THE ROLE OF 8T8R IN 5G NR SUB-6 GHZ NETWORKS

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ABSTRACT

5G promises all kinds of new opportunities for mobile operators to deliver enhanced capacity and end-user experience to customers to address the ever-growing demand for data. But you need to prepare the groundwork correctly, and that means making the right choice of antennas and RF paths.

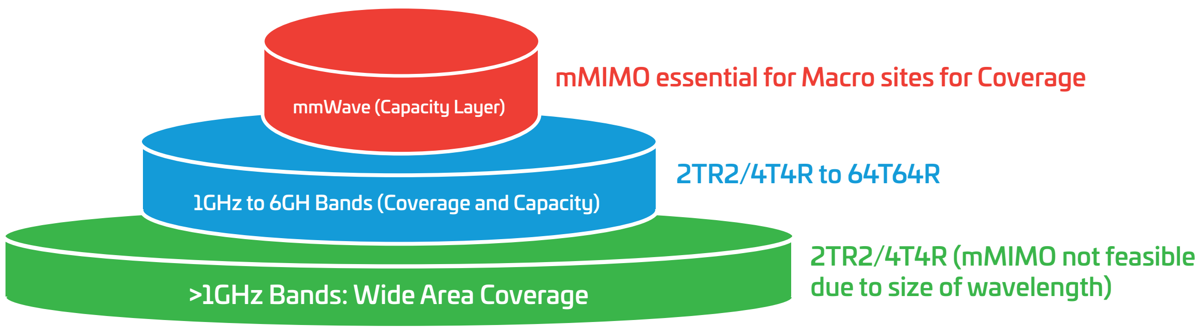
There are challenges to address on the road to 5G: which radio configuration is best suited to your needs? How many beams do you need for specific sites? What's your MIMO strategy?

This paper explores the options available for a pragmatic network planning strategy by comparing the advantages of 8T8R on mid bands with other configurations to deliver the expected coverage and capacity, efficiently and effectively.

Table Contents

INTRODUCTION

5G deployments in mid-band spectrum (>1 GHz) in the sub-6 GHz bands have the most options when it comes to radio configuration. Choices range from 2T2R to 64T64R, different from the sub-1 GHz band where only 2T2R or 4T4R is viable due to size of wavelength, or in mmWave bands where Massive MIMO (mMIMO) is essential for outdoor macro deployments to ensure sufficient coverage.



While this wide choice of radio configurations in mid-bands is nice to have, it also puts pressure on operators to make correct decisions. Picking the wrong radio configuration at one particular site can lead to undesirable outcomes such as:

- Insufficient network capacity and coverage, which creates network quality issues as well as a need for additional investment in site upgrades in a short time period
- Oversizing network capacity and coverage means inefficient CapEx and OpEx and generates minimal return on investment (ROI)

This paper will outline the benefits of 8T8R configuration in 5G network design, particularly C-Band, versus other available options.

Comparison of radio configurations

Making the right choice of antenna is a key factor in ensuring a site's proper coverage and capacity. Upgrading antenna and radio frequency (RF) paths lets operators use existing sites to meet increasing demands for capacity and coverage without the need to add new sites.

Below we compare the various radio configurations from 4T4R to 64T64R in terms of capacity, coverage and cost, and also look at what sites are best suited for each of these configurations.

For comparison, we assume that 4T4R is the lowest antenna configuration for 5G, and all other higher configurations are standardized to 4T4R. This is because 5G devices are expected to be able to receive four RF paths in all bands of sub-6 GHz. The Next Generation Mobile Networks Alliance (NGMN) recommends the following device MIMO configurations for 5G:

Frequency bands	Downlink MIMO	Uplink MIMO
Sub 1 GHz NR bands	2x2 mandatory 4x4 recommended	1x1 mandatory 2x2 recommended
NR FR1 bands above 1 GHz	4x4 mandatory	2x2 recommended

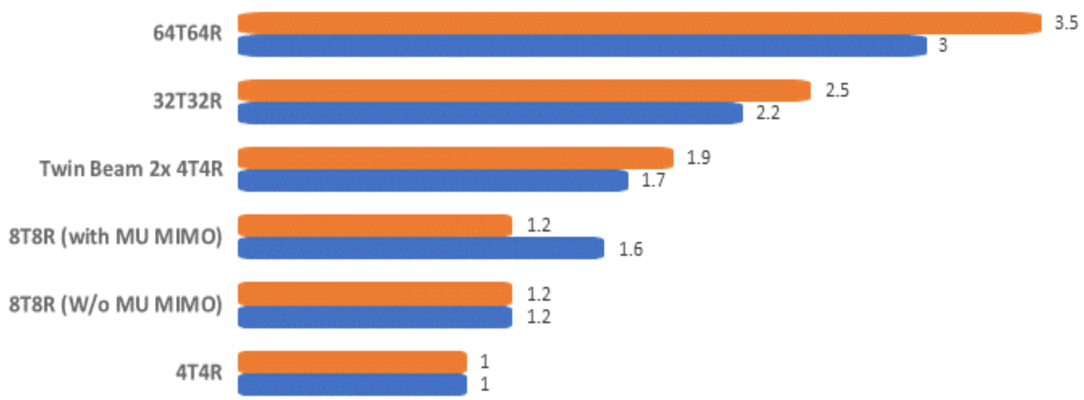
Table: 5G device MIMO capability recommendation by NGMN

Capacity vs cost comparison

The below graph outlines the comparative capacity and CAPEX of various RF path configurations.

This graph is a rough guide to simplifying capacity comparisons and is not intended to be a precise representation. Costs vary from one market to another, and are highly influenced by OEM strategy.

The configurations from 4T4R to twin beam come under the umbrella of Passive Antenna solutions, while 32T32R and 64T64R belong to Active Antenna solutions.

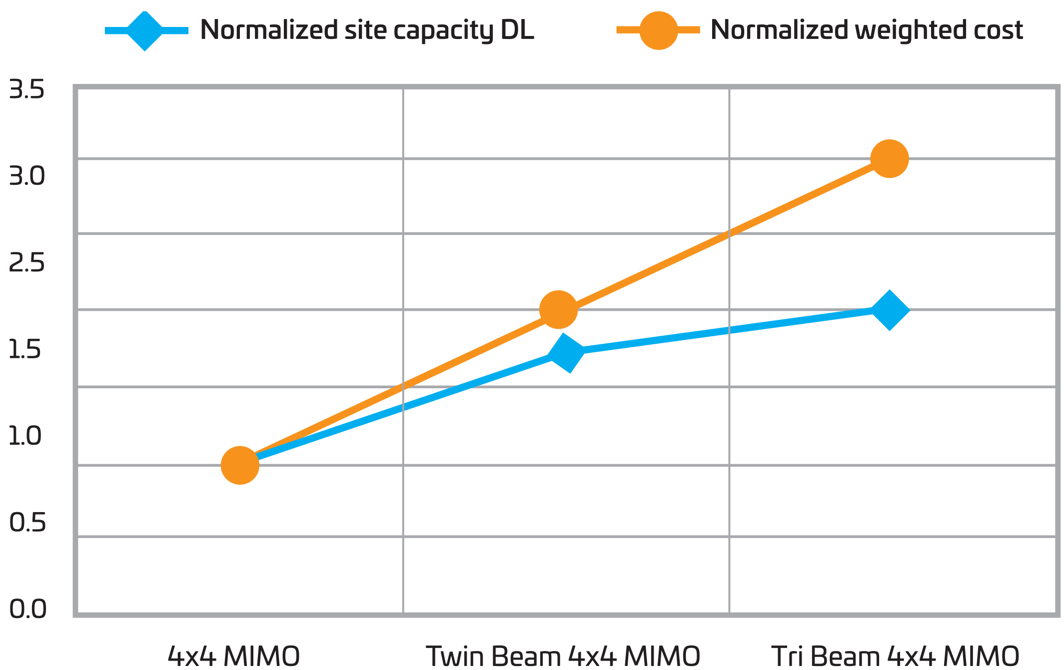


	4T4R	8T8R (W/o MU MIMO)	8T8R (with MU MIMO)	Twin Beam 2x 4T4R	32T32R	64T64R
Normalized Cost	1	1.2	1.2	1.9	2.5	3.5
Normalized Capacity	1	1.2	1.6	1.7	2.2	3

Some important takeaways from the graph and other relevant market observations:

- 8T8R without MU MIMO makes sense from an ROI perspective if the cost of the solution is in line with its capacity benefits. We have seen a lot of variations in costs of 8T8R radio, depending on the OEM and the market. This option has been the choice of operators for 4G networks in TDD bands in certain markets, if they have been able to find the optimum balance between cost and performance. Its adoption in 5G networks will most likely continue to be driven by OEM pricing strategy.
- 8T8R with MU MIMO support from OEMs can potentially be the most efficient solution in terms of cost vs performance. We have seen some OEMs make announcements in support of MU MIMO for 8T8R radios in 5G. With the expected support for MU MIMO for 5G devices, the solution can offer a strong business case for operators rolling out 5G. This option can be used as a default RF configuration for majority of sites (see network scenarios on page 9).
- A twin beam solution provides the highest capacity of passive RF path solutions. The traditional 2x4T4R twin beam solution costs almost twice as much as a single 4T4R configuration, and typically provides an average of 1.6 to 1.7 times the capacity of 4T4R—depending on traffic demand and distribution across beams. Another advantage of this solution is that it can support both TDD and FDD bands—unlike 8T8R beamforming, which is generally deployed with TDD bands in 4G. This is due to the lack of support for beamforming on lower-cost 4G devices in FDD bands, while TDD beamforming is supported by most legacy 4G devices. Most 5G devices are expected to support beamforming in both TDD and FDD bands.

- Multi-beam solutions such as tri-beam, five-beam, and nine-beam have been deployed by operators as specific solutions for specific sites and venues like stadiums and festivals. They are not used on a large scale as each beam requires at least a 2T2R or a 4T4R radio, depending on the MIMO strategy, meaning a tri-beam solution needs at least three radios, and a five-beam antenna needs five radios. The capacity benefits achieved aren't worthwhile versus the investment required, due to increasing inter-beam interference as more beams are added.
- Massive MIMO solutions like 32T32R and 64T64R deliver the biggest capacity benefits but also come with increased costs. Before investing in these configurations, it is worth evaluating the capacity benefits provided by features like support for multiple layers, MU MIMO, and three-dimensional beamforming. These features offer maximum benefits in heavily-loaded cells providing coverage to dense traffic distributed in the vertical plane, such as an urban area that has a lot of high-rise buildings and skyscrapers. In some networks, these are vital elements where it is possible to justify the large investments in them. However, there is a risk that this option can saddle operators with costs that don't generate sufficient returns—either through lack of traffic demand or types of clutter that don't need vertical scanning of beams.



Horizontal coverage comparison

Horizontal coverage depends on the Effective Isotropic Radiated Power (EIRP) of the solution. EIRP represents the sum total of radio power, all the gains and losses in the RF path between the radio and the antenna, and the antenna gain. If you assume that the radio power is kept the same across configurations, then you can compare just the RF path gains and losses and the antenna panel gain.

In massive MIMO configurations, there are generally no RF path losses as there is fiber-based digital connectivity between active antennas and distribution unit (DU). For an 8T8R solution, RF path losses can be minimized by reducing the lengths of jumper cables between the radio and antenna ports, or by using techniques like blind-mate connectors between the radio and antenna ports.

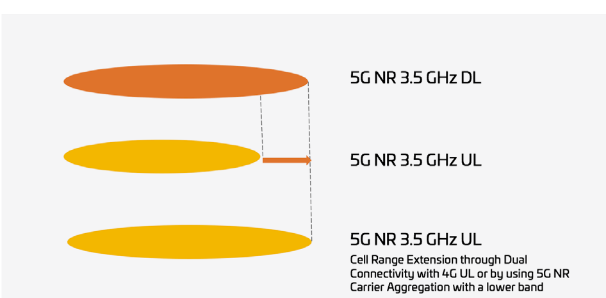
The below graphic shows that an 8T8R antenna panel has 64 half-wavelength dipoles (or 32 dual polarized antenna elements), while 32T32R and 64T64R have 128 dipoles (or 64 AEs). As per antenna theory, the gain of a single half-wavelength dipole is 0 dBd or 2.14 dBi, and a dual polarized dipole will have a gain of 3 dBd or 5.14 dBi.

An 8T8R antenna panel with 32 AEs will have a gain of 5.14 + 3*log2(32) = 20.15 dB. Please note that the second term in the equation is basically increasing the gain by 3 dB for each doubling of the number of dipoles. A 32T32R or 64T64R panel with 64 AEs will have a gain of 3 dB more than 8T8R, as both configurations have twice as many dipoles as 8T8R; therefore, the gain will be 23.15 dB (for the sake of comparison, simplification has been done to ignore the impact of dipole spacing and any other internal losses within the antenna).

The difference in dB terms for downlink coverage between the 8T8R solution and massive MIMO solution will be around 3 to 3.5 dB, if we include cable losses in this example. This translates to roughly 20 percent horizontal range advantage for a massive MIMO solution over 8T8R. By increasing the radio power of an 8T8R solution, you can bridge this gap for downlink. The massive MIMO solutions will still have an advantage in capacity terms through supporting a much higher number of TRXs, and more layers in the downlink and uplink. However, this capacity advantage can only be properly exploited at the right types of sites, as mentioned previously.

8T8R	32T32R	64T64R
Ant. Elements/Subarray = 8	Ant Elements/Subarray = 4	Ant. Elements/Subarray = 2
Subarrays/Column = 1	Subarrays/Column = 2	Subarrays/Column = 4
No. of columns = 4	No. of columns = 8	No. of columns = 8
Antenna Gain/TRX = 14 dB	Antenna Gain/TRX = 11 dB	Antenna Gain/TRX = 8 dB
Panel Gain = 20 dB	Panel Gain = 23 dB	Panel Gain = 23 dB

	8T8R	32T32R	64T64R
Cable Loss	0.5 dB	0 dB	0 dB
Net Gain	19.5 dB	23 dB	23 dB



Uplink coverage is maintained in 5G NR through interworking with LTE and/or 5G NR in low bands using dual connectivity or carrier aggregation.

Coverage of 8T8R beamforming antenna vs 4T4R MIMO antenna

A typical 4T4R MIMO antenna has only one antenna pattern with a nominal horizontal beamwidth of 65 degrees, and a nominal gain of 18 dB in mid-bands. This pattern is used for both traffic channels and the control channels of the 4G or 5G RAN. The graphic here shows the horizontal pattern of a typical 65-degree antenna.

A traffic channel is used to carry user payload and has a much higher throughput requirement than a control channel, which carries only the signalling bits. This means the coverage of a traffic channel will be much lower than that of the control channel in a typical network. Usable coverage is determined by traffic channel coverage in most cases.

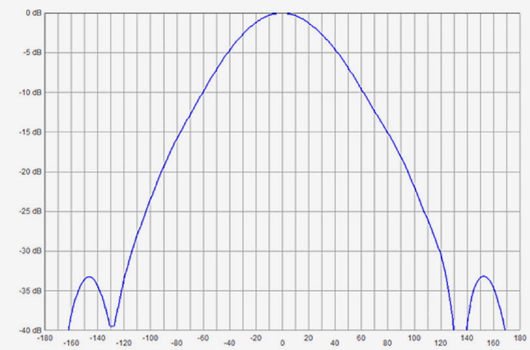
8T8R beamformers can have multiple antenna patterns based on weighting inputs fed to the antenna ports by the RAN. The RAN can utilize 8T8R beamformers to create ~22-degree horizontal beamwidth patterns to carry user payload, known as service beams. The gain of service beam is usually 3 dB to 3.5 dB higher than the 65-degree antenna beam. For example, the service beam gain could be ~21.5 dB. This essentially means an 8T8R antenna will improve the coverage of the traffic channels by 3.5 dB compared to a 4T4R antenna. Compared to the 4T4R fixed beam pattern, the envelope coverage pattern of an 8T8R antenna will usually provide 1 - 10dB gain over the sector, with less improvement near boresight and more improvement at the sector edges.

An example, using a network that has inter-site separation designed at 2300 MHz TDD for 4G: if a 5G NR network in the 3500 MHz band is deployed on an existing site grid designed at the 2300 MHz band, there will be at least a 3.65 dB coverage gap for 5G NR with the underlying 4G network, based on the difference in free space loss between the two bands.

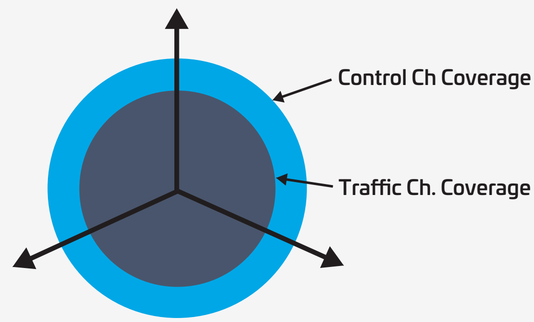
Free space loss difference = 20log(3500) – 20log(2300) = 3.65 dB

There could also be additional difference in coverage for in-building, based on the difference in building penetration losses between the two bands.

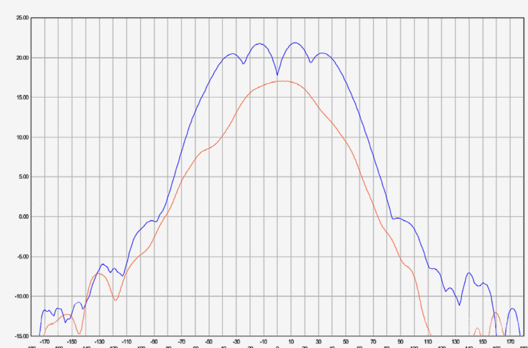
If a 5G NR network at the 3500 MHz band is deployed using 8T8R at a site that has an underlying 4G network at the 2300 MHz band using a 4T4R antenna, then the outdoor coverage difference of 3.65 dB between the two bands can be largely compensated with the higher gain of 3.5 dB of the 8T8R antenna with the service beam. So a beamforming 8T8R solution for 5G NR at 3.5 GHz is preferable thanks to the coverage benefits that can compensate for higher propagation losses compared to lower bands of 4G.



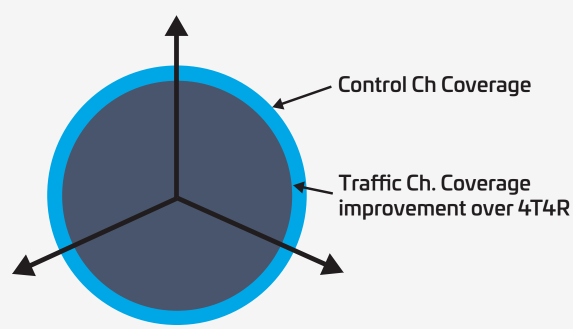
Typical 65° HPBW Pattern of a 4T4R MIMO Antenna



Conceptual Coverage of a typical 3-sector site with 65° HPBW Antennas



Comparison of a 65° pattern in Red vs Service Beam Envelope Pattern of an 8T8R Antenna in Blue (Service Beam shown with just 4 beam directions at ±10° and ±30°, as an example)

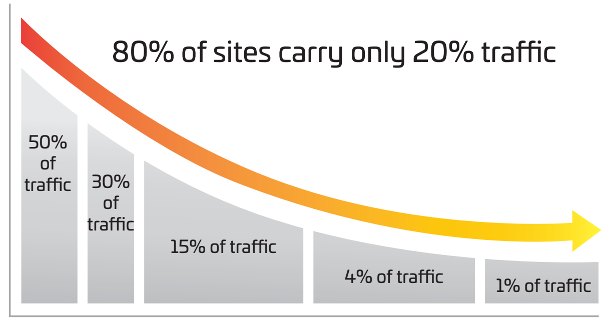


Conceptual Coverage of a three-sector site with 8T8R Antennas that improve traffic channel coverage as compared to a 4T4R Antenna

Network scenario-based cost/performance analysis

In a typical network, only 20 to 30 percent of sites carry the majority of traffic during peak hours. The oposite graphic shows a typical traffic distribution across sites in a commercial mobile network.

So high-capacity solutions are only really needed for those 20 to 30 percent of heavily-loaded sites. As previously outlined, the business case of high-cost configurations can quickly weaken if deployed on an under-utilized site, as the operator won't see any ROI for a long time—potentially years. A more pragmatic approach is to match the traffic load with the right type of configuration to provide sufficient capacity without locking up capital in assets that simply don't generate sufficient returns.



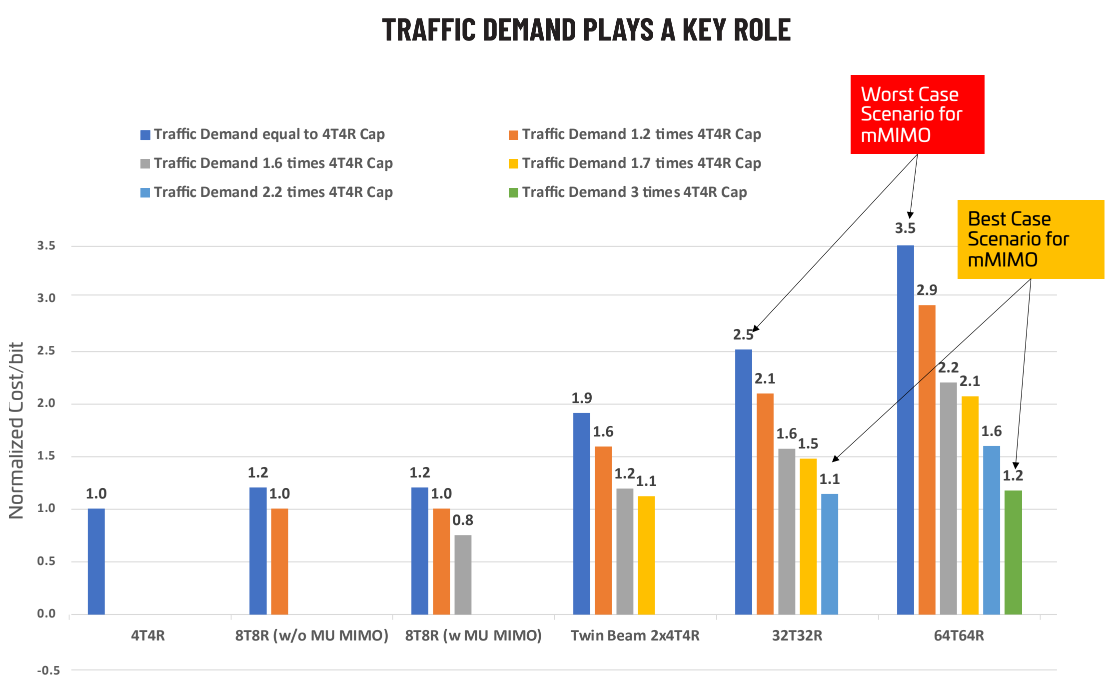
Source: Next Generation Mobile Networks

Traffic demand vs cost

The below graphic shows the impact of site traffic demand on the normalized cost per bit in each of the configurations. The cost per bit for all configurations has been normalized to the cost per bit of a 4T4R configuration when the 4T4R configuration is running at full capacity.

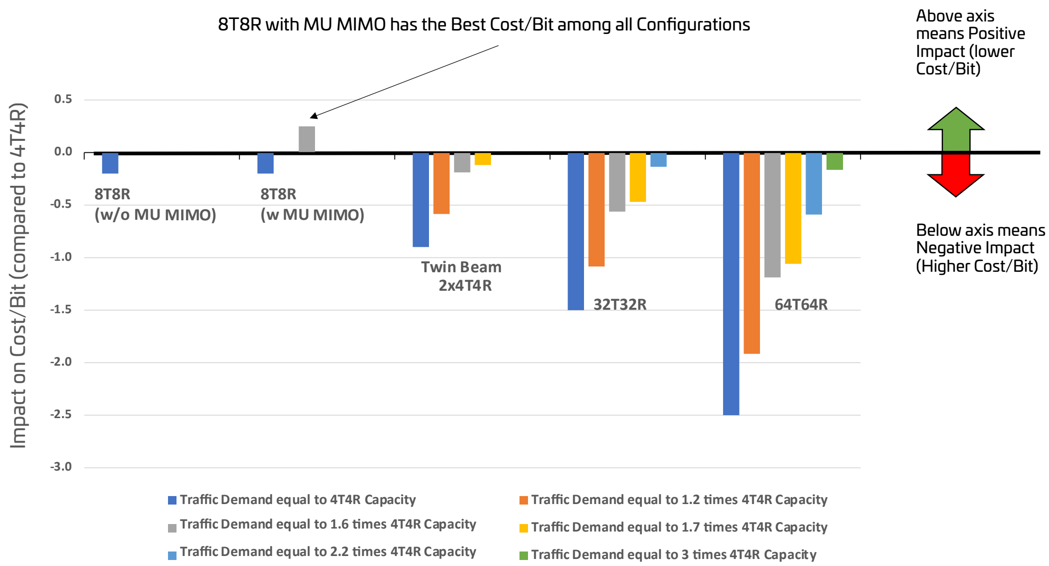
For example, the cost per bit of a 64T64R solution can cost as much as 3.5 times the cost per bit of a 4T4R solution if the site with 64T64R configuration has a traffic demand equivalent to a 4T4R solution.

On the other hand, the cost per bit for a 64T64R solution will be almost the same as that of a 4T4R solution when 64T64R and 4T4R solutions are running at their optimum capacity on a given site. So, assessing traffic demand at a site and the lifecycle of traffic demand at a site both play important roles in the decision-making process when selecting the site configuration size.



The chart below shows another way of representing the impact of traffic demand on the cost per bit of a configuration. The bar values below the normalized cost per bit line of 4T4R have a negative impact, while the bar values above the line have a positive impact—a lower cost per bit. It demonstrates that 8T8R with MU MIMO offers the best cost-per-bit ratio at the cost levels assumed across the configurations.

IMPACT ON COST/BIT WITH CHANGING TRAFFIC DEMAND



Another factor to consider is the power consumption of each radio configuration. The table below shows average industry numbers for power consumption, normalized to 4T4R, for each configuration:

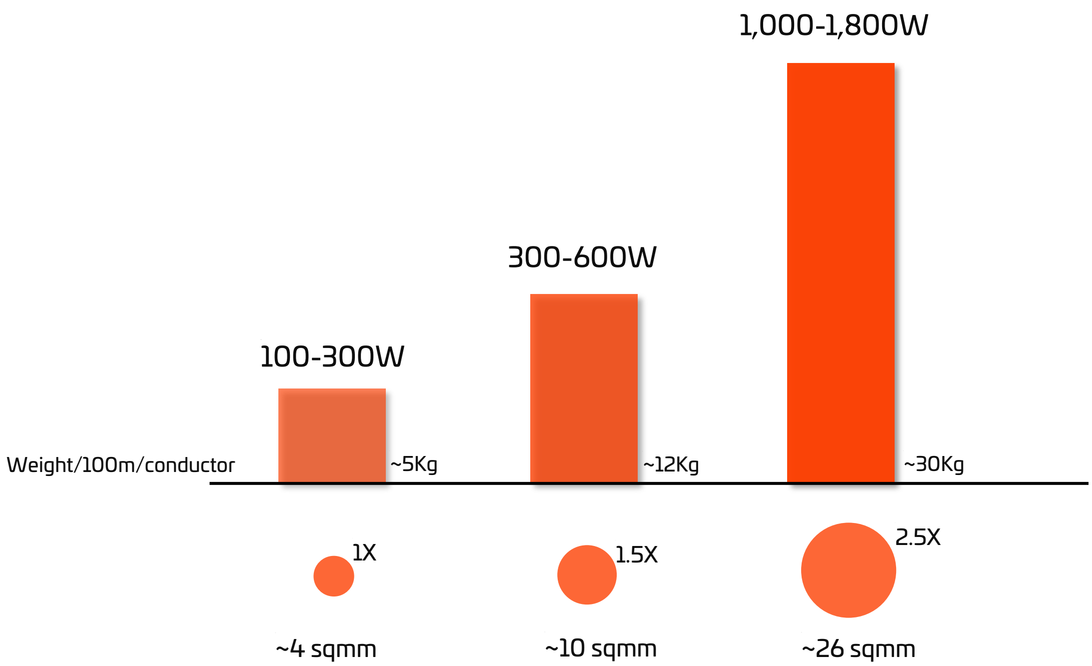
	4T4R	8T8R	8T8R with MU MIMO	Twin beam 2x4T4R	32T32R	64T64R
Normalized power consumption	1	15	15	2	25	3

RAN vendors have been working hard to reduce the power consumption of mMIMO radios. They are also developing features to optimize power consumption of these radios at low traffic demand. However, the cost of power—when operating a site at a much higher configuration than what is needed to serve the given traffic—can mount without generating sufficient returns. If there are multiple poorly-designed sites like this in a large network, the overall impact on the business case of a 5G network can be huge. Many 5G operators have already started looking into powering off under-utilized transmitters with low traffic to save unnecessary costs.

Furthermore, the infrastructure needed to support maximum power consumption at an mMIMO site is also a big factor. The below chart shows the impact on weight and size of power conductors with upgrades.

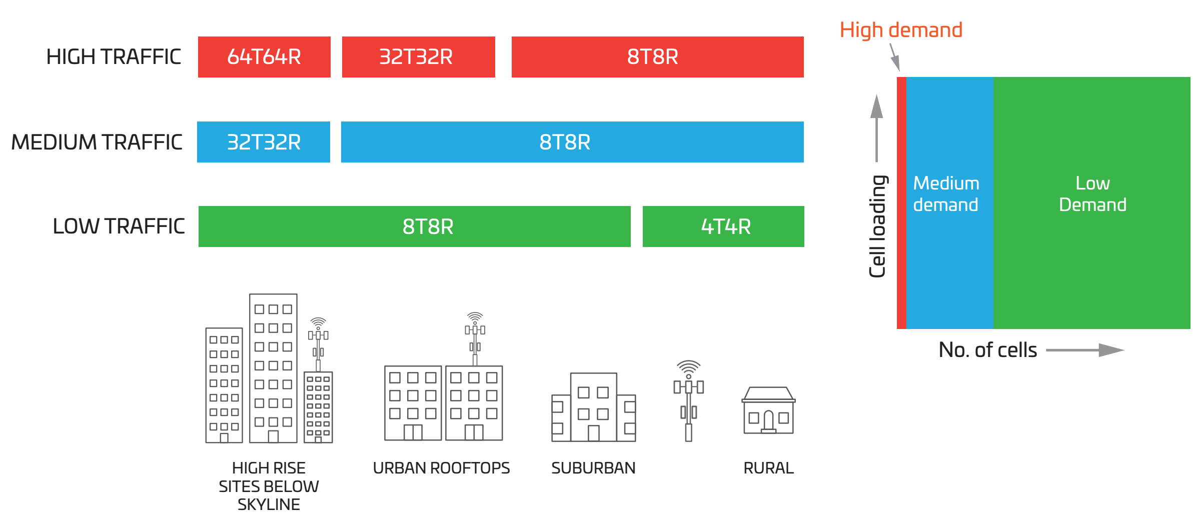
For example, an increase in power consumption from 300W to 1200W may result in a 6x increase in weight and 2.5x increase in size of the power conductors. This means many sites will need significant CAPEX investment for power conductor upgrades and associated services. This will also result in loading towers and poles with the weight of such upgraded conductors needed on the RF path.

BATTERY BACKUP TIME DECREASES WITH ADDITIONAL CABLE LOSS



Bearing in mind the traffic demand and the clutter involved, the graphic below outlines a suggested network deployment strategy for 5G. Using mMIMO delivers the maximum benefits for high-capacity sites that are serving high-rise types of clutter. For most other network scenarios, 8T8R can be a good choice, and 4T4R can be considered for rural sites and urban fill-in sites.

5G DEPLOYMENT STRATEGY - EXAMPLE



In summary

The speed of 5G uptake is already much higher than 4G uptake was in its early stages. According to 5G Americas, 5G reached almost 540 million subscriptions by the end of 2021—a number that took 4G three times as long to achieve. This rapid growth is set to continue, and 5G is forecast to overtake 4G in global data traffic by 2026.

While this 5G growth is impressive, it does bring its own set of challenges for designing an optimum 5G network that will deliver sufficient ROI. The choices available for RF path configurations in 5G for sub-6 GHz bands have increased from only 2T2R and 4T4R, which are being largely deployed on 4G networks. This paper proposes a pragmatic network planning strategy that utilizes 8T8R as the building blocks of 5G network RF design, while also using other configurations at relevant sites.