

SAMSUNG

**Samsung Delivers the
Promises of Massive MIMO**



Mobile network operators (MNOs) continue to find ways to provide better services for their subscribers. Some of the techniques focus on increasing data capacity, while other solutions improve coverage. And with these enhanced services, subscribers' performance expectations continue to rise, too. One of the keys to this success is M-MIMO.

M-MIMO is one of the techniques that achieve both increased data capacity and better coverage. By increasing the number of data paths to the end-user, the cell site sends more data to the user at the same time, resulting in faster connections. By adding more data paths, massive MIMO and beamforming, which is an intelligent antenna technology that focuses radio signal or transmission energy in the direction of the mobile user, taking these improvements up

to a much higher level. With massive MIMO and beamforming, networks more efficiently use their spectrum to create high-speed connections that provide subscribers with better user experiences.

And the good news is that Samsung is making sure the techniques it uses in today's 4G networks continue their benefits in 5G after MNOs upgrade.

Samsung is an industry leader in the massive MIMO technology, demonstrated by leading research and first to market deployment of key solutions that improve MNOs operating metrics. Massive MIMO uses a variety of techniques to increase the utilization of an MNO's spectrum assets to provide higher throughput to more users in a cell.

How is Samsung's Massive MIMO Different?

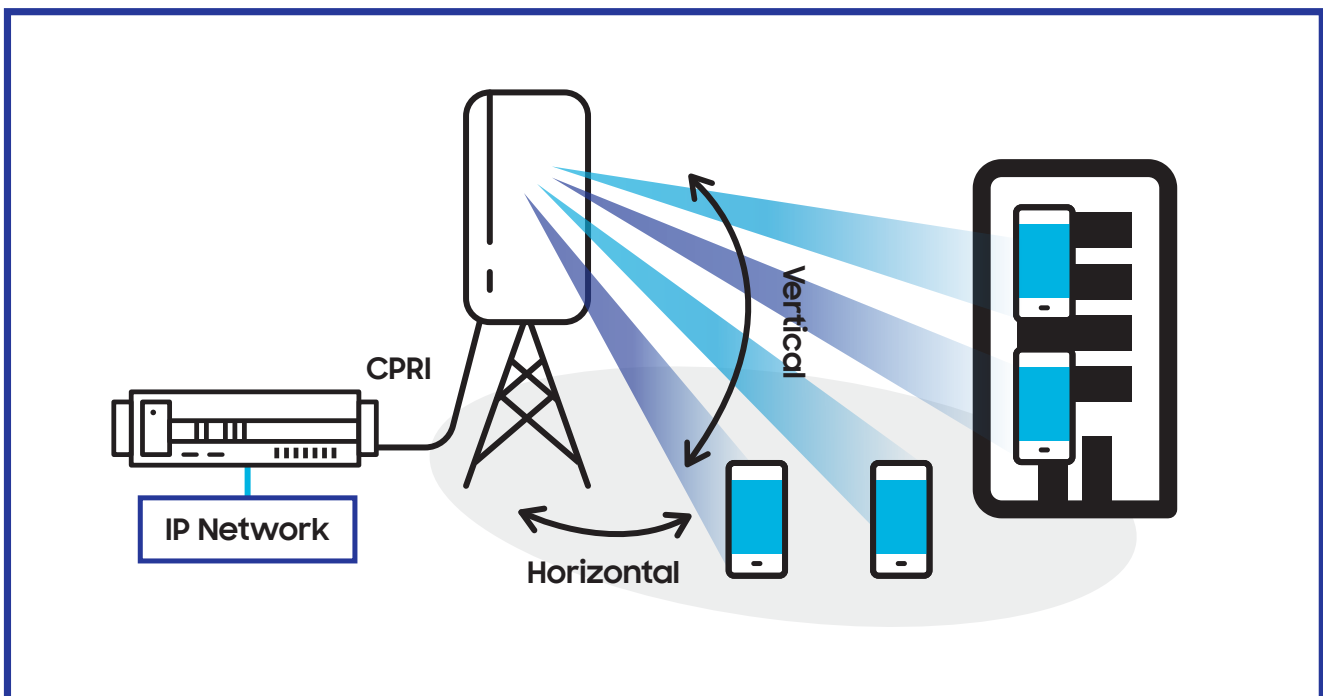
Conceptually, massive MIMO extends the number of transmit and receive antenna elements in the configuration to support "massively" more simultaneous data streams than prior MIMO systems. So simply increasing the number of antennas is not the differentiator; differentiation comes from research, development and real-world experience deploying the technology, and these are all central components of Samsung's differentiation.

Samsung's Massive MIMO Is Field Proven

Samsung was one of the first vendors to deploy and help mobile operators reap massive MIMO's significant operational benefits in commercial solutions beginning in 2017. Joint operator activities and development of new products that leverage continued learnings are driving current improvements that make massive MIMO one of the enabling technologies that help MNOs achieve gigabit data speeds for LTE and 5G networks. Samsung's massive MIMO solutions support 32T32R and 64T64R configurations, and a simple upgrade provides an easy transition from LTE to 5G.

Samsung's 3D Beamforming Increases Spectrum Utilization

LTE Advanced introduced advanced beamforming as a capability that helps massive MIMO antenna systems optimize spectral efficiency, support groups of users in an area, and reduce interference. Technically, radio resources operate in two dimensions – time and frequency, and beamforming adds a third – spatial filtering. With beamforming, a base station is now aiming what it is transmitting in a particular direction instead of broadcasting the signal across a much larger area. Early implementations focused beams in horizontal patterns, but Samsung's solution creates a 3-dimensional beam by adjusting vertical and horizontal transmissions to aim the signal towards the users, similar to a focused beam of light created by a searchlight.



Beamforming is a software-enabled technique that utilizes weight factors to adjust the horizontal spread and vertical spread of a transmitted signal. Samsung's implementation uses these adjustments to allow the system to either focus on a limited and complex area or to cover a vast wide area. In the denser areas, the system tracks the user and transitions the transmission to antennas that may bounce signals off an adjacent building to maintain user connectivity. In the vast areas, the operators can efficiently cover the area by pointing signals to certain areas. In both cases, the MNOs can reduce their CAPEX spend – they are using less equipment to provide the coverage their subscribers need.

Beamforming in three dimensions also improves the operators use of spectrum in two ways. First, the cell is only transmitting information to an area that needs that data, as opposed to painting the entire area. This focus reduces interference with other devices, and reduced interference means faster throughput since there are fewer retransmissions of the signal. Second, the cell is receiving better edge coverage by using the focused transmission to cover the users, which results in fewer dropped sessions as they hand over to a new cell. This better use of spectrum translates into faster throughput and fewer dropped sessions, which means better user experiences, higher loyalty through lower subscriber churn.

Samsung's Massive MIMO Solution Benefits

Samsung Massive MIMO Unit (MMU): The key product in the solution is the Samsung Massive MIMO Unit (MMU), which is operating in the 2.5 GHz and CBRS (3.5 GHz) spectrum bands. This product also supports the following RAN technologies:

- 4G LTE
- 5G NR
- Co-deploy 4G LTE and 5G NR.

A key differentiator of Samsung's MMU is its ability to support LTE and 5G NR simultaneously. The "split mode" configuration allocates 32 of the 64 transmit-receiver pairs to each of the RAN technologies. This unique capability reduces the CAPEX spend by MNOs for co-deployment of LTE and 5G in those sites, as the existing equipment supports both technologies in the existing footprint.

High-Density Antenna System with Integrated Radio Control: The high-density antenna 64T64R option allows MNOs to reduce CAPEX as they now need fewer products to cover the same area. When operating in 2.5 GHz markets, the MMU leverages five 10 Gbps CPRI links, while the solution for CBRS markets uses four 10 Gbps CPRI links.

Carrier Aggregation: This MMU supports carrier aggregation and offers different options based on the deployment. For 2.5GHz, Carrier Aggregation supports up to three 20 MHz carriers, creating up to 60MHz of downlink bandwidth, while deployments in CBRS spectrum supports up to five 20MHz channels, offering up to 100 MHz of downlink bandwidth.

MIMO and MU-MIMO: In addition to supports 2x2 and 4x4 single-user MIMO, the MMU supports multi-user MIMO with by allowing up to 16 layers, or independent streams, of downlink transmission for up to 16 users. For 2.5 GHz deployments, the MMU supports up to 2 layers for uplink MU-MIMO transmissions for multi-user MIMO, while the CBRS solution in the 3.5 GHz spectrum allows up to 8 layers for uplink transmissions.

Multiple Form Factors: Samsung provides massive MIMO products in small form factors that support the specific needs of a site and are among the smallest and lightest packages in the industry.

Efficient Cooling For all Products: All Samsung MIMO units leverage convection cooling. Convection cooling is a natural cooling process where the operating temperature range of the product does not require supplemental fans or air conditioning. With this design, the equipment uses a smaller form factor than systems that use powered cooling systems, operates with minimal ambient noise as there are no fans or air cooling units, and reduces the overall site OPEX by reducing cell site power consumption and by eliminating site visits to repair mechanical failures like fan breakage.

These high-density antenna systems allow MNOs to reduce CAPEX for operators as they now need fewer products to cover the same area.

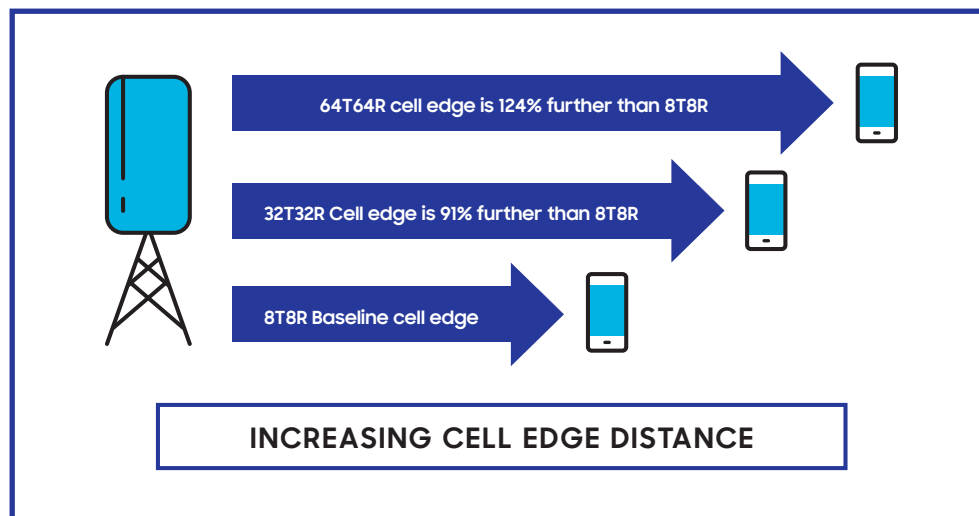
Micro 32T32R TRP: This lower density product provides LTE operations in the CBRS 3.5GHz band. The TRP supports Carrier Aggregation of up to two 20 MHz carriers to allow up to 40 MHz of downlink bandwidth. For massive MIMO, the system supports eight layers of simultaneous data on the downlink and is hardware capable of supporting two layers on the uplink. The TRP leverages four 10 Gbps CPRI links.

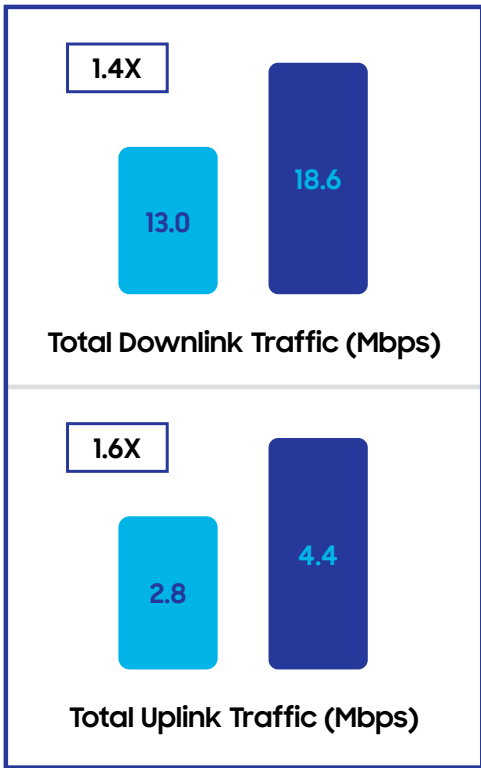
Samsung Continues Proving the Benefits of Massive MIMO

With several years of deployment experience, Samsung knows how to deploy and tune MIMO with beamforming techniques to provide the best operational efficiencies in 2.5 GHz markets and CBRS deployments.

Demonstrating Cell Edge Improvements: The Samsung massive MIMO solution began providing enhanced speed and capacity on Sprint's 2.5GHz TDD spectrum with excellent results in LTE.

The following diagram of the analysis of test data illustrates the proof point that increasing the number of transmission paths using 3D beamforming from the cell site not only increases throughput but also extends the distance to the cell edge.





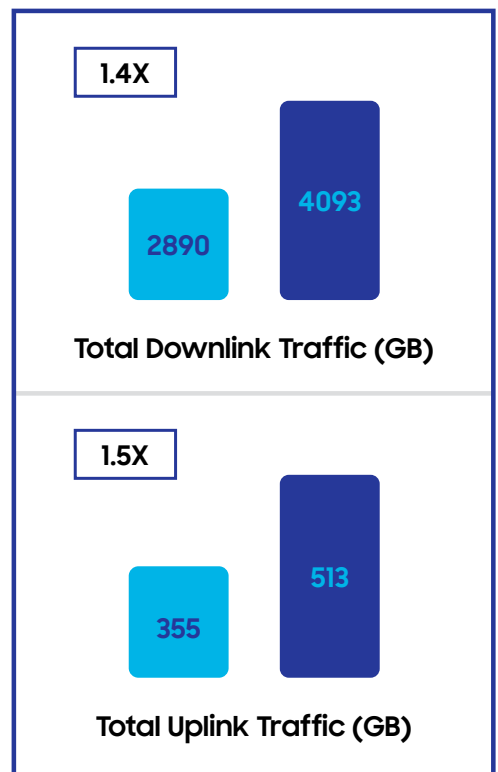
With the completion of testing of the system and subsequent analysis of the results, the performance of the system showcases the value that massive MIMO and beamforming bring to an MNO and its customers. In on-air commercial site operations, both downlink and uplink capacity of massive MIMO confirmed significant increases.

The top-performing site showed downlink end-user service throughput improved from 13.0 Mbps to 18.6 Mbps, an increase of 43%. For the uplink throughput, end-user service increased from 2.8 Mbps to 4.4 Mbps, an improvement of 58%.

For the overall capacity across all users, the top site increased downlink data from 205 GB to 450 GB, resulting in an increase of 120% during the period. Analysis of the uplink results proved similar data processing of uplink data, indicating an increase of 112%.

Across the cluster of sites in this demonstration, the aggregate signaling and user traffic throughput for the downlink and uplink increased 41.5% and 44.5%, respectively.

These increases in 4G link traffic result from engineered coverage for the topology of the deployment area and the current types of user traffic. Samsung’s global deployment experience with massive MIMO will instill confidence in the MNOs who make the right choice by selecting Samsung.



Demonstrating Co-resident 5G and 4G LTE with Split mode: Recently, Samsung’s massive MIMO solution started supporting 5G with commercial on-air testing in a large US market. The activities not only included validating the 5G NR functionality and throughput values for 5G, but also provides insights into performance metrics of 5G and 4G when both are operating on the same site and in the same equipment. Analysis of early results indicate co-resident operations do not impact 4G performance data and cell edge performance. The 32T32R configuration of the MMU for 4G continues to meet pre-upgrade metrics.

Demonstrating Increased User and Cell Throughput: Live market deployment of massive MIMO is confirming that the combination of 3D beamforming that is shaping and transmitting multiple layers of data is hitting the mark. Samsung field engineers recently completed a study using a commercially deployed MMU operating in CBRS spectrum that gave excellent insight into the success of beamforming in a fixed wireless access service. The FWA activity placed 16 Samsung Galaxy S9 devices (tethered to a laptop running a variety of cloud-based applications) across a wide range of distances from the rural US cell site. The testing captured two sets of data for the sixteen users: one set for users considered in the cell center (less than 1 km from the cell site), and the second set for users considered to be at the cell edge (which ranged from between 3 and 5 km from the cell site.)

Location	Range of UE from cell (km)	Min Average UE Throughput (Mbps)	Max Average UE Throughput (Mbps)	Average UE Throughput (all UEs, Mbps)	Average UE Throughput for all UEs (Mbps)	RSPS Range (dB)
Cell Center	.1-.9	25	51	36.75	588	-85 - -70
Cell Edge	3-6	2	69	22.56	361	-108 - -86

Demonstrating Improved User Experiences: Further work by Samsung with a partner operator set out to quantify the benefits of beamforming. The team analyzed and compared results from YouTube traffic streaming on the LTE network with and without beamforming. The baseline MIMO system used 4T4R without beamforming and tracked the network metrics and timing results of a single site where 28 users refreshed a web page every minute or and 28 users viewed a streaming video. After collecting the baseline data for 4x4 MIMO, the Samsung team activated beamforming for the site and proceeded to repeat the tests and collect results using the same process.

The network KPI values proved the increased network capacity with beamforming turned on:

KPI	No Beamforming	With Beamforming	Improvement
DL throughput (Mb/s)	24.94	85.36	3.42 x
DL MAC Volume (GB)	2.63	9.25	3.5 x



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Even more striking was the differences experienced by users watching the YouTube video. By capturing the “video progress” banner every 3 minutes during the 63-minute video, the data showed that 4x4 MIMO without beamforming took considerably longer to view than the 63 minutes, which is not the desired experience. But with beamforming active, users encountered minimal delay or stall time, which confirms that beamforming improves the user experiences of those running latency-sensitive applications.

Point in video	No Beamforming		With Beamforming	
	Average Progress Time (mm:ss)	Average Wait (mm:ss)	Average Progress Time (mm:ss)	Average Wait (mm:ss)
After 3 minutes	2:29	0:31	3:00	0:00
After 6 minutes	4:06	1:54	6:04	0:04
After 9 minutes	4:18	4:42	9:01	0:01
After 12 minutes	5:57	6:03	11:55	0:05

Samsung’s Massive MIMO Delivers!

Samsung’s high density, small form factor massive MIMO solution makes it a natural fit for increasing throughput and improving cell edge connectivity. The expertise and experience developed over years of engineering and tuning its MIMO solution prove it is an innovating leader in the field. Recent successes confirm! The massive MIMO deployment in Sprint’s 2.5GHz TDD spectrum increased bandwidth and both extended and improved the quality of connections at the cell edge, paving their way to 5G. The KT/Samsung partnership achieved 1Gbps speeds over the air on KT’s 5G commercial mobility network in Seoul. Through research, deployment and analysis, Samsung continues to drive solutions that command respect and are improving end-user experience and optimizing MNO CAPEX through unique solutions.

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