ROSENBERGER'S DISRUPTIVE PRESENCE IN THE BASE-STATION ANTENNA MARKET

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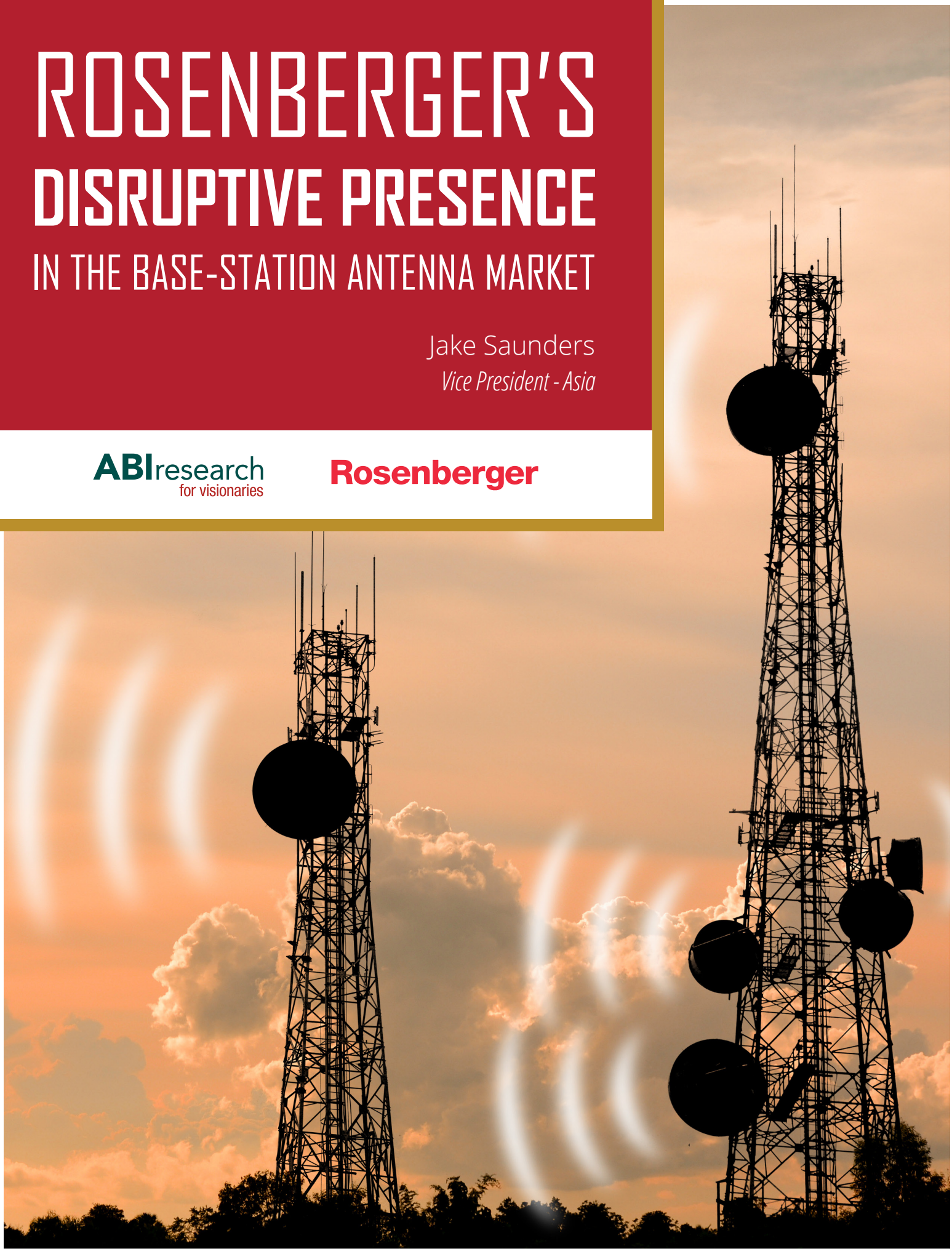
ABIresearch for visionaries

Rosenberger



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1. 5G TELCOS IN NEED OF INNOVATIVE SOLUTIONS

5G will offer an unprecedented leap in bandwidth speeds as compared to previous mobile networks. 4.5G's LTE-Advanced Pro will enable mobile telcos to achieve peak speeds of Gigabit throughput, but 5G will offer a quantum leap in capacity improvement. Downlink (DL) peak data throughput could reach 20 Gbps, while uplink (UL) peak data rate has the potential of reaching 10 Gbps.

As much as 5G is about innovative radio access network (RAN) and core network architectures, network slicing, and end-to-end digital transformation, mobile operators will need to deploy the highest performance macrocell and small cell antenna solutions. Those antennas also need to manage antenna total cost of ownership (TCO), mitigate passive inter-modulation (PIM), and minimize weight and wind load, while integrating the maximum number of mobile telco frequency bands.

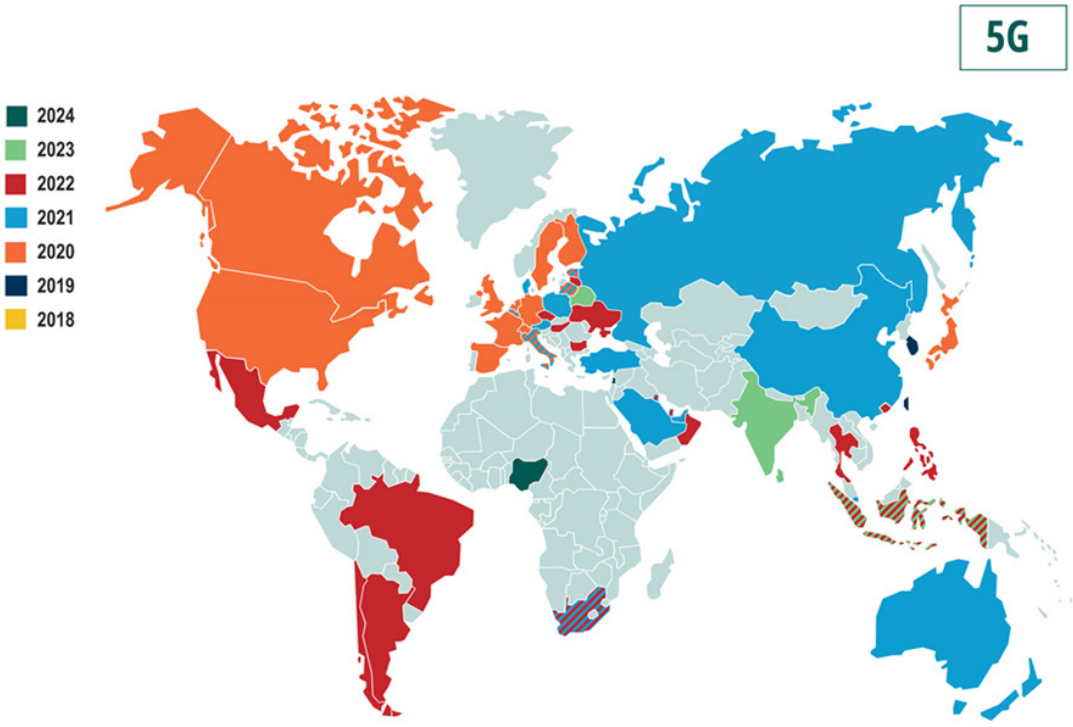
1.1 5G DEPLOYMENTS WILL COME THICK AND FAST

AT&T and Verizon Wireless are jostling to be the first to deploy commercial fixed wireless access (FWA) 5G services by the end of 2018, but the first mainstream 5G mobile and fixed wireless services are expected to commence in 2020. South Korea, Japan, and the United States are likely to be the first countries to do so.

In January 2018, the GSA reported that 113 operators in 56 countries had started 5G trials. Some of these trials have been small technical evaluations, while in other countries, they have been wide area pre-commercial demonstrations. Based on ABI Research's own research, all of the top 50 countries will have one or more 5G networks up and running by 2024 (see Figure 1).

Figure 1: Anticipated Commercial Deployment of 5G Services World Markets, Forecast: 2018 to 2024

(Source: ABI Research)



1.2 THE CHALLENGES THEY FACE

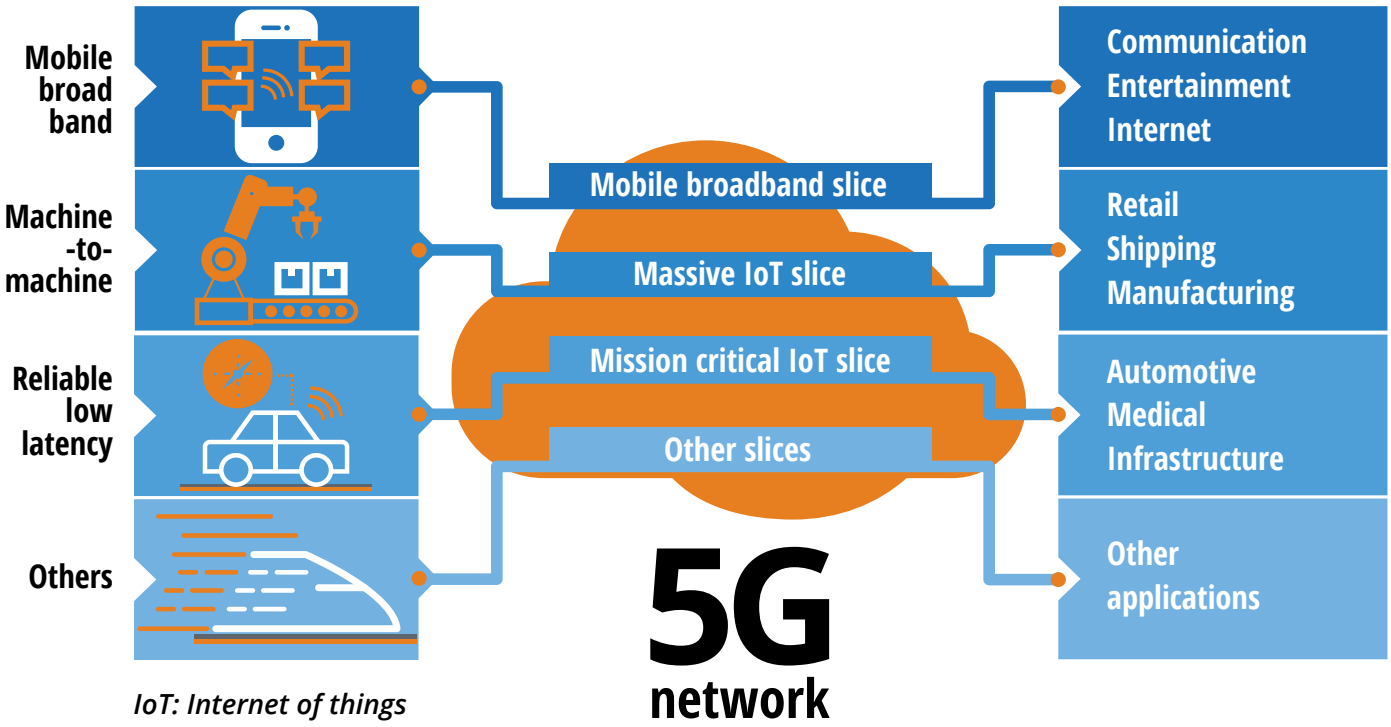
In several ways, such as bandwidth, reliability, latency, enhanced policy control, and flatter architecture, 5G augments the underlying wireless mobility technologies, but it does present mobile service providers with a number of challenges.

1.2.1. 5G Use Cases Will Be Diverse

DL peak data throughput could reach 20 Gbps, while UL peak data rate has the potential of reaching 10 Gbps. 5G can also reduce latency and improve overall network efficiency. Furthermore, low-latency, ultra-reliable types of communication links can be offered for machine-to-machine (M2M) and public safety applications. Examples of network slicing could be WTTx ultra-broadband users, public safety 5G, Industrial IoT, or supporting autonomous driving (V2X).

Figure 2. 5G Capabilities Enable a Range of 5G Services

(Source: ITU)



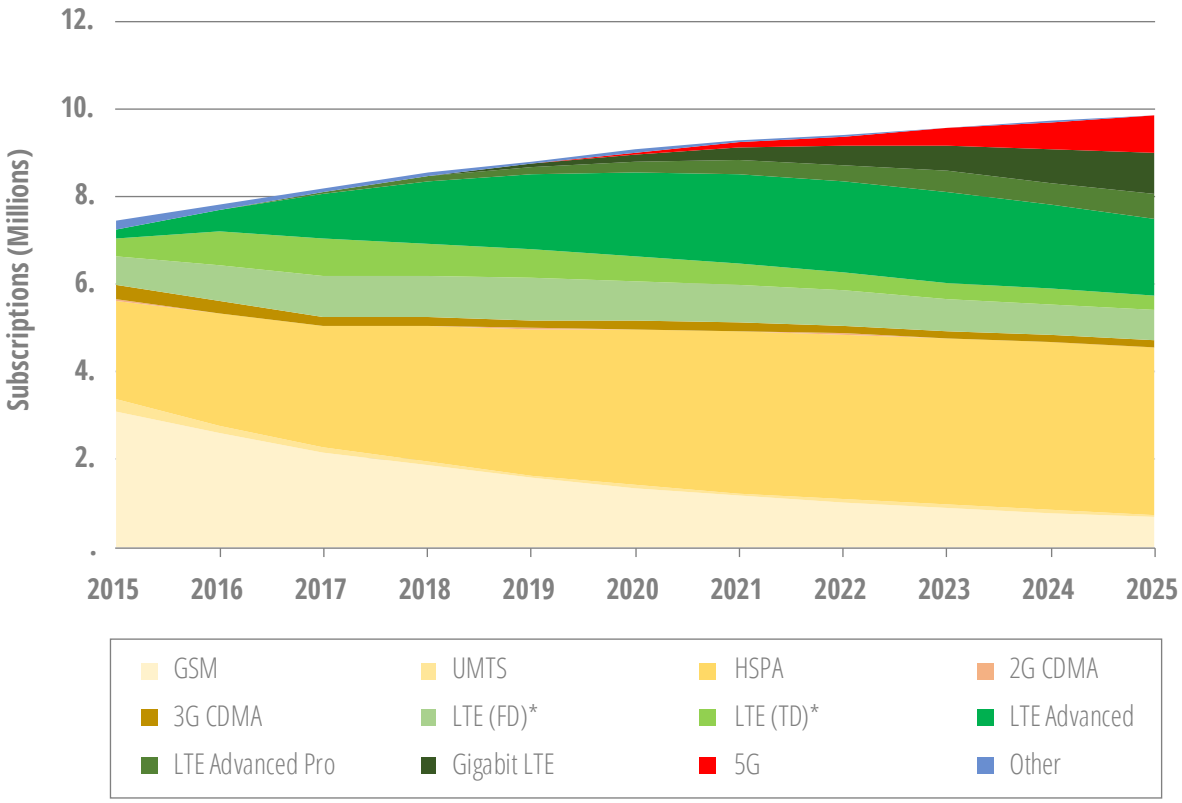
IoT: Internet of things

1.2.2. Growth in Subscriptions

5G services will be fully under way by the end of 2020 and should achieve 350 million by 2025. While 350 million is a respectable number, the real challenge for the mobile telco is managing the sheer number of 5G, 4G, 3G, and even 2G subscriptions. At the end of 2017, total mobile subscriptions worldwide reached 8.12 billion, with an annual growth rate of 5.4% year-on-year. LTE subscriptions have been growing at a rapid rate; at the end of 2017, there were 2.86 billion, which is 35.2% of the overall total, but by 2025, LTE will surpass 43.3%.

Chart 1: 2G, 3G, 4G, and 5G Mobile Subscriptions
World Markets, Forecast: 2015 to 2025

(Source: ABI Research)



1.3 GROWTH IN INTERNET OF THINGS

The Internet of Things (IoT) is well underway and becoming embedded in our society, industry, and government. Sigfox, LoRA, and Weightless are making significant headway now and ABI Research expects that movement to shift toward the 3GPP standard, such as eMTC and NB-IoT. ABI Research estimates that 5.2 billion low-power wide area network IoT devices will be deployed by 2025 and 3GPP-based IoT devices will represent approximately 80.7%.

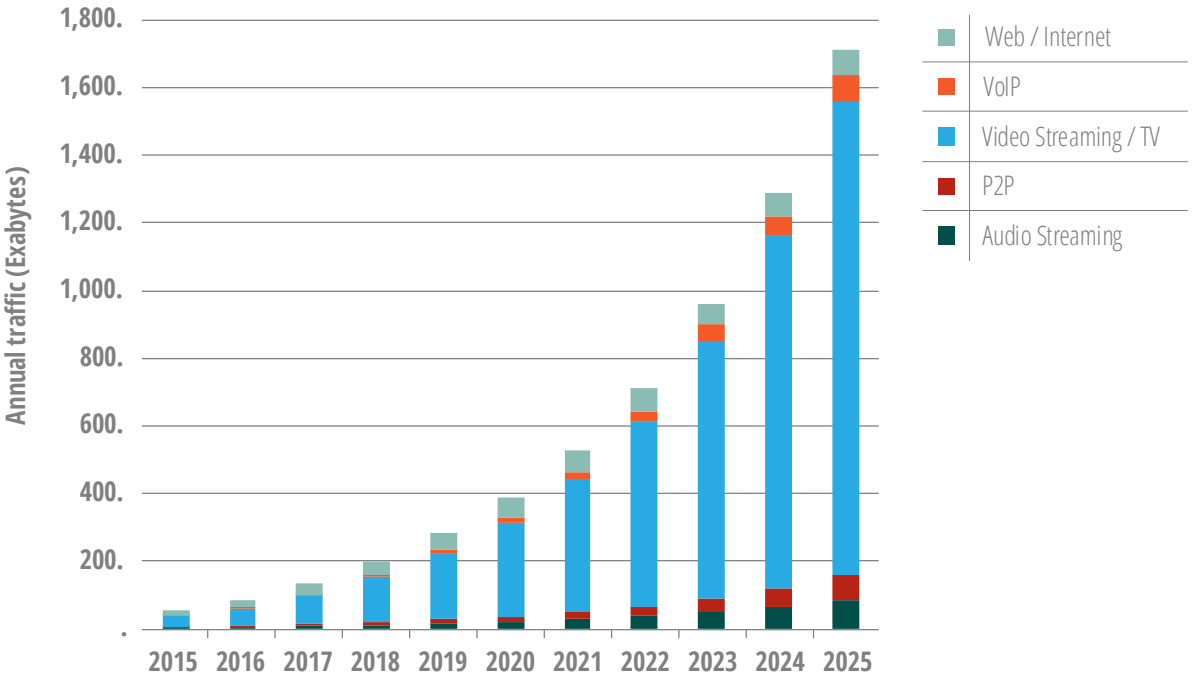
1.4 GROWTH IN TRAFFIC

M2M and the IoE may push up the number of non-human connections, but a large proportion of the data traffic generated will come from end users' smartphones and other mobile devices, such as tablets and laptops. There are dramatic cyclical shifts in data traffic usage throughout the day, as end users commute/travel during a 24-hour day.

All of these mobile data subscribers are continuing to make greater and greater demands on the operators' networks. Over the course of ABI Research's forecasts, mobile data traffic is anticipated to grow at a CAGR of 35.7% to surpass 1,710 exabytes on an annual basis in 2025. 4G and 5G subscribers may only represent 49% of total subscriptions in 2025, but they represent 93% of the total traffic generated in 2025. By 2025, video streaming expands to 82% of the market. The global average amount of traffic generated per user per month will grow from 1.37 gigabytes as of year-end 2017 to around 15 gigabytes.

Chart 2: Mobile Network Data Traffic by Traffic Type
World Markets, Forecast: 2015 to 2025

(Source: ABI Research)



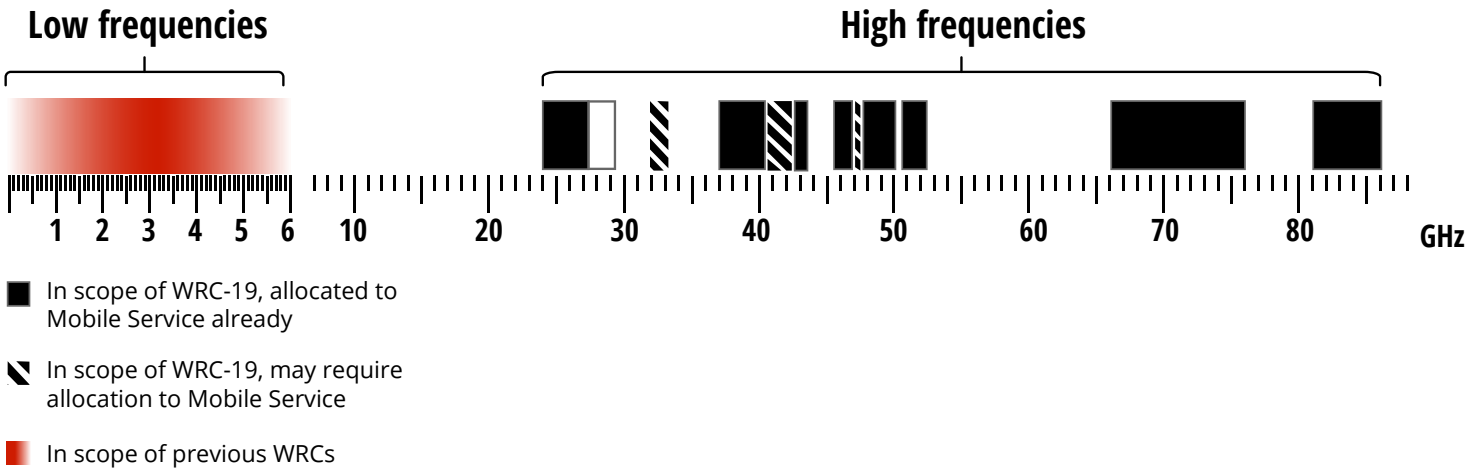
1.4.1. 5G Needs Additional Spectrum

5G offers an unprecedented leap in bandwidth compared to the previous generation. This is made possible by using high-band frequency spectrum, as well as key antenna technologies, such as massive multi-input multi-output (MIMO). Licensed bands in 3 spectrum ranges will be used for 5G: sub-1 GHz, 1-6 GHz, and above 6 GHz.

Given the congestion in the sub-3 GHz bands, 5G stakeholders are proposing spectrum in and around the C-band. The "C-band" technically relates to the 3.7 GHz to 4.2 GHz band, but also to the bands between 4.4 GHz and 5.0 GHz, which are being considered as key "mid-spectrum bands" for 5G services that provide the right balance between capacity and coverage. The 700 MHz band is being proposed for 5G services in some countries, and while the band has excellent propagation characteristics, it has limited spectrum bandwidth per license. The 26 GHz to 28 GHz band would have excellent capacity credentials, but has reduced coverage and line-of-sight constraints. Other high-frequency bands are also being considered, as illustrated in Figure 3.

Figure 3: Frequencies in the Scope of WRC-15 and WRC-19

(Source: ABI Research)



In the United States, operators are already s owing interest in this band to test outdoor small cell operations.

Bands above 24 GHz and up to 86 GHz are also being studied for the World Radiocommunication Conference (WRC) in 2019. Technically speaking, it is the bands above 30 GHz and up to 300 GHz in the radio spectrum that are classified as millimeter bands. Due to their short wavelengths and other propagation characteristics, using mmWave spectrum for mobile access communications with the user does have its challenges.

Other bands that are being considered for 5G include 4.4 GHz to 5.0 GHz spectrum, and even spectrum in the 600 MHz, 700 MHz, 800 MHz, 900 MHz, 1.5 GHz, 2.1 GHz, 2.3 GHz, and 2.6 GHz bands. Spectrum in these bands is not likely to be wide enough for ultra-fast bandwidth services, but rather orientated for wide area coverage for end users on the move and/or IoT applications.

2. ROSENBERGER'S PRESENCE IN THE ANTENNA MARKET

Rosenberger has been making rapid strides in the mobile cellular antenna market. The vendor has been able to leverage not just its R&D to create innovative antenna design.

2.1 OPERATIONAL BACKGROUND

Rosenberger was founded in Germany in 1958 and is a highly respected manufacturer of high-speed connectivity solutions worldwide. Rosenberger provides products and solutions for the telecommunication, automotive electronics, information technology, test & measurement, aviation, and medical & industries sectors. For more than half a century, Rosenberger has been a leading supplier of impedance-controlled and optical connectivity technology.

Rosenberger maintains 19 factories and 9 R&D centers, with its Kunshan plant in China and its Goa plant in India being its largest antenna manufacturing centers.

Figure 4. Rosenberger's Global Footprint

2.1.1. Rosenberger Antenna Expertise

Rosenberger's Antenna R&D center is based in Kunshan, Jiangsu Province in China, with more than 4,000 employees. It develops advanced antenna technology for multi-band and multi-port antennas and has more than 300 professional RF experts with relevant telecommunications academic and professional qualifications.

The company also has its own advanced, near-field test chamber, an outdoor far-field test range, and a number of other environmental test equipment and chambers. These test facilities serve to deliver the high-performance characteristics of Rosenberger's antenna products based on the strictest variable environmental conditions testing.

Figure 5. Rosenberger's Antenna Pattern Test Center (Near & Far)

SG128 Test System from SATIMO

2.1.2. Antenna Portfolio

To support the growing mobile data traffic and the development of 5G technology, as a global wireless solutions provider, Rosenberger offers advanced 5G solutions, including a 64T64R massive MIMO antenna and a 16T16R MIMO antenna covering wide frequency bands (1,710-2,300 MHz, 2,400-2,690 MHz, and 3,400-3,800 MHz), which use beamforming technology to enhance the mobile data capacity and improve spectrum efficiency. Furthermore, Rosenberger has developed massive MIMO antenna solutions to meet operators' various needs.

Rosenberger provides additional communication solutions for densely populated areas. These include multi-band small cell antennas, as well as panel, quasi-omni, and small diameter omni whip antennas. To meet the wide range of spectrum needs of mobile service providers, its antennas can provide broad frequency coverage (617-960 MHz, 1,695~2,400 MHz, 3,550~3,700 MHz, and 5,150~5,925 MHz) for site-sharing among 3G/4G/5G systems. Rosenberger antennas can support up to LTE-Advanced and 5G NR 4 x 4 MIMO and carrier aggregation (CA).

2.1.2.1. Multi-Beam Antennas

Mobile operators are facing extreme challenges as traffic volumes grow exponentially. To address these constraints, operators will start to deploy six and higher sector solutions to meet the capacity expansion requirements.

Figure 6. Rosenberger's Multi-Beam Antenna, 10 Port Hybrid 1L2H1TB (694MHz to 2,360GHz)

For a more sectorized cellular network, a twin/multi-beam antenna can be installed to enhance the network performance and simplify antenna deployment and installation compared with a traditional 3-sector, 65° horizontal beam width antennas. Minimal overlapping areas between sectors enable easier control of the soft handover zone in 3G systems. The radiation pattern of two or more beams is designed to be more isolated to reduce interference between any two sectors, which is an essential factor in increasing the cells' signal to interference/noise ratio (SINR) that, therefore, leads to maximum data throughput. Only one mounting space is required for multi-beam antennas, which helps to reduce tower loading and personnel installation expenses.

Additionally, Rosenberger adopts radiation pattern beam shaping designs for twin/multi-beam antennas to further reduce the horizontal side lobe even further than traditional twin/multi-beam antenna designs. Completely enclosed phase shifters ensure minimal PIM and improved front to back ratio performance. Innovative Butler matrix boards and a reduced dipole size, among other factors, provide conditions for a more competitive antenna size, which is a key parameter given the current limited space available for the operators to install their equipment.

2.1.2.2. Small Cell Antenna Solutions

To complement its macrocell range of basestation antennas, Rosenberger has also developed a wide variety of small cell antennas for 5G: multi-band/multi-port panel antennas, multi-band/multi-port quasi-omni antennas and ultra slim, multi-band, whip antennas. Key attributes that Rosenberger has integrated into these small cell solutions include high reliability, lightweight, robust design, and simplified on-site installation.

Figure 7. Rosenberger's Quasi-Omni Antenna, 10-Port (1,695~2,400 MHz, 3,550~3,700 MHz and 5,150~5,925 MHz)

In particular, Rosenberger's 7" diameter quasi-omni antenna has reduced weight & footprint, as well as improved pattern radiation performance. The ultra-slim, multi-band, whip antennas are the first whip antenna in the world to cover three bands (1695~2180 MHz, 3550~3700 MHz, and 5150~5925 MHz). Due to its well-recognized connector design expertise, Rosenberger's small cell antennas are fitted with innovative NEX10 connectors, which are the latest generation of RF connectors designed for 5G applications, featuring superior PIM performance, compact size, and robust design.

Figure 8. Rosenberger Ultra-Slim, Whip Antenna with NEX10 Connector

Alongside Rosenberger's 5G solutions, the company also provides complete multi-port antenna solutions with broad frequency coverage (617-960 MHz, 1,427-2,690 MHz, and 3,200-3,800 MHz), compact size, and enhanced performance. The current portfolio features antennas with up to 18 ports (enna-band), up to 3 columns of low band elements (6 ports), and up to 6 columns of high-band elements (12 ports); supporting independent remote electrical down-tilt, multi-band CA, and 4x4 and higher-order MIMO.

2.2 ASIA-PACIFIC PRESENCE AND WORLDWIDE MOMENTUM

Rosenberger has been building up macrocell and small cell antenna shipments and mobile service provider relationships since 2008. Rosenberger has a complete range of antenna solutions, including single-band, dual-band, triple-band, hexa-band, and even enna-band, to meet MIMO and CA requirements and ultrafast data capacity requirements for 4G and 5G networks. Several trials and deployments have taken place in various regions, which are described below.

2.2.1. India

India's 982 million mobile subscribers make it a significant market for mobile antenna installations. Rosenberger is a major antenna supplier for Reliance Jio, Bharti Airtel, Vodafone, and Idea (note: Vodafone and Idea merged in April 2018). To help support the deployment of 4G LTE infrastructure in India over the past 5 years, Rosenberger established two local factories in Goa and Manesar to provide faster lead times for the local market. It is estimated that Rosenberger has supplied approximately 60% of the antenna market share in India for 2G/3G/4G networks.

2.2.2. Southeast Asia

Rosenberger has supplied antenna solutions in Singapore for key 4G operators in Vietnam and provided LTE antennas for the Philippines and Malaysian markets. In 2017, the antenna vendor shipped several FDD multi-port, FDD+TDD 10-port, and 12-port antennas to mobile operators in Indonesia.

2.2.3. United States

As a key strategy to increase market share in the United States, Rosenberger has developed several innovative small cell antennas and participated in a number of trials:

- **Long Beach Trial:** In a trial conducted by a major telco infrastructure vendor in May 2017, Rosenberger's 5G 10-port panel antenna was put through a battery of tests. The objective was to do initial evaluation of CA using AWS band and the 5 GHz unlicensed or "License Access Assist" (LAA) band. A key reason the Rosenberger antenna was selected for this trial was to use a single antenna with at least two ports of AWS coverage and two ports in the 5 GHz UNII band (LAA), in order to evaluate the performance of 2x2 MIMO with CA.

- **San Antonio Trial:** One of the main operators in the United States performed an extensive trial in San Antonio Texas to quantify the gains when splitting sectors from a single 65° beam width sector to two 33° beam width sectors. The trial consisted of five phases:

    - *Phase 1* characterized a traditional hex port antenna using a 4T4R radio in the PCS band. Phase 2 replaced the hex port with a twin beam antenna that provided 2T2R for each beam in the PCS band.
    - *Phase 3* used dual split beam in PCS to provide 4T4R with pairs of ports in two antennas separated by around eight wavelengths.
    - *Phase 4 & Phase 5* each used a single antenna providing vertically stacked pairs of twin beams in the PCS band.

- **Chicago Trial:** One of the main operators in the United States conducted a trial in Chicago to define the MIMO and other RF performance characteristics for a public network in the United States. Rosenberger supplied the third configuration that offered a smaller antenna width due to the low-band columns being stacked vertically, instead of the usual horizontally stacked columns. The solutions provided four low-band ports for evaluation of 4x4 MIMO performance in the 700 MHz band.

2.2.4. Other Regions

Rosenberger has been deepening relationships with mobile operators in China, including China Mobile, China Unicom, and China Telecom. The vendor has also increased its presence in the Middle East, the CIS region, Latin America, and Africa.

2.3 5G STRATEGIC INITIATIVES

Rosenberger has entered the U.S. 5G market with the deployment of several small cell antennas. Its most popular antenna models in the U.S. market are its 10- and 12- port panel and quasi-omni antennas. Its 10-port antennas provide four ports in the mid-band, 1,695-2,360 MHz, four ports in the 3,550-3,700 MHz, CBRS band, and two ports in the UNII (LAA) bands, 5,150-5,925 MHz. Rosenberger's 12-port model has two additional ports for the low band, 698-894 MHz, four ports in the mid-band, 1,695-2,360 MHz, four ports in the CBRS band, and two ports in the UNII band.

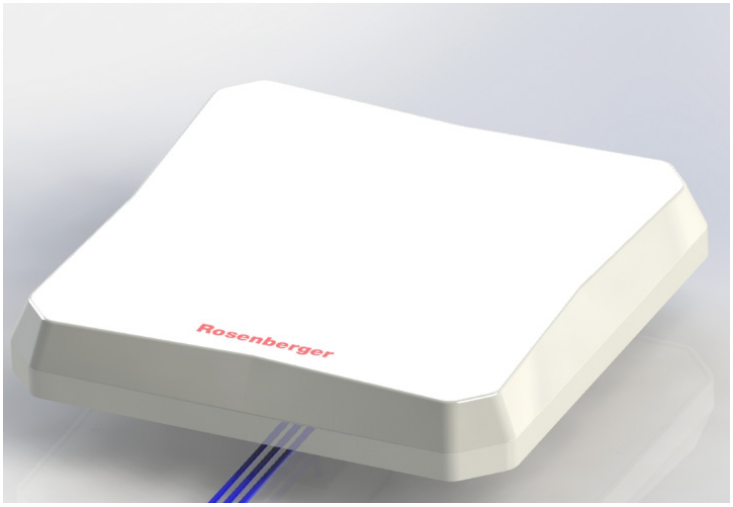
Rosenberger has also qualified three different quasi-omni antennas:

- Model 1, with 7-inch diameter, 10 ports (4 mid/4 CBRS/2 LAA)
- Model 2,10-inch diameter, 10 ports (4 mid/4 CBRS/2 LAA)
- Model 3, 12-inch diameter, 12 ports (2 low/4 mid/4 CBRS/2 LAA)

Additional models of omni and panel antennas are in the process of submission or will be submitted in the near term for customer qualification.

Its current portfolio of small cell antenna models represents the initial product offering from Rosenberger. The roadmap includes the models listed above at greater fixed beam tilts, with remote electrical tilt (RET) capability that allows customers to use traditional AISG hardware to change the electrical beam tilt after installation and expanded bandwidths to include the BRS (2,496-2,690 MHz) band.

Figure 9. Rosenberger's Small Cell Antenna, 3 Port, 5,450 MHz to 5,875 GHz



Cell Densification is a major focus for U.S. operators. Deployment scenarios typically call for quasi-omni antennas to be placed in areas of reduced coverage and KPIs within a cluster of macro sites.

Two clear 5G small cell customer roadmaps have been developed. The first is an operator direct variant. The second is a service provider variant driven by consolidated sites and C-RAN build partners. Rosenberger's strategic decision is to offer small cell antennas that cover low, mid/CBRS, and LAA frequencies. Additional antennas include these bands, plus support for low-band (698-894 MHz) coverage.

ABI Research, therefore, considers Rosenberger to have a coherent strategy to target the 5G, sub-6 GHz band antenna shipment market being deployed in the United States.

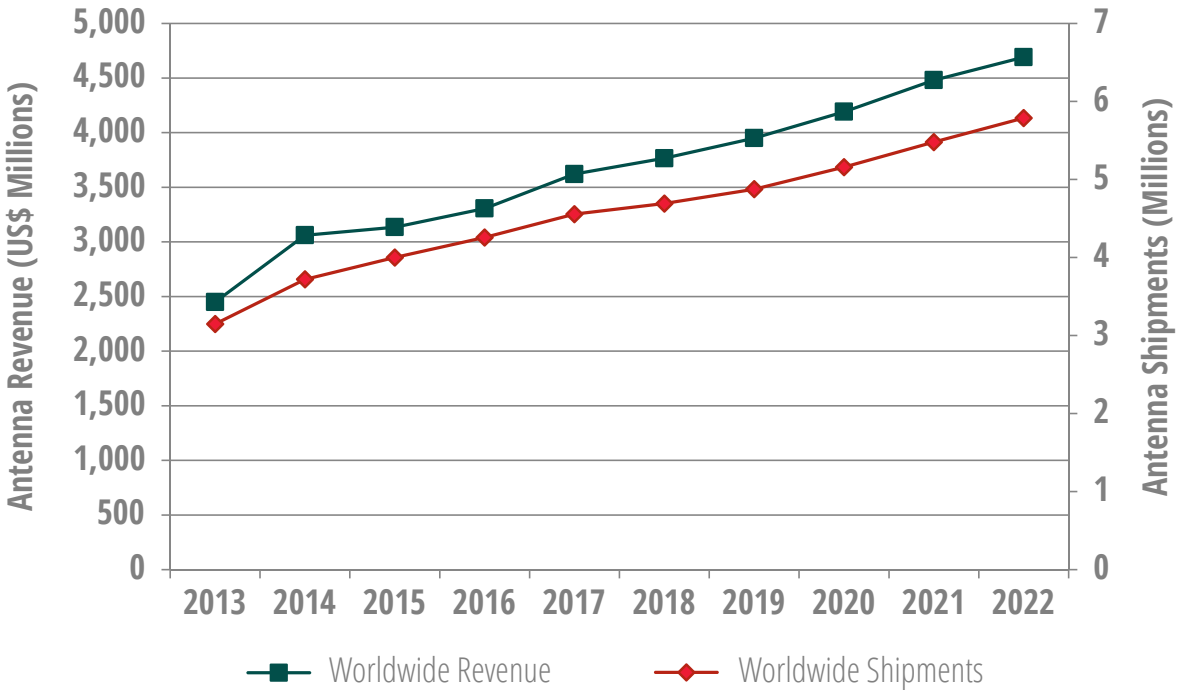
3. MOBILE ANTENNA MARKET OUTLOOK

3.1 OVERALL MACRO CELLULAR ANTENNA SHIPMENT MARKET

Leading up to 2010, the market for macro cellular basestation antennas was largely driven by the deployment of new macro cell sites for 3G coverage. Between 2010 and 2014, carriers built out the coverage of their LTE networks and then filled in their networks to remove black spots and improve indoor coverage for 4G data services. Between 2014 and 2017, the rate of growth in macro cellular antenna shipments has flattened to single-digit growth (see Chart 3).

Chart 3: Mobile Cellular Antenna Revenue and Shipments World Markets, Forecast: 2013 to 2022

(Source: ABI Research)



In 2017, while mobile cellular antenna unit shipments grew at 7%, antenna sales revenue increased at a slightly higher rate of 9.5%, to US$3.62 billion. Competition between vendors is still very intense, but ASPs improved slightly as operators purchased an increasing ratio of higher multiport antennas that have a higher ASP.

The outlook for 2018 to 2020 is going to be shaped by the mobile infrastructure telco landscape. The year 2018 will be one of 5G trials and 2019 will see some tangible 5G commercial RAN deployments. From 2020, a larger volume of 5G commercial deployments should provide the mobile antenna vendors a significant boost. Massive MIMO deployments will start to take a material hold on the market from 2020, but it should be noted that massive MIMO is not an exclusive 5G opportunity, but also a 4.5G opportunity, as LTE-Advanced Pro supports higher-order MIMO.

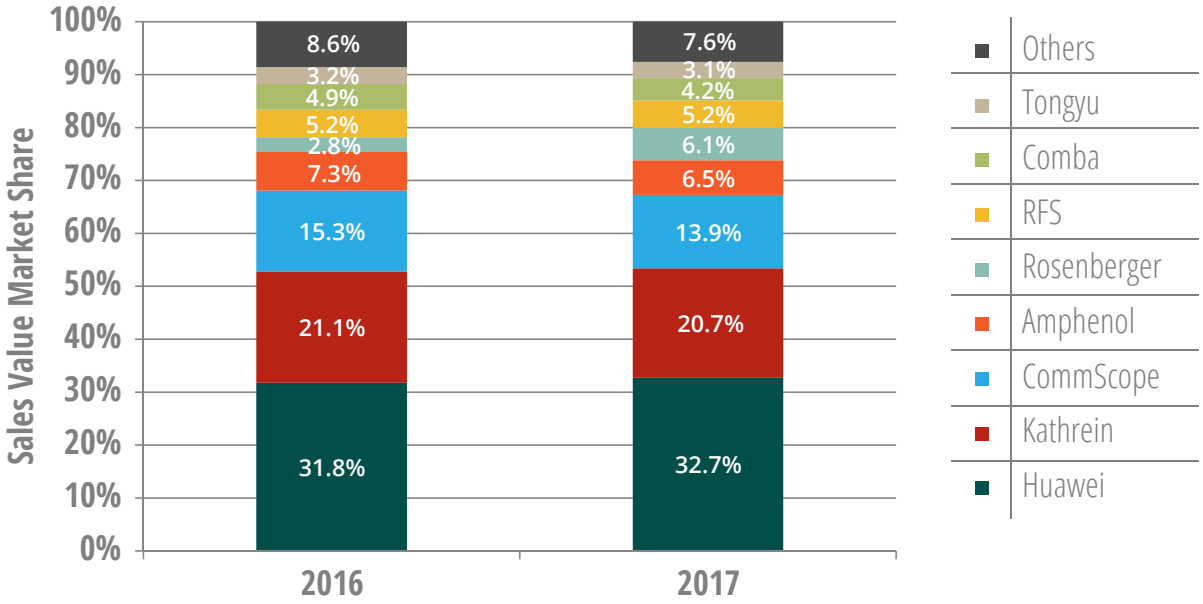
The year 2018 is likely to show single-digit antenna sales revenue growth of around 4%. The outlook for growth should prick up from 2020 as 5G rollouts, higher-order multiport, and higher-order and massive MIMO shipments shift up a gear to 6+%.

3.2 MACRO CELLULAR ANTENNA MARKET SHARE ANALYSIS

The market segment has an assortment of passive panel sector antennas, active antennas, omni antennas and other configurations. Each has its own distinct ASPs and shipment volume profile. Therefore, ABI Research evaluates market share based on macro cellular antenna (2G, 3G, and 4G) revenue as the principal unit of analysis. Chart 4 defines the market share for 2017 *versus* 2016.

Chart 4: Mobile Cellular Antenna Revenue Market Share World Markets, 2016 versus 2017

(Source: ABI Research)



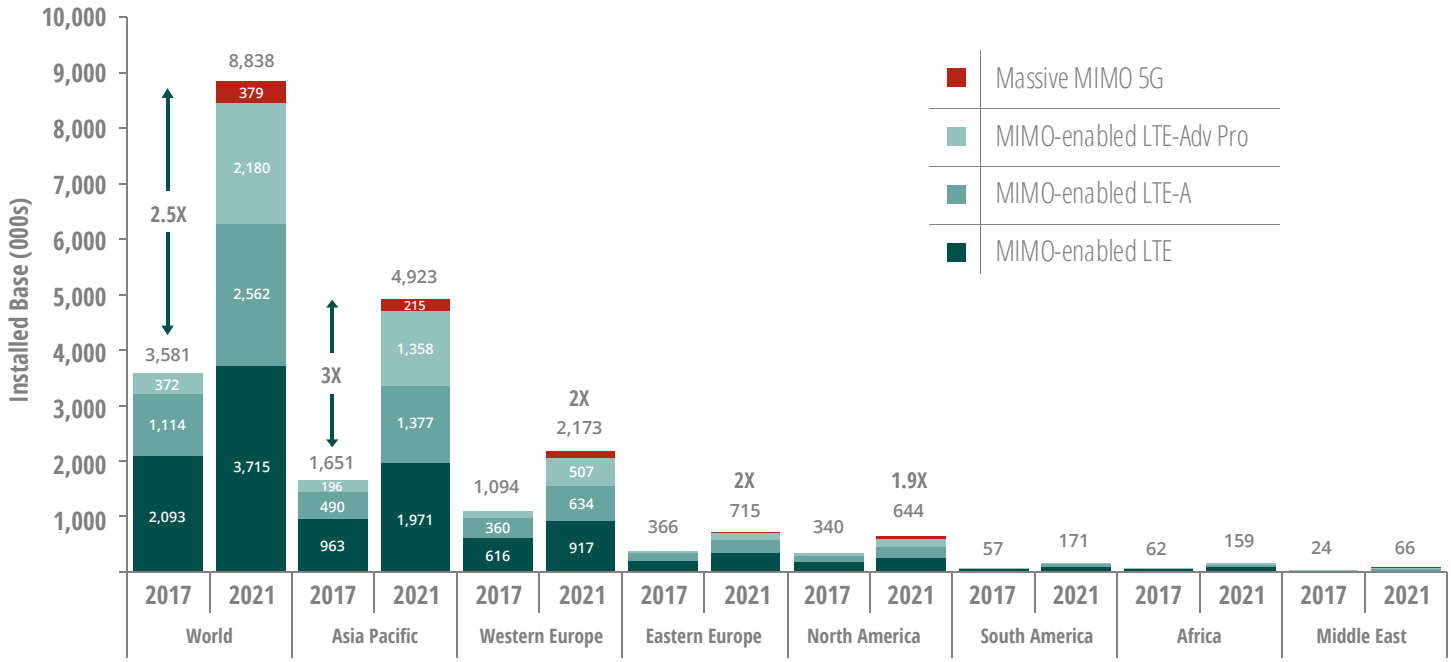
The largest antenna vendor in the market has been Huawei since 2015. In 2017, the vendor retained its number position in the market with a 32.7% share, up slightly from 31.8% in 2016. Kathrein and CommScope have second and third place in the global antenna market with 20.7% and 13.9%, respectively, in 2017. CommScope and Kathrein have prominent positions in the North American and European markets, but they both have had to proactively pursue the Asian market to ensure volumes, keeping their pricing competitive by restructuring their manufacturing plants and moving assembly lines to Asia.

Rosenberger has seen a rapid increase, especially in 2017, ranking number 5 globally. Market traction has come from significant antenna sales in the Asia-Pacific region, especially in India and Southeast Asia. In 2016, Rosenberger secured a 2.8% global market share, while in 2017, this increased to 6.1%. Antenna shipment contracts can be dependent on variable but potentially significant contract awards from mobile telcos, but there should also be significant opportunities for antenna sales due to multi-band and multi-port support as additional 4G and 5G spectrum comes online, as well as higher-order MIMO deployments.

3.3 THE MASSIVE MIMO OPPORTUNITY

A key segment of additional revenue growth should come from the rollout of massive MIMO antennas. To estimate the massive MIMO installed base, ABI Research believes that, in developed regions, massive MIMO antennas will be installed only in dense urban hotspots that require elevated sector capacity density. ABI Research believes that, for an MNO, 10% of sites will merit massive MIMO and that rollout will take a period of 5 years.

Chart 5. MIMO Antenna Installed Base by Platform and Region
World Markets, Forecast: 2017 versus 2021



Massive MIMO penetration for both LTE-Advanced Pro and 5G reaches 4.7% worldwide in 2021. This is equivalent to 418,000 installations. Asia-Pacific is the largest region, with a penetration of 4.9% for a total of 243,000 massive MIMO antennas, followed by Western Europe at 5.4% with 117,000 antennas and North America at 6.3% with 40,000 antennas. This is a conservative estimate given the cost, power, and size constraints, and the limitations of MNO CAPEX. However, ABI Research does believe that massive MIMO will find deployment scenarios that incentivize MNOs to invest to maintain or improve quality of service and reduce churn. The trials and deployments outlined below, and those to come, will be instructive as this model is refined.

3.3.1. Massive MIMO Deployments

As of the end of 1Q 2018, there are three commercial massive MIMO deployments and more than 50 tests and evaluation trials taking place. All deployments are in the mid-band and range from 1.7 GHz to 3.5 GHz in either 32T32R or 64T64R configurations.

Figure 10. Known Mid-Band Massive MIMO Deployments, 2017

One of the earliest announcements was from SoftBank in Japan, which has deployed 100 massive MIMO basestations in hotspots around Tokyo. These early systems were provided by Huawei and ZTE and feature 128 antenna elements (64T64R) deployed on commercial LTE networks at 3.5 GHz.

SoftBank has said that it considers massive MIMO the foundation of its future 5G deployments. Also, T-Mobile in the Netherlands and Vodafone UK both have commercial deployments in 2.6 GHz in selected dense urban areas. China Mobile has perhaps the most commercial massive MIMO deployments.

As can be seen in Figure 10 above, major operators globally have started massive MIMO trials or limited deployments in 2017. Key operators are Sprint, Deutsche Telekom, China Telecom, China Unicom, Singtel, Vodafone Australia, Optus, and Telefónica. SoftBank-Sprint in the United States plans to deploy 64T64R at 2.5 GHz at selected sites in the United States in 2018, as does Verizon in the AWS bands.

4. RECOMMENDATIONS FOR TELCOS

4.1 MACROCELL BASESTATION ANTENNA CONSIDERATIONS

- **Compact Design and Weight Constraints:** Mobile telcos need to take into consideration antenna form factor size and weight when evaluating antenna options. Telcos and tower management companies have evolved LTE mounts to support up to 350 Kg and consist of 6 square meters of space. However, it is still common to find cell sites that only support a payload of 200 Kg. Mobile telcos in Europe and Asia have informed ABI Research that mobile antennas often have to be limited to 1.2 meters to 1.5 meters.

- **Environmental Considerations:** Macro cell and small cell deployments, both indoor and outdoor, are increasingly requiring a discrete, more environmentally friendly profile. Lamp posts are proving to be an ideal form factor to integrate the basestation hardware into the urban landscape, as are slim-line omnidirectional wall-mounted antennas and slim-line rooftop units.
- **Support for the Latest Connectors:** Many incumbent antenna systems use 7/16 connectors, which is a design that goes back to before World War II. It has been a fairly successful design, but issues due to incorrect tightening/coupling can result in water ingress, corrosion, and passive inter-modulation. Therefore, mobile telcos need to migrate to more robust design solutions, such as the NEX10 and 4.3-10 connectors.
- **Quality of Service:** Modern antennas are highly innovative, but consist of multiple components. It is essential that the mobile telco fully test the antennas to eradicate or minimize PIM, which is an essential requirement for the mobile carrier. PIM is a constant challenge. Welded joints are becoming the requisite, rather than screws, to assemble antennas to reduce the possibility of PIM.

4.2 MASSIVE MIMO CONSIDERATIONS

Massive MIMO will be a complementary and essential element of the mobile operator's 4.5G and 5G RAN infrastructure. Mobile service providers need to consider not just power, cost, and size, and ABI Research recommends evaluating the following factors:

- How effective is the massive MIMO antenna in low SINR conditions, such as the cell edge, where low SINR from inter-cell interference could negate the sector throughput advantages of massive MIMO?
- How effective is the massive MIMO antenna in discriminating end-user devices in clusters with low angular spread?
- How effective is the massive MIMO antenna in elevation beamforming for deployment scenarios that include high-rise buildings?
- How efficient is the CSI calculation for FDD mode, and is there a limit to the number of simultaneous end-user devices that can be served?
- What speed limitations are there for high-mobility end-user devices?
- Can digital filtering be applied in the antenna to allow coexistence with incumbent and alternative radio systems in neighboring bands?
- Can the antenna be migrated to 5G if required?

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