CRA Insights:
The Economics of 5G

CRA Charles River Associates

August 2020

The economics of 5G deployment in the “race” to 5G: The role of Massive MIMO

Massive MIMO (Multiple Input, Multiple Output) technology is anticipated to play a prominent role in the global deployment of 5G mobile communications networks. Massive MIMO is an antenna system that substantially improves the coverage, capacity, and speed of wireless networks, and is being deployed broadly in 5G build-outs around the world. In this *Insights* we look at the market for Massive MIMO, the economic forces underlying the relative lack of deployment of this technology in the US to date, and the implications of the current structure of the equipment supply market for the “race” to 5G in the US.

Massive MIMO improves capacity, coverage, and speed of 5G networks

A wireless communications network generally consists of the radio access network (RAN), the “core” network, and other components providing transport between the RAN and the core. The RAN is responsible for the radio-related functionality of the network, including transmitting signals over the airwaves between the users’ handsets and the equipment managing the wireline part of the network. The portion of the network effectuated by the RAN is what is sometimes termed the “last mile,” and it is the only part of a wireless network that necessarily transports traffic wirelessly. RAN equipment includes antenna systems and base stations that transmit and receive radio signals.

MIMO technology is a component of the RAN network. MIMO uses multiple transmit and receive antennas on a radio, typically up to eight. A Massive MIMO device, an evolution of MIMO technology, consists of even higher numbers of transmit and receive antennas, typically 32 or more, referred to as an “active antenna array.”[1] The large number of active antennas in the MIMO array increases network capacity, coverage, and speed.[2] MIMO technology is not new to 5G; rather, MIMO antennas were used in 3G and 4G wireless networks since approximately 2009, and Massive MIMO has been deployed in 4G networks.[3] Softbank, a major Japanese carrier, was one of the first to deploy Massive MIMO in its 4G LTE networks in 2016.[4]

A distinctive innovation of Massive MIMO is that, unlike legacy antenna technology that essentially sends and receives signals over a geographic area in which the handset’s antenna must locate the signal, Massive MIMO delivers focused beams that can track user handsets and user equipment in a process known as “beamforming.”[5] The large number of focused antenna elements allow the base station to concentrate its energy where it is needed, which not only increases network capacity and coverage, but also reduces interference and increases speed.[6] Massive MIMO, and its beamforming functionality, thereby improve the customer experience.

Deployment of Massive MIMO in the US and the rest of the world

Outside the US, many countries have deployed or are deploying Massive MIMO in their 5G networks. Indeed, globally, Massive MIMO accounted for the vast majority of total 5G spending on the RAN in Q4 2018 and Q1 2019 according to Dell'Oro Group, a market research firm. In the US, however, Massive MIMO deployment has so far been limited. To date, Sprint (now, T-Mobile), is the only US carrier that has deployed Massive MIMO in its 5G network.[7]

The difference in Massive MIMO strategies among the major US wireless carriers, and between the US wireless carriers and wireless carriers in the rest of the world, appears to be driven by the differences in spectrum assets.

Outside the US, available data, press releases, and analyses indicate that, to date, all the countries that are deploying 5G networks are deploying their networks in mid-band spectrum, including Australia, China, Japan, Kuwait, Saudi Arabia, South Korea, Spain, Switzerland, and the UK.[8] Many carriers in these countries have deployed or are deploying 5G Massive MIMO.

In the US, as we discussed in our previous ***Insights***, mid-band spectrum necessary for 5G deployment has not yet been made available to all US mobile carriers. Only Sprint (now, T-Mobile) currently has access to mid-band spectrum among US carriers and, as a result, only Sprint (now, T-Mobile) has a 5G deployment in mid-band spectrum in the US. Before its merger with Sprint, T-Mobile used low-band and millimeter wave (high-frequency, or "mmW") spectrum to deploy 5G.[9] AT&T has also deployed 5G networks using low-band and mmW spectrum in multiple markets.[10] Verizon has deployed 5G networks in mmW spectrum, and has announced that it will be deploying 5G nationwide in low-band spectrum.[11]

Since its merger with Sprint, T-Mobile has augmented Sprint's deployment of 5G Massive MIMO with Massive MIMO deployments in its own 5G networks in New York and Philadelphia using the mid-band spectrum it acquired in the Sprint merger.[12] No carriers have deployed Massive MIMO in mmW or low-band spectrum. While all major US carriers have access to low-band (below 1 GHz) spectrum for 5G deployment, Massive MIMO is not anticipated to be used in low-band spectrum because the longer wavelengths of the lower spectrum bands require antennas that are too large to be accommodated in large arrays.[13] Development of Massive MIMO technology for use in mmW spectrum—to which all US carriers also have access for 5G—is not as advanced as the Massive MIMO technology currently available for mid-band spectrum,[14] for reasons we discuss below.

Both Verizon and AT&T have stated that they will deploy Massive MIMO when mid-band spectrum becomes available to them.[15] It is unclear whether either company plans future Massive MIMO deployments in mmW bands.

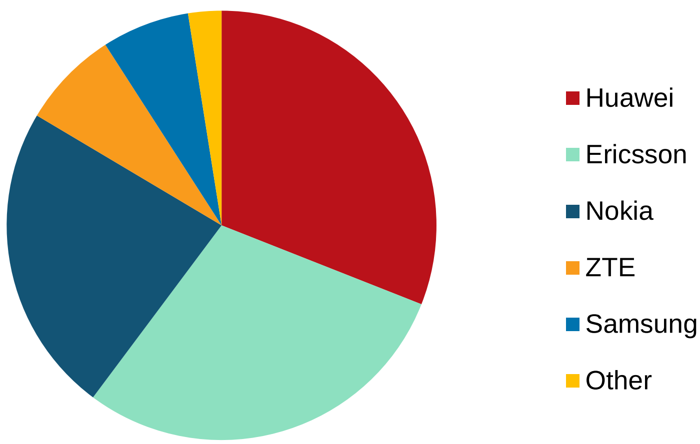
The RAN equipment market is highly concentrated with significant barriers to entry

Access to mid-band spectrum has enabled carriers in other countries to deploy Massive MIMO, which in turn further enhances the performance of their networks. The relatively delayed development by the equipment vendors of Massive MIMO for mmW spectrum appears to be driven, at least in part, by economic factors that determine the incentives vendors of RAN equipment face as to where to deploy their limited research dollars and expertise. Because the US is the only country that has commercially launched 5G in mmW spectrum, and because no other country appears to be deploying 5G broadly in mmW, the US is the only country in the world right now that is a significant potential customer for mmW Massive MIMO. The US market for RAN equipment, while attractive, represents less than a quarter of the worldwide market when measured by sales.[16]

In addition to the less robust demand for mmW equipment, the structure of the industry supplying RAN equipment has not been conducive to encouraging research attention on mmW Massive MIMO. First, there are only five suppliers of RAN equipment (including Massive MIMO) worldwide that have significant market shares. In fact, Figure 1 shows that well over three-fourths of global sales of RAN equipment are accounted for by three companies: Telefonaktiebolaget LM Ericsson (Ericsson), Huawei Technologies Co., Ltd. (Huawei), and Nokia Corporation (Nokia). RAN equipment for 5G is expected to be a $7.3 billion global market by 2023,[17] and sub-6 GHz (low-band and mid-band) technology is predicted to account for the largest share of expenditures on 5G infrastructure.[18] It would be risky for an equipment supplier to fall behind its competitors in developing technology for mid-band equipment for the global market—technology that is rapidly evolving in real time—to divert additional attention to a technology with a narrower market.

Equipment suppliers undoubtedly also recognize that while the US is currently focused on mmW deployments, the Federal Communications Commission (FCC) has been attempting to press forward with mid-band spectrum auctions as soon as feasible. The FCC just completed its first auction of mid-band spectrum in the 3550-3650 MHz range on August 25, 2020. The lack of demand by major US carriers for mid-band RAN technology is likely to be a temporary phenomenon, further discouraging significant diversion of additional attention of the major vendors to mmW research. In the meantime, the US is disadvantaged by the relatively less-developed state of RAN technology for the spectrum bands most available here.

Figure 1: Global revenue shares of RAN equipment vendors, 2018



Note:

These data include sales of GSM, CDMA, WCDMA, LTE, and 5G RAN equipment.

Source:

Dr. Debra J. Aron, "The Impact on the U.S. Economy of Excluding Huawei from Participation in the U.S. Market for Wireless Network Equipment," Expert Report, October 7, Figure VI.1 (submitted as Attachment 1 to Written Ex Parte Submission of Huawei Technologies Co., Ltd., and Huawei Technologies USA, Inc., In the Matter of Protecting Against National Security Threats to the Communications Supply Chain Through FCC Programs, Before the Federal Communications Commission, WC Docket 18-89 (November 14, 2019)).

Additionally, Huawei, the largest supplier of RAN equipment in the world and one of the largest suppliers of Massive MIMO;[19] and ZTE, the fifth largest global RAN supplier, are banned from selling 5G RAN equipment to US carriers by US policy.[20] In the US, suppliers other than Nokia and Ericsson have benefitted very little from their absence. No maverick has emerged on a significant scale, and the absence of the banned suppliers has not led to new entry or expansion of market share by the smaller-share providers such as Samsung. Rather, Nokia and Ericsson alone provide more than 80 percent of RAN equipment in the US, and, as in the rest of the world, Samsung and "Other" collectively constitute less than 20 percent of the US RAN market. "Other" includes Airspan, Fujitsu, NEC, and companies with even smaller revenue shares.

Significant barriers to entry are likely responsible for the failure of entrants to emerge to take advantage of the opportunities created by the unique circumstances in the US. According to Dell'Oro Group's data, there was no significant new entrant in the global market for RAN equipment between 2008 and 2016.[21] The data indicate that the biggest entrant into the global market for RAN since 2008 has been the US-based vendor Airspan, which began supplying RAN equipment in 2016.[22] To date, however, its revenue share has remained immaterial, both globally and in the US.[23]

One of the barriers to entry into the market for provision of RAN equipment is that meaningful participation in the RAN market requires significant and risky investments in R&D. Ericsson, Nokia, and Huawei each spent between $1.9 billion and $19.1 billion on R&D each year since 2009. These companies employ tens of thousands of workers who are engaged in R&D activities, constituting over a quarter to nearly half of their respective workforces worldwide.[24] In addition, manufacturing RAN equipment requires acquiring licenses to standard essential patents, which may create additional barriers to entry for new market players who do not have their own standard essential patents.[25]

Economics predicts that when mid-band spectrum becomes available in the US for 5G deployment, the high market concentration of RAN equipment suppliers in the US and the presence of entry barriers into the provision of RAN equipment will likely create higher RAN equipment prices, including prices for Massive MIMO, in the US than in countries whose market structure looks more like Figure 1, all else equal. Higher equipment prices would, in turn, be expected to further slow the deployment of RAN insofar as carriers must raise and justify the capital necessary for deployment over time. Current estimates are that 5G deployment in the US will require total industry investment of $297.92 billion over a seven-year period.[26] According to one study, RAN equipment accounts for 25 percent of total US 5G deployment costs, implying that RAN equipment alone will demand over $74 billion in capital expenditure in the US.

The high market concentration of RAN supply in the US, the current lack of mid-band spectrum in the US, and the focus of global suppliers on mid-band rather than mmW spectrum technology are interconnected and together are serving to delay and disadvantage the US in the "race" to 5G. In addition, the Chinese vendors that have been excluded from the US are generally acknowledged to be further advanced in development of certain RAN technologies, including Massive MIMO. Chinese companies have been excluded from the US for reasons related to national security and/or politics, depending on one's perspective. We offer no position or insight on the merits of these claims nor on the optimal strategies to protect national security and personal privacy interests, but note only that as an economic matter, exclusion of Chinese companies from the ability to supply 5G RAN equipment will be an independent source of delay of US deployment of 5G networks.[27]

Concluding remarks

The high level of concentration of the RAN equipment market in the US has not gone unnoticed by policy makers and has been of concern to them.[28] Of additional concern to US policy makers has been the fact that none of the available suppliers of RAN equipment in the US (or worldwide) is an American company. Because the entry barriers into RAN equipment supply are recognized as formidable, policy makers have not expressed serious expectations that a US company can realistically replicate RAN technologies such as those supplied by Nokia, Ericsson, Samsung, and, elsewhere, by Huawei and ZTE, in a timely fashion to maintain American competitiveness in the global 5G deployment and adoption "race."

There is optimism in the US and globally that alternative technologies can serve as substitutes for the RAN equipment provided by the five major suppliers and provide a viable avenue for US entry in the provision of 5G RAN equipment.[29] These alternative technologies are referred to as "OpenRAN" and "virtualized RAN" (or "vRAN"). We will discuss these emerging alternative RAN technologies and the likelihood that they will be produced at scale in time to be used for 5G deployments in our next article in this series.

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[18] According to Dell'Oro Group's RAN equipment sales data, Huawei is by far the largest supplier of Massive MIMO for LTE. Its revenue share in 2018 exceeded that of the next largest supplier by a factor of over 9. Based on data provided by Dell'Oro Group.

[19] John S. McCain National Defense Authorization Act for Fiscal Year 2019, Sec. 889(a), (b)(1), (f)(3)(A); Order, In the Matter of Protecting Against National Security Threats to the Communications Supply Chain Through FCC Programs – Huawei Designation, Before the Federal Communications Commission, PS Docket No. 19-351, DA 20-690 (Released: June 30, 2020), 1, 63. Order, In the Matter of Protecting Against National Security Threats to the Communications Supply Chain Through FCC Programs – ZTE Designation, Before the Federal Communications Commission, PS Docket No. 19-352, DA 20-691 (Released: June 30, 2020), 1, 29.

[20] ZTE, Alvarion, and Cisco entered the global RAN market in 2007 according to Dell'Oro Group data. Alvarion and Cisco never gained significant revenue share in the global RAN market. Both Cisco and Alvarion supplied only WiMAX equipment and both companies exited the market in 2009 and 2013, respectively. ZTE's presence has been very limited in the US market for RAN equipment since it entered the market in 2008. The revenue share of ZTE in the US market for RAN equipment has always been immaterial and it reached near zero in 2018.

[21] Airspan offers 4G and 5G RAN equipment solutions. According to its website, Airspan offers indoor and outdoor RAN products such as femto, pico, micro, and macro base stations; it also offers products for a variety of technologies such as mmW, Sub 6 GHz, Massive MIMO, and open virtualized RAN architectures. Airspan also offers Fixed Wireless Access solutions. According to data provided by Dell'Oro Group, all of Airspan's sales came from small cell solutions such as pico and micro base stations. It appears that among major US carriers only Sprint to date has used Airspan's products, having deployed Airspan's small cell solution. See "About Airspan: A multi-award-winning 4G & 5G network densification solution provider," Airspan, at https://www.airspan.com/about-airspan/; "Airspan's innovative solutions are key to scaling regional and rural mobile network deployments," press release, October 8, 2019, at https://www.airspan.com/news/airspans-innovative-solutions-are-key-to-scaling-regional-and-rural-mobile-network-deployments/; Monica Alleven, "Airspan snags Gogo, other high-profile wins," *FierceWireless*, October 31, 2019, at https://www.fiercewireless.com/wireless/airspan-snags-gogo-other-high-profile-wins.

[22] Based on data provided by Dell'Oro Group. Airspan's revenue share in the North American market has not risen above a small fraction of one percent.

[23] In 2018, Huawei reported that more than 80,000 employees (45 percent of its total workforce) were involved in R&D. See Huawei Investment & Holding Co., Ltd., 2018 Annual Report, p. 44. Ericsson reported 24,800 employees (26 percent of its total workforce) working on R&D. See Ericsson Annual Report, 2018, pp. 1, 35. Nokia's 2017 "People and Planet" report states that Nokia employed approximately 103,000 people, out of which more than a third (approximately 34,333 employees) worked in R&D. See "People and Planet Report 2017," Nokia Corporation, p. 5.

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[26] Multiple sources, including the US Department of Defense, conclude that Chinese equipment manufacturers, and Huawei in particular, have been leaders in Massive MIMO technology. A report from the Defense Innovation Board called Huawei and ZTE "the leader [sic] in massive MIMO radio systems." See Department of Defense, Milo Medin and Gilman Louie, "The 5G Ecosystem: Risks & Opportunities for DoD," Defense Innovation Board, April 2019, p. 17, at https://media.defense.gov/2019/Apr/04/2002109654/-1/-1/0/DIB_5G_STUDY_04.04.19.PDF; Rethink Technology Research said that "Huawei has been in front of the field in areas such as Massive MIMO and flexible spectrum usage." See Caroline Gabriel, "Nokia and Ericsson pin hopes on 5G to catch up with Huawei," *Rethink Technology Research*, August 20, 2018, at https://rethinkresearch.biz/articles/nokia-and-ericsson-pin-hopes-on-5g-to-catch-up-with-huawei-2/. According to the Wall Street Journal, European carriers said that Nokia and Ericsson "have been slow to release equipment as advanced as Huawei's." See "Huawei's dominance in 5G technology makes it nearly impossible to restrict the controversial Chinese company from telecom networks," *Wall Street Journal*, March 11, 2019, video at 2:24, at https://www.wsj.com/video/why-it-almost-impossible-to-extract-huawei-from-telecom-networks/122E816F-856B-4D3F-A361-B832D9862A99.html; GlobalData, a provider of research and consulting solutions for several industries, compared portfolios of 5G RAN equipment of Ericsson, Huawei, Nokia, Samsung, and ZTE in the second half of 2019 in four categories: (1) baseband unit (BBU) capacity, (2) radio unit portfolio, (3) ease of installation, and (4) technology evolution.

GlobalData found that Huawei had a leadership position in every category. See "GlobalData Releases 2019 5G Competitive Landscape Assessment: Huawei Remains 5G RAN 5G Leader," Mobile World Live, January 7, 2020, at https://www.mobileworldlive.com/huawei-updates/globaldata-releases-2019-5g-competitive-landscape-assessment-huawei-remains-5g-ran-5g-leader/?from=timeline; "GlobalData PLC," Bloomberg, at https://www.bloomberg.com/profile/company/DATA:LN. A similar observation was made by the UK's Secretary of State for Digital, Culture, Media and Sport, Oliver Dowden who said that banning Huawei would delay 5G rollout by about a year in the UK. An executive from Telus Corp., a Canadian provider of wireless telecommunications services, also warned that excluding Huawei from the Canadian market for RAN equipment would lead to added costs to and potential delays in 5G rollout in Canada. See Leo Kelion, "Huawei 5G kit must be removed from UK by 2027," *BBC News*, July 14, 2020, at https://www.bbc.com/news/technology-53403793; Natalie Wong, "Telus Warns of Potential Cost Fallout if Canada Bans Huawei," *Bloomberg*, February 14, 2019, at https://www.bloomberg.com/news/articles/2019-02-14/telus-says-huawei-ban-could-materially-raise-5g-deployment-cost.

[27] See, for example, Remarks of Commissioner Jessica Rosenworcel Mobile World Congress Americas Los Angeles, California, October 22, 2019, p. 4, at https://www.fcc.gov/document/rosenworcel-remarks-mobile-world-congress-americas; Center for Strategic International Studies, "Attorney General William Barr's Keynote Address: China Initiative Conference," February 6, 2020, at https://www.csis.org/analysis/attorney-general-william-barrs-keynote-address-china-initiative-conference.

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