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Massive MIMO Brings 5G into Focus

Summary

Massive MIMO (mMIMO) has captured market attention because of its promised performance gains for 4G and particularly 5G networks with its focus on higher band spectrum.

Tolaga Research has used natural language processing (NLP) techniques to determine that the greatest public relevance for mMIMO in 2018 was held by Nokia and Ericsson amongst the Tier 1 vendors and Commscope was amongst the specialist radio vendors. However, these and other vendors must evolve their messaging and positioning as mMIMO matures and becomes relevant to broader market audiences.

Although mMIMO is still a nascent technology, it will become table-stakes for 5G and will depend on continued innovation for the foreseeable future to expand market opportunities, including into small cells. Tier 1 infrastructure vendors will expand their mMIMO development activities as will operators such as Sprint, which is deploying mMIMO in the 2.5GHz band for both 4G and 5G using Nokia and Samsung antennas. This will challenge specialist radio and mMIMO technology providers to develop differentiated solutions and to remain publicly relevant.

Massive MIMO Hits the Limelight

The history of the humble base station antenna is one of a quiet work-horse with an understated role in radio network design. However, this has changed with the recent introduction of massive MIMO (mMIMO) technology. And for good reason. mMIMO promises tremendous radio performance gains but is a complex technology with demanding deployment and operational requirements. Technology trials over the last 24 months have demonstrated the benefits of mMIMO, but also highlighted implementation challenges and the need for continued technology innovation. These challenges are exemplified by continued communication service provider (CSP) trials and a variety of recent announcements, including Ericsson's plan to acquire Kathrein, and Nokia's water-cooled mMIMO and advanced mMIMO scheduling solutions.

MIMO has a long heritage of technology innovation

Massive MIMO capitalizes on advancements in beam-forming and intelligent antenna systems to enhance the capabilities of conventional MIMO. The fundamental design principles for MIMO were originally identified in the 1980's, and MIMO is already widely used for Wi-Fi and LTE networks. In essence, MIMO capitalizes on spatial variations in radio propagation to simultaneously transmit multiple data streams within the same radio channel. This so called ‘spatial diversity', is used to either:

- **Increase radio network capacity**, when different information is transmitted on each of the multiple data streams, or;

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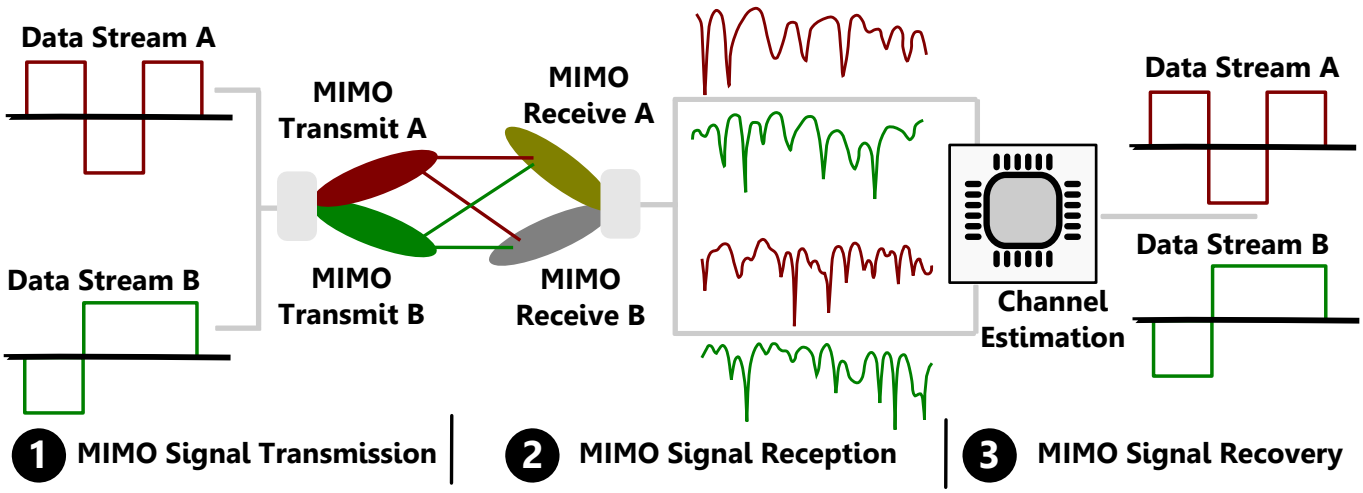
- **Improve radio network coverage and reliability**, when the same information is transmitted on multiple data streams for redundancy.

Exhibit 1 illustrates the basic functionality associated with MIMO and includes the following:

1. **MIMO signal transmission:** Where multiple data streams (i.e. data stream A and data stream B in Exhibit 1) are simultaneously transmitted at the same site using the same channels through spatially separated or multipolar antennas, or different beams in the case of multi-beam antennas.
2. **MIMO signal transmission:** As signals propagate between transmitting and receiving devices, (i.e. through 'the channel'), they are scattered and attenuated by environmental objects in the path. Scattered radio signals become dispersed, and each dispersed signal follows a different path (with different path-length) to the receiving antennas. When the scattered (multi-path) radio signals are combined at the receiving antennas, the combined signals exhibit multi-path fading. This fading reflects that constructive and destructive combining of the multi-path signals. Since scattering is highly variable, the multipath signals to and from diverse antennas are normally different. If this difference can be predicted through channel estimation, then each of the MIMO signals can theoretically be recovered. This is the basis of MIMO spatial diversity.
3. **MIMO signal recovery:** Using radio channel estimates and advanced signal processing, the individual MIMO signals are identified, and the original data recovered.

The illustration in Exhibit 1 has two transmitting (Tx) and two receiving (Rx) antenna paths, which would ordinarily be described as 2Tx/2Rx MIMO. Existing LTE base stations commonly have at least two physical antennas in each sector for the purposes of diversity. It is common for CSPs to retrofit MIMO to existing LTE base stations using these antennas. In some cases, CSPs have also implemented higher order MIMO for LTE, such as 4Tx/4Rx, however this is less common.

Exhibit 1: MIMO illustration with a 2Tx/2Rx architecture
Source: *Tolaga Research, 2019*



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MASSIVE MIMO IS STILL A NASCENT TECHNOLOGY

Advancements in beam-forming and intelligent antenna systems have enabled so called massive MIMO (mMIMO). Current mMIMO systems have up to 32Tx/32Rx paths for sub-6GHz and 128Tx/128Rx paths for millimeter wave operations. The theoretical performance gains achieved with mMIMO are tremendous. For example, in 2017 researchers at the University of Bristol demonstrated that under laboratory conditions, mMIMO can achieve in excess of 30 times the capacity of today's LTE Advanced technologies, using 128Tx/128Rx antenna paths. In field trials with 64Tx/64Rx, Sprint and Ericsson demonstrated a four-fold peak capacity increase relative to a 4G-MIMO system with 8Tx/8Rx operations. A growing number of CSPs have engaged in technology trials to determine mMIMO performance under practical operating conditions, and to better understand its implementation challenges. Notable challenges include:

- **Accurate channel estimation and beam optimization:** Mobile networks require both downlink (base-to-mobile) and uplink (mobile-to-base) connections. These connections either operate at different frequencies (i.e. are frequency division duplexed - FDD) or different timeslots in the same frequency (i.e. are time division duplex – TDD). For TDD systems, the radio channel does not change between uplink and downlink connections and therefore channel estimation on the uplink reflects the downlink channel as well. This contrasts FDD systems, where the channels are not the same. For this reason, channel estimation and beam optimization are significantly easier for TDD systems than for FDD. The processing demands for channel estimation significantly constrain the number of Tx/Rx paths that FDD systems can support. This is a challenge for many CSPs and a vibrant field for ongoing research, since most sub-6GHz mobile spectrum is channelized for FDD operations.
- **Power consumption:** mMIMO has tremendous processing demands and requires many more RF chains than conventional systems. This dramatically increases the power consumption of mMIMO cell sites. It increases the heat energy which must be dissipated in mMIMO antennas and overall site utility costs and power rating requirements.
- **Antenna size and loading:** With added active and passive components, mMIMO antennas that operate at sub-6GHz frequencies are physically large and heavy. This can prove challenging and expensive, particularly for sites that require structure upgrades and changes to site leases and zoning approvals.
- **Cost and optimization:** The unit costs for mMIMO systems are significantly more than that for traditional passive antenna systems. Therefore, mMIMO must be sufficiently optimized before it can be economically justified. Large scale mMIMO implementations are complex to optimize and depend on sophisticated algorithms and accurate radio channel estimation schemes. In addition, high resolution network design and planning tools are needed to ensure that the impact of mMIMO can be modeled effectively and networks designed and optimized accordingly.

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COMPETING FOR MASSIVE MIMO SUCCESS

mMIMO is a complex technology that will require continued innovation for the foreseeable future. This is good news for technology vendors as they develop differentiated solutions. However, because of its strategic importance, particularly for 5G, the competitive landscape for mMIMO will change over the next 24-36 months. Tier 1 infrastructure vendors including Ericsson, Huawei, Nokia and ZTE, will bolster their mMIMO capabilities with solutions that are embedded in their radio network architectures. As this occurs, the mMIMO market will become increasingly competitive for disruptive and specialized radio technology vendors like Samsung, Airspan, Amphenol, Commscope, Comba, RFS and Kathrein (which was acquired by Ericsson).

Ultimately successful mMIMO solutions will be those that not only meet the commercial and operational demands of 5G networks, but also those that are publicly recognized for their differentiated capabilities. This recognition will depend on effective ingredient marketing' strategies on the part of technology vendors, which we believe can be quantified from relevant web content and thought leadership published in company blogs and whitepapers.

In Exhibit 2, web content from 2015 to 2018 that is relevant to mMIMO was analyzed to estimate the public engagement of mMIMO technology providers. These estimates used proprietary natural language processing (NLP) tools to grade the level of public engagement of mMIMO vendors into one of three categories, namely:

- **On the horizon:** for vendors that are mentioned in mMIMO related web content. The vendors are loosely associated with mMIMO (based on the results of deep learning algorithms that estimate word similarity and association) and the web content is biased towards sites with relatively low ranks.
- **Publicly recognized:** for vendors that are directly associated with mMIMO related content (based on estimated word similarity and association) and web content that is biased towards sites that have modest web ranks.
- **Publicly engaged:** for vendors that is strongly associated with mMIMO and high profile mMIMO activity and web content with a bias towards high profile web ranks.

Amongst the Tier 1 infrastructure vendors, the ranking in Exhibit 2 has Nokia, Ericsson and Huawei leading mMIMO public engagement in 2018. Commscope leads amongst specialist radio technology vendors, followed by Airspan, whose public engagement was driven through its acquisition of Mimosa in 2018.

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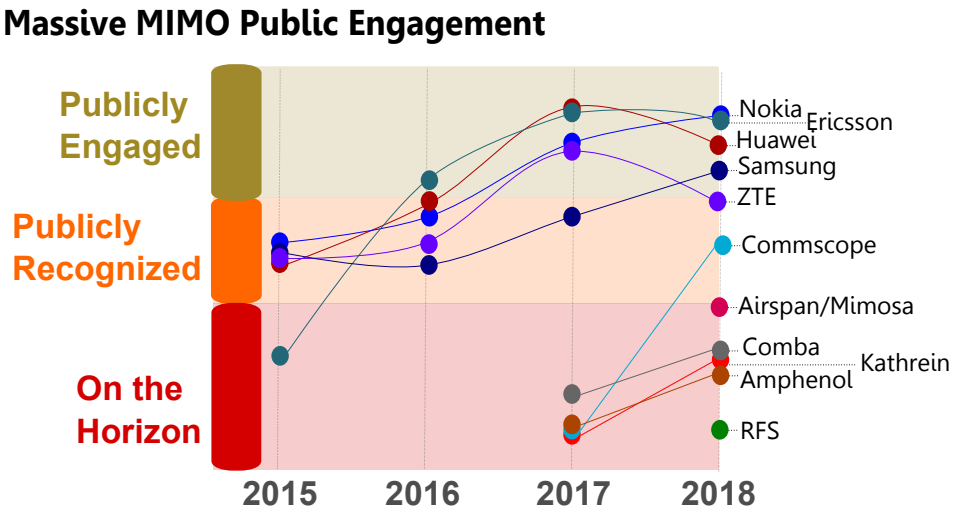
Exhibit 2: Public engagement for mMIMO technology vendors
Source: *Tolaga Research, 2019*



Rank Factors	On the Horizon	Publicly Recognized	Publicly Engaged
Presence in public disclosure	Mentioned in articles relating to mMIMO	Major entity in mMIMO web content	Direct association with high profile activity in mMIMO web content
Company name word association with MIMO	Loose association with mMIMO	Associated with mMIMO	Strongly Associated with mMIMO
Site web rankings (e.g. Alexa)	Bias towards low ranking sites	Neutral	Bias towards high ranking sites

The blogs and white papers published by Airspan, Comba, Commscope, Ericsson, Huawei and Nokia since 2016 were analyzed using proprietary NLP tools to assess thought leadership. For the purposes of this report, these tools ranked the blog and white paper content relative to keywords and phrases that relate to networks and network technology, see Exhibit 3. The ranking in Exhibit 3 has Nokia leading in its thought leadership, followed by Ericsson and Huawei. Commscope's thought leadership ranking in Exhibit 3 and public engagement ranking in Exhibit 2 were bolstered by the large number of blog documents that it has published since 2016. Today the thought leadership of companies like Commscope and Airspan is narrowly focused towards network technologies. This contrasts Comba, Ericssion, Huawei and Nokia, whose thought leadership covers a broader range of topics. We believe that it is important for companies like Commscope and Airspan broaden the scope of their thought leadership to ensure they maintain mindshare and relevance as the market matures.

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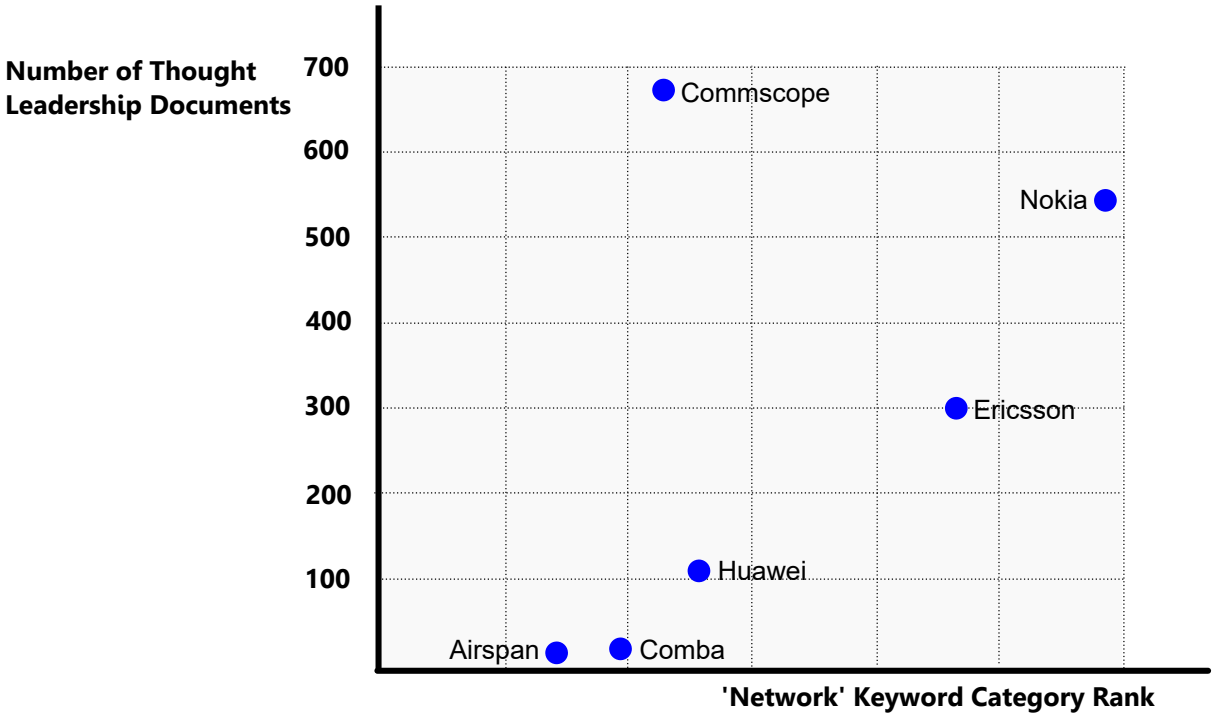
Exhibit 3: 'Network' keyword ranking in vendor thought leadership documents
Source: *Tolaga Research, 2019*



TAKEAWAYS

- mMIMO has proven its ability to deliver tremendous network capacity gains and will ultimately become 'table-stakes' for 5G TDD based systems. The opportunities for large scale FDD mMIMO solutions are more complicated and less certain.
- mMIMO is still nascent and will benefit from tremendous innovation to improve technical and operational performance, energy efficiency and suitability for existing and future cell site architectures.
- Competition for mMIMO will increase as it gains mass market adoption. This will challenge the technology positioning and marketing efforts of specialist and pure-play mMIMO technology vendors.

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About the Author

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Phil Marshall is the Chief Research Officer of Tolaga, where he leads Tolaga's thought leadership program. Before cofounding Tolaga, Dr Marshall was an Executive at Yankee Group for nine years, and led its service provider technology research globally.

Marshall has 25 years of experience in the wireless communications industry. He spent many years working in various engineering operations, software design, research and strategic planning roles in New Zealand, Mexico, Indonesia and Thailand for Verizon International (previously Bell Atlantic International Wireless) and Telecom New Zealand. In addition, Marshall was an electrical engineer at BHP New Zealand Steel before he attended graduate school. He has a PhD degree in Electrical and Electronic Engineering and is a Senior Member of the IEEE. His technical specialty is in radio engineering and advanced system modeling, and his operational experience is primarily in communications network design and optimization.

About Tolaga Research

Tolaga Research is a leading consulting and advisory firm with a focus towards communication networks and the Fourth Industrial Revolution. Tolaga was founded in 2009 and is the world's first firm to apply artificial intelligence with natural language processing and system dynamics modeling to industry research. By combining these sophisticated capabilities with its extensive primary research, Tolaga delivers unique and actionable insights that are fortified with robust data science and system modeling solutions.

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