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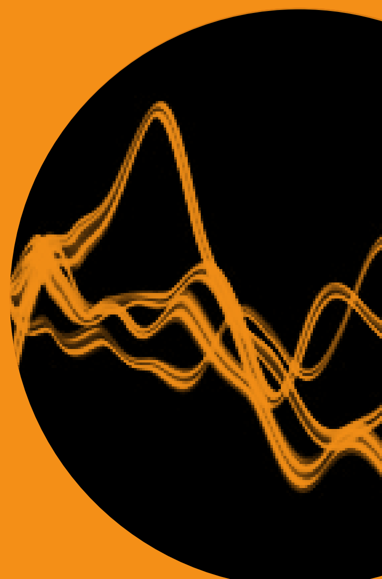
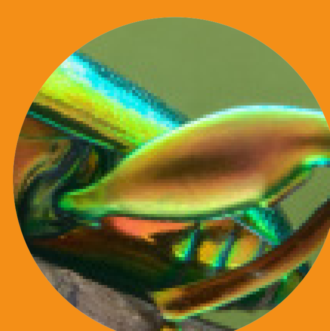


THE ROLE OF
MASSIVE MIMO
IN 5G NETWORKS



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Meeting 5G network requirements with Massive MIMO

5G New Radio (NR) has been designed to fully support Massive MIMO as a native technology from the start. The vastly increased coverage, capacity and user throughput that Massive MIMO provides has quickly made it a natural and essential component of cellular network deployments.

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Massive MIMO (multiple-input, multiple-output) radios are the leading radio solution for new 5G deployments on mid-band TDD spectrum. The ability to use a larger number of radio chains – 16-64, for example, compared with the 2-8 typically used in conventional radio solutions – makes it possible for communication service providers (CSPs) to benefit significantly from multi-antenna techniques.

■ Although Massive MIMO is still a relatively new technology – the term was first coined in academia about a decade ago with the first commercial solutions hitting the market about five years later – the technology has matured rapidly, enabling the creation of cost-efficient solutions that are both small in size and light in weight. Most of the Massive MIMO solutions on the market today have already gone through multiple hardware generations, often with optimized application-specific integrated circuits for beamforming and physical layer processing. They are available in a multitude of different models optimized for a wide variety of deployment scenarios [1, 2, 3].

Network requirements overview

5G networks are expected to outperform today's 4G networks in terms of capacity and user experience to cater for never-ending traffic growth and rising expectations, not only on mobile broadband services but also on new services such as XR (extended reality).

With this in mind, there are three ways a CSP can improve capacity and user throughput: by improving the spectral efficiency of existing frequency bands, by adding new spectrum and by densifying the network with more sites [3]. The high cost associated with acquiring and maintaining new sites means the decision to densify the network is typically only made when the other two alternatives have been exhausted.

Improving spectral efficiency is typically explored first, as it is associated with the least cost. However, additional spectrum will almost certainly be needed to meet 5G performance requirements. Many countries have released substantial amounts of new spectrum for 5G deployments that have the potential to unlock vast amounts of capacity. However, this spectrum is usually on a higher frequency band, such as 3.5GHz, with more challenging radio propagation compared with the frequencies used for 4G. The only way to efficiently use this spectrum on existing sites is with radio solutions that provide improved coverage.

From a user perspective, the requirements on throughput are often similar in all parts of the network. From a network perspective, however, the cells served by different sites may differ greatly in terms of size and traffic load, implying varying requirements on coverage and capacity. Cells with high, medium or low traffic load can be found in all environments.

Furthermore, there are often considerable variations in traffic load for each site over time. The peak-hour load level for each cell together with the expected traffic growth over time set capacity requirements. A site must handle the expected traffic load over the entire investment cycle, which is typically five to seven years.

> NETWORK REQUIREMENTS IN TERMS OF COVERAGE, CAPACITY AND EASE OF DEPLOYMENT VARY FOR DIFFERENT SITES

In addition to the performance requirements, there are deployment-related requirements to consider for some sites. The most important of these constraints are ease of deployment and cost efficiency. Ease of deployment includes aspects such as size, weight and the visual impact of the equipment. Cost efficiency in terms of both capex (that is, the cost of site equipment) and opex (site rental and energy consumption costs, among others) is always important, as the investments that the CSP makes are expected to provide sufficient value. A commonly used metric for cost efficiency is cost per capacity, which provides a trade-off between the cost of the product itself and the value it offers in terms of network performance.

In short, the network requirements in terms of coverage, capacity and ease of deployment vary for different sites in the network. Using the same radio solutions at all sites would be neither cost-efficient nor feasible, which is why different radio solutions are available.

Multi-antenna technologies

Massive MIMO improves network coverage and capacity through the use of the three multi-antenna

Terms and abbreviations

CSI – Channel-State Information | **CSP** – Communication Service Provider | **DL** – Downlink | **EIRP** – Effective Isotropic Radiated Power | **MIMO** – Multiple-Input, Multiple-Output | **MU-MIMO** – Multi-User MIMO | **NR** – New Radio | **RRU** – Remote Radio Unit | **SINR** – Signal-to-Interference-plus-Noise-Ratio | **SU-MIMO** – Single-User MIMO | **TCO** – Total Cost of Ownership | **UE** – User Equipment | **UL** – Uplink

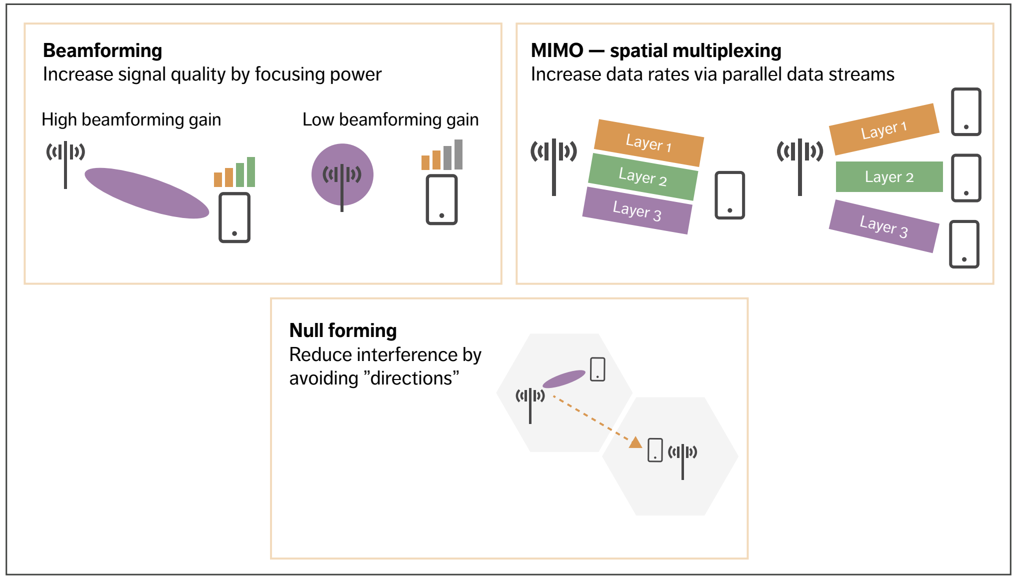

Figure 1 The three main multi-antenna technologies used in Massive MIMO

technologies – beamforming, null forming and spatial multiplexing – shown in *Figure 1*. All three are applicable to both the downlink (DL) and the uplink (UL).

The purpose of beamforming is to amplify transmitted/received signals more in some directions than others. The goal is to achieve a high beamforming gain in the direction of the device of interest to improve link quality in terms of signal-to-interference-plus-noise-ratio (SINR). This translates into higher spectral efficiency and/or better coverage for a single link, which in turn results in better network coverage, capacity and user throughput.

Null forming is a variant of beamforming that strives to lower the beam gain in certain directions or even reduce it to zero. By intentionally creating nulls or lower gain in the directions where the interfered transceivers are, interfering signals can be filtered out, resulting in a lower interference level, higher SINR and higher spectral efficiency.

Spatial multiplexing refers to the technique of multiplexing several data streams, or layers, on the same time-frequency symbol. The multiplexed data streams can all go to the same device or to different devices. Cases in which all the layers belong to the same device are referred to as single-user MIMO (SU-MIMO), while cases that involve spatial multiplexing of multiple devices are called multi-user MIMO (MU-MIMO). Spatial multiplexing can increase the spectral efficiency, which translates into increased user throughput and network capacity.

Beamforming and SU-MIMO are central to Massive MIMO. The ability of beamforming to increase the received signal level while not increasing the average interference level is key to obtaining high performance. Substantial beamforming gains can be achieved in a wide range of situations, regardless of DL/UL, traffic load, or if the user is in a good or bad spot. Coverage, capacity and user throughput are generally improved.

A particularly important strength of beamforming is its ability to increase DL and UL coverage, hence extending the area where users can benefit from

MASSIVE MIMO ✱

TDD mid-band deployments based on reuse of the existing site grid dimensioned for 4G FDD deployments.

Spatial multiplexing with SU-MIMO benefits from high signal levels. Beamforming helps to improve signal levels, which can then be exploited for single-user spatial multiplexing. Particularly in the DL, more than one layer to a specific user can often be supported in large parts of a cell. This contributes to its general applicability.

MU-MIMO improves performance at high traffic loads and in good channel conditions. These are conflicting requirements, as high traffic loads often lead to higher inter-cell interference levels, which means worse channel conditions. Compared with SU-MIMO, there are considerably more requirements on MU-MIMO to reach meaningful performance improvements. MU-MIMO is nevertheless a great capacity enhancement tool for highly loaded cells.

Intentional null forming to selected users serves to reduce interference to those users. It is a key sub-component of MU-MIMO to mitigate intra-cell interference, and it is also commonly used on the receiver side in both the UL and the DL to suppress inter-cell interference.

Massive MIMO features

All Massive MIMO solutions consist of both hardware (one or more Massive MIMO radios) and software (Massive MIMO features). A Massive MIMO feature can be described in terms of three factors [3]:

1. The network requirement(s) that the Massive MIMO feature is intended to meet
2. The available channel knowledge
3. The multi-antenna technique (or combination of techniques) that can be applied using the channel knowledge gathered in #2 to meet the requirement(s) in #1.

Different permutations of these three factors will yield unique Massive MIMO features – potentially with varying trade-offs and applicability to different conditions.

Firstly, it is essential to be clear about the requirement(s) that the feature is intended to meet – should it improve coverage, boost capacity or increase throughput? In some cases, one feature can solve multiple problems, while in others, trade-offs may be necessary. A feature that improves energy efficiency may have a negative effect on capacity, for example. It is therefore essential to assess which performance requirements are most important for a certain cell at a certain time. For instance, during off-peak hours, the capacity demand in a cell may be low, making it acceptable or even desirable to apply a feature that sacrifices capacity to improve energy efficiency.

All Massive MIMO features result from applying a combination of the three basic multi-antenna techniques – beamforming, null forming and spatial multiplexing – to a physical channel or signal, using available channel knowledge to solve a certain problem. This may sound simple, but there are several aspects to consider, resulting in a wide variety of potential features. A central question is how to acquire the channel knowledge required to perform beamforming, null forming or spatial multiplexing. This can be achieved in several ways, but it is important to understand that there is always a cost associated with acquiring channel-state information (CSI). Increased overhead is just one example.

There is also a problem of CSI availability. Different sounding and feedback methods are available in the 3GPP standard, and different user equipment (UE) may have different capabilities and support different CSI feedback and sounding formats. The network must therefore support several Massive MIMO features in parallel. Even if a UE supports a certain

“ALL MASSIVE MIMO SOLUTIONS CONSIST OF BOTH HARDWARE (MASSIVE MIMO RADIOS) AND SOFTWARE (MASSIVE MIMO FEATURES)”

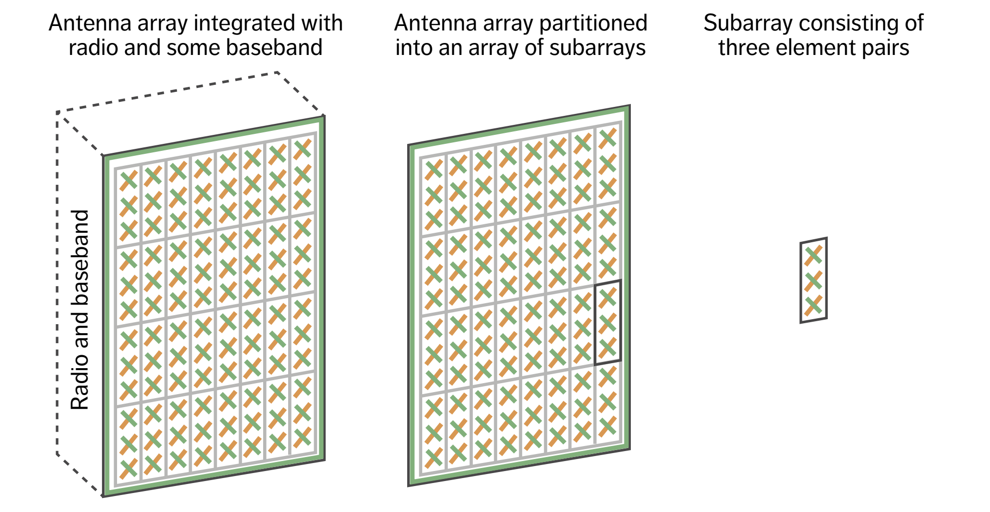

Figure 2 Massive MIMO radio, antenna array and subarray

CSI feedback and sounding formats, that CSI may not be available at a certain instance in time. For example, when a UE first connects to a cell, no channel information is generally available and measurement or sounding configurations will need to be set up, implying that there is a lead time before such CSI is available to the network.

Different sets of MIMO features are needed when limited/no CSI is available, compared with when CSI is available. Massive MIMO features can be classified at a high level as using either feedback- or sounding-based channel information and employing either SU-MIMO or MU-MIMO. In practice, there are many options for how to implement these aspects of a feature, both from what is available in the 3GPP standard and from a proprietary algorithm perspective.

By comparing the Massive MIMO features with respect to the network key performance indicators of interest (coverage, capacity and user throughput) they exhibit different strengths and weaknesses. Feedback-based beamforming has an advantage in coverage over sounding-based beamforming. Similarly, SU-MIMO has a coverage advantage over MU-MIMO. This is because MU-MIMO requires more detailed CSI and because MU-MIMO needs to split the available transmit power between multiple users. To fully utilize the potential of a Massive MIMO solution, it is necessary to dynamically adapt/switch the algorithm so that coverage, capacity and peak rate can be maximized jointly, which is how Massive MIMO solutions are typically designed.

Massive MIMO radios

Unlike conventional solutions in which separate basebands are connected to remote radio units (RRUs) that are connected to separate passive antennas, Massive MIMO radios integrate the radio, the antenna and some baseband functionality in the same unit. The reason for constructing Massive MIMO radios in this way is to avoid the need for them to support very high data rates on the interface between the radio and the baseband. *Figure 2* illustrates a Massive MIMO radio with an integrated antenna array that is partitioned into multiple subarrays.

There are two main characteristics of the antenna that have an impact on the properties of the MIMO radio solution. The first is the total antenna array size: the maximum antenna gain is proportional to the total antenna array size. The second is how the antenna array is partitioned into subarrays. Each subarray is controlled individually using a pair of radio chains. The finer the partition (that is, the smaller the subarrays), the better the steerability. A finer partition also results in higher cost and greater complexity, however, as more radio chains are needed for the same size of array.

A key factor affecting the effectiveness of subarray partitioning is the deployment scenario, and in particular the angular spread of users. As users typically are distributed uniformly in the horizontal domain, it follows that a fine partitioning in the horizontal domain, offering superior horizontal domain beamforming, is beneficial. The spread of users in the vertical domain is, however, highly scenario dependent.

In dense, urban, high-rise deployments, there may be a significant spread of users in the vertical domain – that is, the cells could be almost as tall as they are wide. In these scenarios, vertical-domain beamforming that features short subarrays and many radio chains offers performance benefits. However, in other, more suburban or rural deployments where the spread of users in the vertical domain is smaller, taller subarrays and fewer radio chains are most likely to offer competitive performance, making this solution the more cost-efficient choice.

In general, there are several important design parameters to consider when choosing between different radio solutions:

1. Radio parameters, such as the number of radio chains, output power, bandwidth and the number of frequency bands
2. Antenna array characteristics such as antenna size and subarray structure
3. Cost-efficiency and form-factor parameters such as size and weight.

> A CSP TYPICALLY WANTS TO MAXIMIZE THE USE OF THE AVAILABLE SITES BEFORE ACQUIRING NEW ONES

All of these parameters are essential when selecting a Massive MIMO radio solution with suitable characteristics for the different parts of the network.

Selecting the appropriate radio solution – guiding principles

For many CSPs, the first and most cost-efficient way of evolving their networks to meet network requirements is to deploy all available spectrum, including new 5G mid-band spectrum. This will unlock substantial capacity and provide a superior consumer experience. Performance can then be further differentiated by the choice of radio solution, either Massive MIMO or conventional, along with software features. Coverage of new 5G mid-bands is often more challenging than for existing 4G bands, which gives Massive MIMO, with its superior beamforming capabilities, an advantage over RRUs.

To ensure the selection of the appropriate radio solution, a CSP should begin by reviewing the existing network assets along with the strategies that it has put in place to meet its unique set of business objectives. Existing network assets – spectrum, sites and equipment – are central to determining how to evolve a network. Spectrum is the most valuable asset for a CSP, as it directly affects the achievable network capacity and consumer experience. Radio sites constitute another important asset that are often difficult and expensive to acquire and maintain. Therefore, a CSP typically wants to maximize the use of the available sites before acquiring new ones.

With respect to strategy, a CSP must consider any strategies it has that relate to the question of which services to offer, what QoS to offer, and where in the network to offer these services. The requirements of different services can be mapped to network

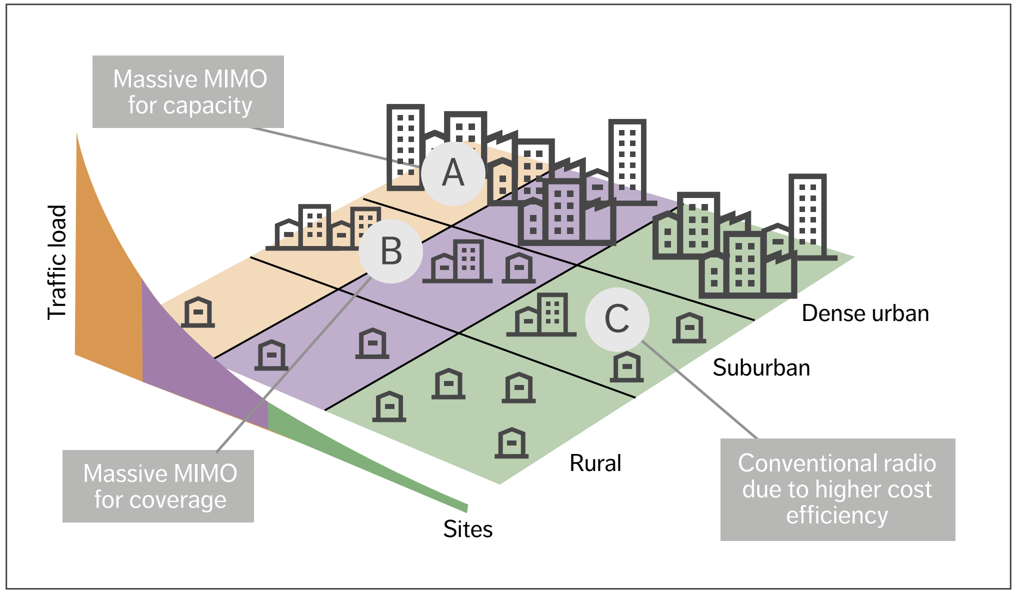

Figure 3 Suitable radio solutions when adding 5G mid-band spectrum at three site locations

requirements in terms of capacity and user throughput.

Once the inputs about existing network assets and strategy have been gathered, the next step is to do an analysis to find the performance requirements and constraints relevant for each site in the network. The answers to the questions about services (which, what and where) can be translated into specific network requirements. The current network traffic load and the predicted traffic growth including old and new services provide input on the maximum traffic volume (capacity) the network must support.

The deployment environment also has a profound impact on which radio (hardware and software) characteristics pay off in terms of network performance. For many sites, there are requirements on physical size, ease of installation, small visual impact and so on. These requirements may be driven by factors such as site building constraints, esthetical requirements, wind load and site accessibility, and in some cases, they are the determining factor in the selection process.

Based on an assessment of the total cost of ownership (TCO) per capacity for the whole investment cycle (typically five to seven years), the final step in the decision-making process involves choosing radio and feature solutions that meet the requirements and constraints for each site over the investment cycle. The radio solution toolbox includes both Massive MIMO and conventional radios. Feature solutions can be implemented more gradually than radio solutions, in response to emerging requirements.

Network evolution example

Figure 3 shows a network evolution example in which 5G mid-band spectrum is added at three different site locations – sites A, B and C. The colors orange, purple and green represent the traffic load levels high, medium and low, respectively.

Site A is in an area with high traffic load and high traffic growth, and there are no deployment restrictions with respect to size, weight and so on. To unlock the full potential of the 5G mid-band spectrum in this scenario, we would recommend the use of a high-end Massive MIMO radio that provides large bandwidth, high effective isotropic radiated power (EIRP) and many radio branches facilitating superior horizontal- and vertical-domain beamforming. Vertical-domain beamforming is motivated, as the UE distribution in the vertical domain is large. From a feature perspective, all available capacity-enhancing features should be deployed.

Site B is in a suburban area with a large inter-site distance, high traffic load and high expectations on traffic growth. As in site A, in this scenario we would recommend a high-end Massive MIMO product that provides large bandwidth and high EIRP to meet coverage and capacity requirements. Unlike site A, however, the UEs in site B are confined to a small angular area in the vertical domain. Therefore, a product supporting less vertical-domain beamforming (that is, fewer radio branches) would be sufficient.

Site C is in a low-traffic suburban area with low traffic growth where ease of deployment is an important factor. The latter point calls for a small radio solution, while the former indicates that a low-end radio offering less capacity would still meet the requirements. A conventional radio solution with few radio chains would therefore be a cost-efficient alternative to a Massive MIMO solution in this scenario.

Conclusion

Massive MIMO (multiple-input, multiple-output) technology boosts spectral efficiency through the use of multi-antenna technologies, which results in significantly increased network coverage, capacity and user throughput. Most 5G mid-band TDD deployments today incorporate Massive MIMO technology to unlock the full potential of new spectrum without the need for site densification. Massive MIMO radios have matured quickly and become competitive in terms of size, weight and cost.

“ MASSIVE MIMO UNLOCKS THE FULL POTENTIAL OF NEW SPECTRUM WITHOUT THE NEED FOR SITE DENSIFICATION ”

Multiple radio and feature options are available with different characteristics to meet the specific requirements of various types of sites in the network in a cost-efficient way.

Further reading

- Ericsson blog, How to build high-performing Massive MIMO systems, available at: *https://www.ericsson.com/en/blog/2021/2/how-to-build-high-performing-massive-mimo-systems*
- Ericsson, Massive MIMO boosts network throughput, available at: *https://www.ericsson.com/en/ran/5g-radio-fdd*

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