination of massive MIMO beamforming and low band uplink allows similar coverage to be provided for the 5G downlink at 3.5 GHz as for the existing LTE at 1.8 GHz, making it practical to reuse existing LTE base station sites for 5G deployment. The first solution for low band uplink is dual connectivity where low band LTE is used for the uplink user plane. The next solution is low band 5G deployment which is beneficial both for uplink and for downlink 5G coverage and is a good starting point for providing wide area ultra-reliable connectivity. The low band 5G deployment is facilitated by the Nokia Dynamic spectrum sharing feature.
Abbreviations

ACK Acknowledgement
CRS Cell Reference Signals
CSI Channel State Information
DSS Dynamic Spectrum Sharing
FDD Frequency Division Duplex
LTE Long Term Evolution
MIMO Multiple Input Multiple Output
NSA Non Stand Alone
PDCCH Physical Downlink Control Channel
PDSCH Physical Downlink Shared Channel
PUCCH Physical Uplink Control Channel
PUSCH Physical Uplink Shared Channel
RLC Radio Link Control
SRS Sounding Reference Signal
SUL Supplemental Uplink
TDD Time Division Duplex
TDM Time Division Multiplex
UE User Equipment
ULSUP Uplink Sharing from UE Perspective

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