



The Fifth Generation of Wireless Network Communications

Smarter, Faster and More Dense Deployment with Smart
Solutions from TE Connectivity - Opportunities and Challenges

ABOUT THIS PAPER

In our first 5G white paper, we discussed mass connectivity in the 5G era —and the need to supplement the capacity of 4G networks. In this second 5G white paper, we provide more technical detail on the connectivity solutions that may enable the successful deployment of 5G. We cover the key issues faced by design engineers with the move from remote radio unit (RRU) to active antenna system (AAS), challenges with the radio unit, role of fiber and cloud solutions — and specifically focus on the portfolio of 5G solutions and capabilities from TE Connectivity (TE).

Introduction

Most industry analysts agree that upwards of 75 billion Internet of Things (IoT) devices¹ will be connected by 2025, and most will use wireless technology. 4G may not be able to keep up, so thankfully, 5G is on its way. This fifth generation of wireless technology brings advantages in three areas: greater speed to move more data, lower latency to be more responsive, and the ability to connect many more devices at once from sensors to smart devices. In fact, 5G networks are expected to accelerate data up to 100 times faster than today's technology. This will require advanced connectivity for broader bandwidth and high-clarity communications. Increased data speeds in the future may enable an interactive ecosystem for a smarter, productive, and an even more connected world. TE can be your partner for this new world.

*5G is on its way.
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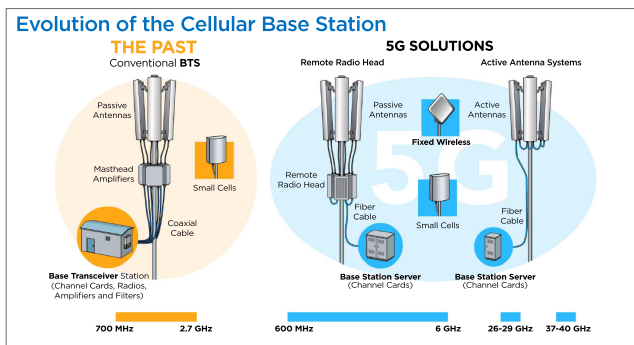
¹ <https://www.achrnews.com/articles/132303-billion-iot-devices-predicted-by-->

Additional source: <https://www.statista.com/statistics/471264/iot-number-of-connected-devices-worldwide/>

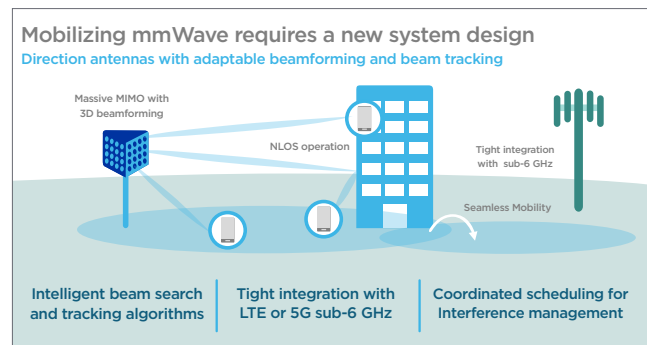
ARE YOUR DESIGN ENGINEERS READY FOR 5G?

As a critical but scarce resource in the 5G era, spectrum in three key frequency ranges is expected to deliver widespread coverage and support all 5G use cases: sub-1 GHz, 1-6 GHz, and above 6 GHz. The first two are often referenced as sub-6GHz. This is important as cellular data traffic continues to increase and enhanced mobile broadband is set to become the core consumer value proposition. Enhanced mobile broadband (eMBB) is one of three sets of use cases defined for 5G. As an extension to existing 4G broadband services, these use cases will be the first commercial 5G services to launch. However, they will go far beyond just enabling faster download speeds.

We expect both the United States and China to lead the first wave of 5G deployments. China will focus initial deployments in the C-band (3-5 GHz). The United States, on the other hand, will focus initial deployments on fixed wireless access through millimeter wave (mmWave) (above 24 GHz) frequency spectrum, as well as deployments in low bands (600 MHz).



NXP 5G Wireless Infrastructure



mmWave solution for mobile applications - Qualcomm

We believe that in the long run, C-band spectrum may be challenged to deliver enhanced mobile broadband due to limited spectral efficiency and system capacity improvements, as well as the challenging 1ms latency. To support the requirements for wide contiguous bandwidths, mmWave will need to be considered.

In fact, with the current technical maturity and economic feasibility, a hybrid network is very likely. For instance, in major urban areas, mmWave is expected to be deployed for fixed wireless or hot-spot-like coverage, while sub-6 GHz is expected to deploy for coverage in suburban areas or small cities. 5G will continue to co-exist with 4G.

Source:

<https://www.nxp.com/video/nxp-5g-wireless-infrastructure:NXP-5G-WIRELESS-INFRASTRUCTURE>
<https://www.forbes.com/sites/tiriasresearch/2018/07/24/qualcomm-makes-millimeter-wave-a-reality-for-first-gen-5g-phones/>

DEPLOYING 5G — THE RIGHT CONNECTIVITY SOLUTIONS FOR SOLVING TOUGH TECHNICAL CHALLENGES

For deploying 5G, it's important to understand key technologies such as the move from separate RRU and antenna systems to AAU with massive multiple-input, multiple-output (MIMO) integrating antenna elements and other active electronics. Antenna systems are expected to move from passive structures into active antenna units, containing electronics positioned directly at the antenna edge. The new active antenna systems are expected to move massive MIMO antenna to serve multiple users through multiple wireless channels, the so-called multi-user massive MIMO or MU-MIMO. We expect this to generate a high amount of data per antenna element through internal connections such as connectors and cables.

With the 5G new radio standard (NR), the key components may combine the RRUs and the antennas into an AAS.



An Integrated Solution — AAS.

From rural towers to urban placements, the market pressure is on to design next-generation wireless radio systems that need to be broadband, multi-mode, highly efficient, and highly integrated to handle a vast and diverse set of applications and services. Urban placements might also include rural towers inside cities and other untraditional spaces such as rooftops, streets lights and the streets themselves, and even in tunnels. Long-haul antennas will likely still be doing the long-haul distance coverage in rural areas — similar to what we have today with 4G.

AAS is an active antenna system that integrates active radio electronics (transceiver) with the passive antenna array to boost capacity and coverage, reduce RF cable requirements and cable loss — a key component of 5G.

Massive MIMO is considered to be a core, foundational component of the super-fast, 5G network of the future. While it involves multiple technologies, MIMO is essentially a wireless multiplexing technology that allows the transmitting and receiving of multiple data signals simultaneously over the same radio channel, typically using a separate antenna for the transmitting and receiving of each data signal. While there's no set figure for what constitutes a Massive MIMO set-up, the description tends to be applied to systems with tens or even hundreds of antennas. For example, Huawei, ZTE, and Facebook have demonstrated Massive MIMO systems with as many as 96 to 128 antennas.

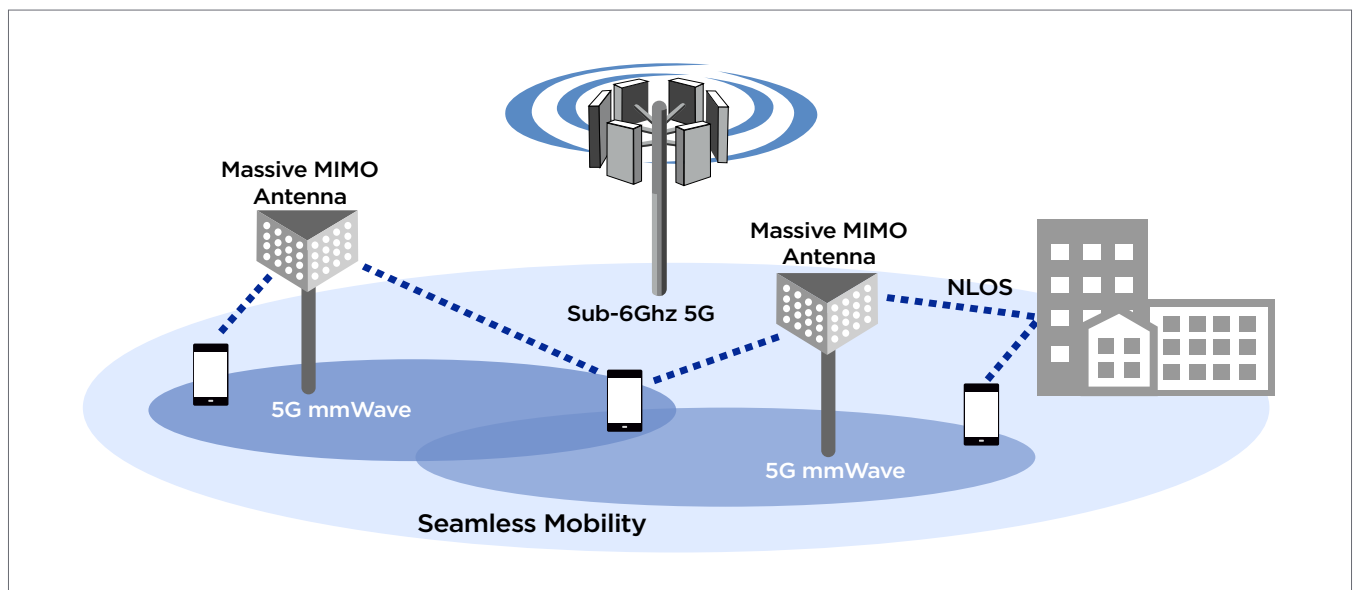


The Advantages of Massive MIMO

Massive MIMO increases the capacity of a wireless network by as much as 50-fold. With more antennas, you also achieve better data rate performance and link reliability and more resistance to interference/jamming.

However, here are the challenges design engineers may face:

- **AAS and Massive MIMO require greater design complexity.** They also require more component miniaturization and high-speed interconnects within the AAS. The components used in the radio need to be qualified for signal integrity (SI), electromagnetic interference (EMI) and thermal performance. These are the three critical aspects inside the radio.
- **Connections have to be fast, cost efficient, powerful, rugged, and small.** The connections have to handle high-speed, higher-power, more stringent thermal requirements and, at the same time, the connections have to be smaller to limit the overall physical size of the AAS. Many connections are often required, given the massive number of antenna elements - fitting large numbers of components at a reasonable cost are challenges that need to be managed. This is a key value that a TE Connectivity solution can provide.



Massive MIMO Antennas

Why Partner with TE for 5G?

TE has years of high-speed interconnect, RF, signal integrity, thermal, rugged and mechanical design expertise. We also support a state-of-the-art global manufacturing footprint, delivering first-in-class components and solutions. In addition, TE offers an extensive interconnect portfolio that can address the design and manufacturing challenges of AAS. TE works in closely with our customer's R&D departments on new designs.

Beyond datacom and wireless connectivity, TE is in many other markets — so as a customer, you benefit from our learning, advanced technology, and customer service. We are a global team with deep engineering talent, quality assurance in our factories, and strategic product development in our engineering centers. We have a big picture view and can understand your issues and help with next-generation problem solving.



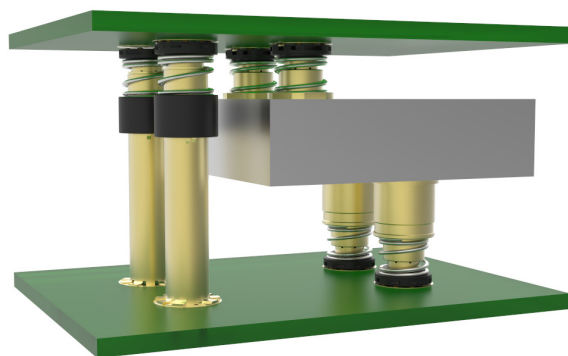
TE PRODUCTS FOR CONNECTIVITY

RF Board-to-Filter and RF Board-to-Board Connectors:

[Our newest 5G offering, ERFV RF coax connectors are designed for 5G AAS.](#)

Key benefits?

We recognize that future 5G wireless equipment designs will require a new level of highly reliable and customizable components, offered at lower costs that can enable the expanding worldwide wireless infrastructure. TE's new ERFV RF coax connectors support next-generation 5G wireless designs by implementing antenna and radio board-to-board and board-to-filter connections at a lower cost and convenience of assembly due to their one-piece, compressive design. ERFV coax connectors are designed with the advent of 5G in mind and they offer proven reliability with excellent misalignment tolerance, insertion loss and return loss.



Antenna Elements and Capabilities:

Our antenna designs accommodate many sets of frequency bands for operation on any network - in both regional and global markets - at a competitive price point.

Key benefits?

Our 5G antennas will distribute data with innovative techniques like beamforming and MIMO, which can allow your 5G networks to be reliable and scalable. Our broad portfolio of antenna technologies include standard and custom antennas, with two-shot molding, stamped metal, flexible printed circuit (FPC), printed circuit board (PCB) and laser direct structuring (LDS) solutions.



FullAXS and FullAXS Mini connector sealing system and cable assemblies

These connector sealing systems are installed in rugged outdoor environments. TE's FullAXS Mini connectors deliver the small size and scalability to design-in fiber, power and signal connectivity for many environments. These new connectors are 23 percent smaller than TE's current FullAXS interconnects and can be placed almost anywhere on the box due to their flexible sealing system.

Key benefits?

These connectors are ruggedized, robust, and can be easily installed outside and adapt to power, fiber and copper cable. They are very durable at IP68 level for a broad range of 5G applications.



High Speed I/O Connectors & Cages:

Our broad portfolio of high-speed I/O cages and connectors are designed to help provide high-speed I/O connections for AAS, baseband units & edge cloud infrastructure systems.

Key benefits?

TE's high-speed I/O products are designed for speed, density, and flexibility as well as efficiency and standardization. Our latest generation of I/O products have been further enhanced for thermal performance and signal integrity, both key requirements for high-speed communications. Products include: SFP28, QSFP28, QSFP-DD.

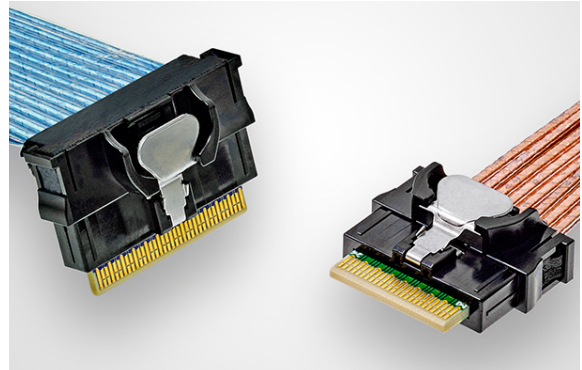


Internal Cabled Interconnects:

One of the most flexible solutions, our [Sliver](#) internal cabled interconnects provide up to 25 Gbps data rates, useful for applications such as 5G AAS, data center and telecom switching and routing.

Key benefits?

This product family allows for a novel and efficient way of supporting high-speed connections within communications systems. Our Sliver family of products simplify design and help lower overall system costs by eliminating the need for re-timers and costly lower-loss printed circuit board (PCB) materials, while reaching speeds up to 25 Gbps with the use of TE high speed cable.

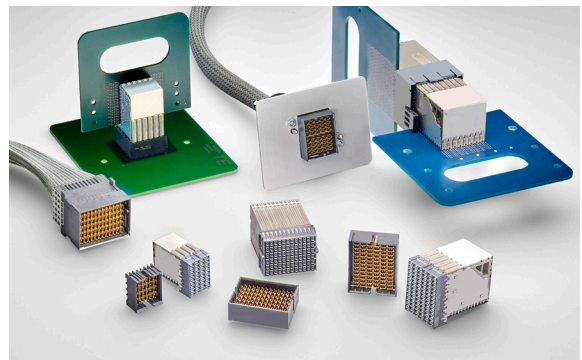


Mezzanine and Backplane Connectors:

Our efficient, high-speed stacking connectors make effective use of PCB space with a board-to-board connection solution and deliver +15 Gbps of high-speed performance.

Key benefits?

Our STRADA Mesa connectors offer a design that provides three pin and socket signal contact arrangement options — high-speed differential, high-density single-ended and RF/ coaxial — to suit various application requirements. The compact profile helps with the thermal dissipation in the system. Through our STRADA Whisper backplane connector family, we offer a unique design that can transfer data at blinding speeds of 25 Gbps and offers innovative scalability up to 112 Gbps. This allows you to achieve efficient future system upgrades without costly backplane or midplane redesigns. It was designed to address your need for high-performing, high-bandwidth systems in mind.



Power Connectors and Power Cable Assemblies:

From internal and semi-internal to external power interconnects, TE's power products and systems and can keep your power flowing. These products include [ELCON Mini](#) power connectors for system performance and DC jack connectors that offer faster charging in a USB size format.

Key benefits?

Our highly reliable power products can deliver higher power in smaller form factors and support board-to-board and cable-to-board applications. As an example, the ELCON Mini connectors offer a cost-effective solution for cable-to-board power, support high currents up to 40A per contact and provide confidence in connectivity with positive metal and latch retention.



High Speed Cable Assemblies

These are lightweight assemblies designed specifically for edge applications like Virtual Reality (VR), gaming as well as medical and industrial applications.

Key benefits?

With their standard and platform design, these assemblies can be modified easily and quickly to address user needs. They offer low-loss connections, simpler system layout, and flexible connections for systems. The receptacles and cable assemblies are proven to transmit signals without interruption, providing superior performance with high-data rates. In addition, our high-speed pluggable I/O copper cable assemblies have been engineered for 56 Gbps and beyond. Our signal integrity (SI) and system architecture expertise allow us to provide one of the highest-performing portfolios of QSFP28/56 and SFP28/56 cable assemblies in the market. These cable assemblies support aggregate data rates up to 400 Gbps. At the forefront of next-generation connectivity, our cable assemblies meet 100G Ethernet and InfiniBand enhanced data rate (EDR) requirements. We also offer custom cabling solutions and corresponding pluggable I/O cages and connectors.

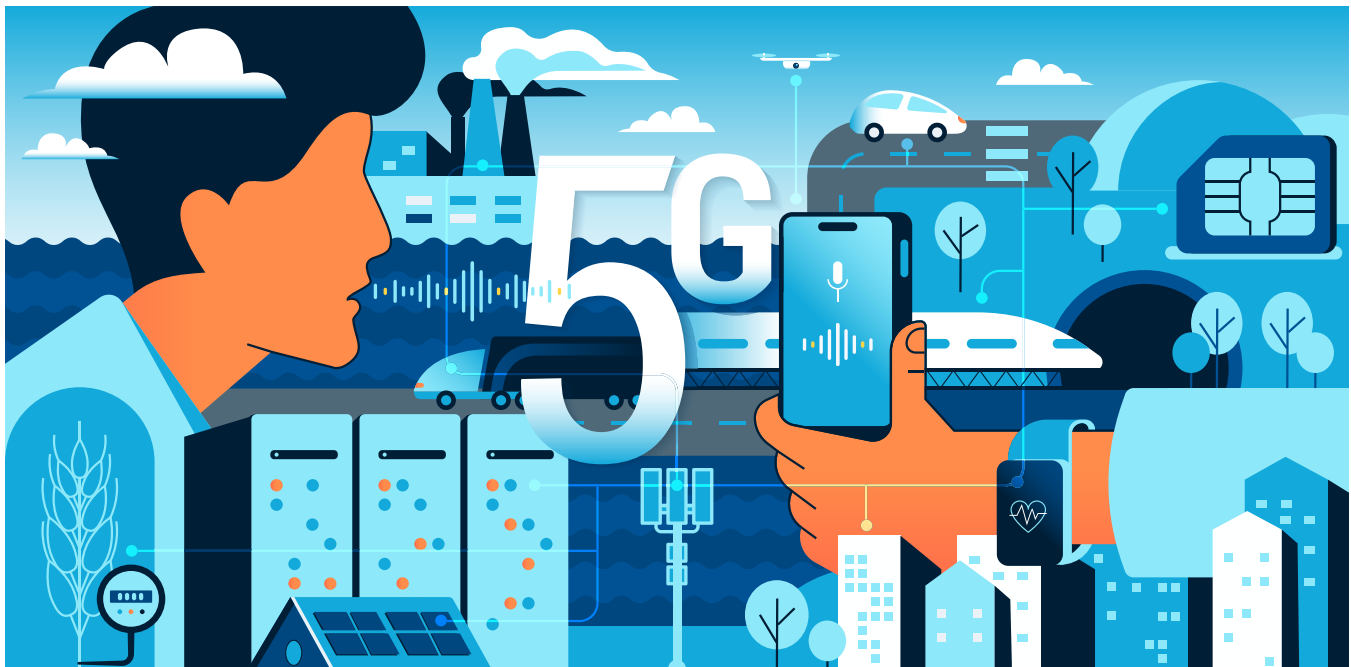
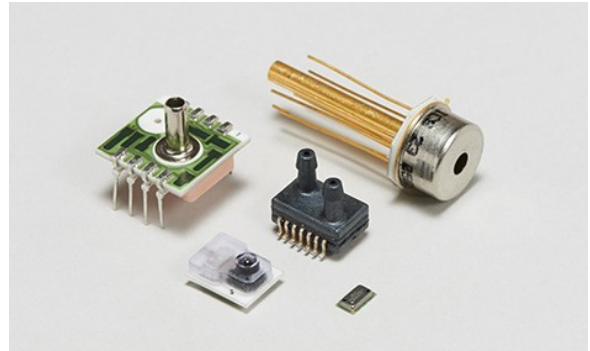


Sensors:

TE's compact, reliable sensors help protect your network RRU and AAS. TE offers a range of sensors including temperature, humidity, control, and shock sensors.

Key benefits?

Our sensors are used in various applications in miniaturized packages, multi-sensor modules, ultra-low power designs, and packages for harsh environments. Reliable, accurate sensors create a foundation for your engineers to understand the various properties in applications from motor bearings to patients under home care. The rollout of 5G will enable a “real time” response to the network, which allows many more connections at lower cost and power. With the ability to connect to thousands of devices at once at exceptionally fast speeds and low end-to-end latency, engineers anticipate 5G could have a significant impact on industrial, personal, and medical applications. As companies begin to comprehend the type of sensors needed and how they will connect to the complete system, customized sensors will be developed to satisfy the specific needs required to deploy a fully connected system. The sensors used in these applications are important for accurate and reliable data.



INSIDE THE RADIO UNIT — CHANGES AND CHALLENGES

Inside the radio unit for 5G, active electronics are integrated with the passive antenna array. These components are arranged so that there is a need for an antenna board and electronics board and filter.

Keep in mind:

- Consists of many antenna elements (64 → 128).
- Requires high-speed connections to connect the I/O interface to the radio board.
- In addition, they require high-speed I/O interfaces for inside and outside the AAS.
- Most likely include power, fiber and hybrid (power, RF, low speed signal) interfaces.
- In addition, other than the interconnects and sensors, you will need to consider the silicon, duplexers, oscillators, etc.



What are the key challenges for radio unit connections?



- Connections have to handle high-speed, high-power signals with more stringent EMI and SI requirements, stressed by more stringent thermal requirements.
- Connections have to be smaller to limit the overall physical size of the AAS.
- And, as mentioned earlier, many connections are required given the massive number of antenna elements and ease of handling in manufacturing.

How does TE solve these challenges?

The antenna is the most important element to communicate in a wireless system. TE has a broad design and manufacturing portfolio to create high-performance 3D antenna structures. The feeding point of the antenna in massive MIMO systems is often a board-to-board coaxial connector. TE has various solutions in its portfolio, of which the ERFV coax connector might give you a new approach on how to solve critical connectivity. The ERFV connector can be described as a one-piece connector, featuring spring forces to contact to the PCB board — providing very reliable connections and smoothing out the assembly tolerances. The filter, as the next important component in your design, is connected with a press fit ERFV coax connector to the antenna, and with a second coax connector to the amplifier board. The amplifier board collects all the antenna data.

A huge amount of data must be transported toward the central processor. High-speed cable assemblies, such as TE's Sliver interconnects feature high-design flexibility, low crosstalk, low insertion-loss performance, and enable high-speed data transport.

In addition, the radio is part of the wireless network and needs an optical connection toward the network. TE's high-speed I/O portfolio supports the EMI and thermal challenges. As an example, SFP, SFP28, QSFP, and QSFP28 are a good fit for radio applications. Those connectors, mated with an optical transceiver, might need to be protected for some environmental conditions, featuring TE's FullAXS interconnects product portfolio.

In addition, you may likely need to power for your system. TE's ELCON Mini connectors a powerful and reliable feeding point to the radio unit.

TE for Radio Products:

- Include our ruggedized solutions, such as FullAXS connectors, to protect the sensitive, high-speed, power, fiber systems.
- TE's customized thermal solutions, including the interleaved heatsink solution, can improve the I/O cooling and lead to longer lasting optical I/O modules.

FIBER PAVES THE WAY TO 5G

(BETWEEN RADIO UNIT AND BBU)

In 5G networks, we expect to see greater use of cloud-like concepts applied to both the radio access network and the core network. As an example, C-RAN (Cloud-Radio Access Network) will focus on both centralizing base band units (BBUs) and the adoption of cloud technologies such as virtualization.

While OEMs can choose where to split the BBU functionality, this split will have a direct impact on the needed I/O bandwidth. TE's I/O product portfolio supports 10G up to 400G interfaces, supporting a multitude of possible solutions the industry might need.

However, by centralizing the BBUs at a C-RAN hub, a new layer is introduced into the network known as fronthaul. Fronthaul is the link between the BBU pool and the remote radio heads at the cell site or the small cell location. While fiber is the best fronthaul option as it delivers more bandwidth, likely there will always be a place for microwave links, depending on the location.

To minimize the optical fiber connections, some radios can be daisy-chained by use of TE's low loss, direct-attached copper (DAC) cables. This is a typical solution proposed by TE that can lower your thermal stress, thereby avoiding heat-generating components such as the optical transceivers.

What challenges do these changes have on connections?

The massive MIMO active antenna system will be packed with electronics inside the box, generating a lot of heat. All components will need to withstand some higher thermal stresses.

How does TE Connectivity solve these challenges?

TE has been focusing on improving the thermal behavior and performance of its high-speed I/O connector cages. These solutions can provide the cooling or thermal conductivity needed for the application.



C-RAN for Connections:

For C-RAN, higher bandwidth connections are needed. In fact, high-frequency bands are increasing from around 1.8 Ghz to around 6 Ghz as well as the mmWave space of above 24 Ghz and up to 100 Ghz. This will be supported by new higher bandwidth transceivers, using new modulation schemes. TE Connectivity solves these challenges by offering a range of solutions including the integration of our high-speed I/O, power, socket, Sliver interconnects, board-to-board backplane cables, and ruggedized equipment.

High-frequency bands are increasing from around 1.8 Ghz to around 6 Ghz as well as the mmWave space of above 24 Ghz and up to 100 Ghz.

TE Products for between the radio unit and BBU:

- Rugged cable - FullAXS interconnects — pre-chamber options available.
- TE SFP/QSFP product family (SFP, QSFP, SFP28, QSFP28, QSFP-DD).
- High Speed I/O and DAC cables

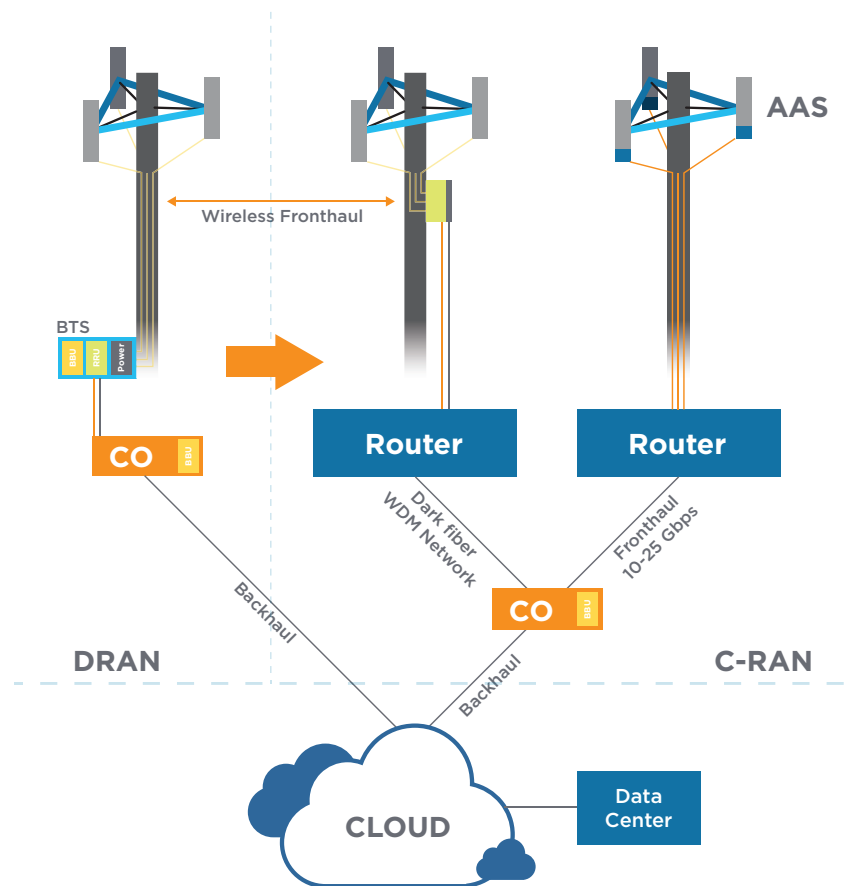
TE Products Inside the BBU:

- TE's high-speed I/O, DAC cable/cable assemblies, STRADA Whisper, Sliver interconnects, power product families showcase our expertise in data center and cloud-to-cloud RAN architectures.

THE FUTURE OF 5G LIES IN THE CLOUD

The core network for 5G will need to rely on an extremely efficient cloud infrastructure. Cloud RAN (or centralized RAN) is a recent trend and operators in Asia Pacific are leading the way. As an example, Chinese, Korean and Japanese operators are aggressively rolling out advanced new C-RAN architectures. With C-RAN, the baseband processing for many cells is centralized. Benefits of C-RAN include improved performance due to the ability to coordinate between cells, and also cost reductions as a result of pooling resources.

As data centers have escalated in size and power, a new trend has emerged: **edge computing and edge cloud**. Instead of data centers doing most of the computing, in this distributed computing paradigm, distributed device nodes such as smart devices (with embedded sensors) or edge devices may perform the work. Many believe that device design is shifting to include smart sensors with integrated microcontrollers, actuator-driver chips, and modules. This will change the role and requirements of the connectors and cables involved in a system.



To the Cloud and Back Again

TE Connectivity, with our high-speed and high-performance interconnects and power products enable highly sensitive data to be transferred from the device to the cloud and back again.

As an example, with our high-performance antennas in the devices and in the Active Antenna Systems (AAS) of telecommunications providers, the data and power will run from the AAS systems down to the edge cloud units through our FullAXS interconnects. These systems support ruggedized fiber/power/Ethernet quick-install interfaces. The signals then enter the edge cloud units through our high-speed I/O ports with thermal and EMI protection features through TE's Sliver internal, high-speed cabling systems, which reduce latency and increase system flexibility. The signal is then distributed via the subsystems in the edge cloud units either by our STRADA Whisper backplane and board-to-board products or our high-speed DAC cables and then back up again to the telco mast and AAS systems and returning wirelessly to the device. The entire network's power requirements will be supported with TE's broad power portfolio, including board-to-board and cabled power distribution for both internal and external applications.

The Benefits of Edge Computing and CORD®

5G edge computing, where end-user applications will run at the core network edge, will provide greater capacity, lower latency, more mobility, and increase reliability and accuracy. Furthermore, cloud computing will bring the efficiency and power of enormous data centers to even the most compact of 5G devices.

CORD® is a type of edge computing that distributes the cloud out to the users. According to the Open Networking foundation, CORD® could transform edge into an agile service delivery platform, enabling the operator to deliver an efficient end-user experience along with innovative next-generation services.

Source:

<https://opencord.org/>

"The CORD (Central Office Re-architected as a Datacenter) platform leverages SDN, NFV and Cloud technologies to build agile datacenters for the network edge. Integrating multiple open source projects, CORD delivers a cloud-native, open, programmable, agile platform for network operators to create innovative services."

— Open Networking Foundation

Key benefits?

It will enable a more standardized infrastructure and open building blocks that enable data center economies of scale.

Challenges posed by C-RAN for connections?

- Higher bandwidth connections are needed.
- This will be supported by new higher bandwidth transceivers.

How do TE's connectivity solutions help solve these problems?

- We offer a range of solutions including the integration of our high-speed I/O, power, socket, Sliver, BTB backplane cables and ruggedized equipment.

TE Products Inside the BBU:

- TE's high-speed I/O, DAC copper, cable/cable assemblies, STRADA Whisper, Sliver, and power product families showcase our expertise in data center and cloud-to-cloud RAN architectures.

ABOUT THE AUTHORS

Lieven Decrock

Lieven is a Technologist and Principal Electrical Engineer for TE's Data & Devices business unit and has been with TE for 22 years. As a signal integrity engineer, he has been involved in the development of high-speed connectors and cable assemblies. As a technologist, he is working on the cutting edge of electrical and optical systems, helping to define the solutions for the next generation systems.

Lieven received his Master of Science degree in electro-mechanical engineering from the University of Leuven in 1996 and obtained his Master of Science degree in Electromagnetic Compatibility and Radio Communications from the University of York (UK) in 2004. Lieven owns multiple patents.

Rickard Barrefelt

Rickard is the Field Application Engineering Manager for EMEA & India for TE Connectivity's Data & Devices business unit. Rickard has been with TE for 7 years, focusing on new design and innovation for the wireless, consumer and datacom customer applications and next gen platforms.

Rickard has a Mechanical Engineering background specializing in Industrial Design from the Royal Institute of Technology (KTH) in Stockholm, Sweden. He received a "TE Expert Innovator" level for multiple patents and has been focusing on 5G, edge computing and edge cloud.

Marshall Chen

Marshall is the Engineering Director for the TE Connectivity's Data & Devices business unit and has been with TE for 6 years. Over the last 20 years, he has been focusing on RF and high-speed connectivity solutions for wireless and data center applications. He's leading development activities through early engagement with global customers in new connection solutions for wireless infrastructure including RRU/AAS, and data center systems like switch, server, storage and consumer devices. He also provides design proposal and advanced development concepts to customers' next generation platforms. Marshall earned a Bachelor of Engineering from the University of Electronic Science and Technology of China, specializing in electrical materials and components. Marshall has multiple patents in RF and high-speed connector design.

WHY TE? WE'RE HELPING UNLOCK THE POTENTIAL OF 5G

TE Connectivity has a wide breadth of product portfolios to support your 5G needs. In fact, we work closely with all of the main wireless telecom OEM and cloud players in 5G around the world, and are considered an innovation leader in high-speed, thermal, EMI/SI, and harsh environments. We have decades of experience and deep rooted, highly capable engineering expertise.

We have an extensive global manufacturing footprint and know-how, including a high-precision stamping and molding process, as well as customized automation machines, which help to drive high-efficiency manufacturing and improve the cost-competitiveness of our products. We also have a strong commitment to China and partner with the China Mobile 5G Innovation Center — an alliance created to develop 5G solutions for China, the world's largest wireless communications market at this time.

TE contributes global expertise and insight to the China market, in addition to driving the expansion of the local 5G industry.

5G is expected to achieve faster transmission rates, more powerful data exchange networks, and more seamless real-time communication. This will enable tremendous growth for advanced and innovative connectivity solutions.

Learn more about TE Connectivity today. We are your full industrial technology solutions leader for all of your connectivity needs.

te.com/5g

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TE Connectivity Ltd. is a \$14 billion global technology and manufacturing leader creating a safer, sustainable, productive, and connected future. For more than 75 years, our connectivity and sensor solutions, proven in the harshest environments, have enabled advancements in transportation, industrial applications, medical technology, energy, data communications, and the home. With 80,000 employees, including more than 8,000 engineers, working alongside customers in approximately 140 countries, TE ensures that EVERY CONNECTION COUNTS. Learn more at www.te.com and on LinkedIn, Facebook, WeChat and Twitter.