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Ubiquitous 5G from the Inside Out

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The telecommunications industry is working to build a future in which mobile connectivity is truly ubiquitous and accessible for all. To achieve this vision, mobile operators across the United States are rolling out 5G networks to support more bandwidth and enable faster download speeds that will eventually provide up to 10 gigabits per second (Gbps) and gigabit/s upload speeds. Concurrently, smartphone manufacturers like Apple and Samsung are marketing their respective devices, such as the iPhone 12 and Galaxy S20, with 5G capabilities to take advantage of the new mobile standard.

The deployment of outdoor 5G networks is an important and necessary step to achieving ubiquitous mobile connectivity. However, delivering reliable cellular coverage indoors remains an elusive goal—even though most people spend the majority of their time inside buildings. These include residential multi-dwelling units (MDUs), offices, hotels, airports, railway stations, stadiums and healthcare facilities. It should be noted that approximately 80 percent of mobile data was routinely consumed indoors—even before the 2020 COVID-19 pandemic and resulting lockdowns that limited certain outdoor activities and travel. Looking into the near future, the average monthly smartphone use in North America is expected to increase from approximately 8.5 GB in 2019 to 45 GB per month by 2025.

The limitations of outside-in

RAN technology was initially developed for outdoor use and subsequently adapted for indoor deployments, with neighboring outdoor macro networks leveraged to serve indoor spaces on a best-efforts basis (a practice known as 'outside-in'). Even prior to 5G, the effectiveness of outside-in has been limited by the radio-frequency blocking characteristics of modern structural materials and by the concentration of data usage present in some buildings. To be effective, the signal must originate inside the building.

Remote radio heads (RRH) have been used to extend the radios of an outdoor base station—which were connected over coaxial cables to a series of passive antennas distributed throughout the building. Alternatively, macro base stations were linked to a set of indoor antennas using a proprietary Common Public Radio Interface (CPRI) connection, forming a distributed radio system (DRS). Lastly, standalone small cells (also known as femtocells) have been used within enterprises.

Although these approaches and techniques were somewhat effective for supporting legacy 3G and low-traffic LTE applications, outside-in coverage is notoriously difficult to achieve with the high and midband 5G frequencies utilized by many U.S. operators—even with current LTE usage volumes. Consequently, without an in-building system, indoor 5G mobile access risks being spotty and unreliable. This poses real-world challenges for a number of key high speed and low latency 5G use cases such as those described below:

Industrial automation

5G's potential for ultra-low latency (<1ms) make it an ideal candidate to address real-time connectivity needs for factory robotic controls, sensors and inventory tracking, all of which take place in controlled indoor environments.

Edge computing

Combined with the optimized latency performance of 5G NR, air interface and 5G core processing can reduce round-trip time by up to two orders of magnitude in scenarios where there is tight control over all parts of the communication chain. As well, edge compute is important for data localization and efficient data processing.

Ultra-high-density (UHD) videos

Although these can be viewed outdoors, people are more likely to consume long-form video indoors. UHD videos requiring the most data—such as telemedicine, training and real-time video-conferencing—are typically viewed indoors. 5G UHD capabilities are especially important for scenarios in which local broadband Internet pipes are overwhelmed by individuals learning or working from home.

Augmented Reality and Virtual Reality (AR/VR)

These evolving technologies—which require high speed and low latency—are often used indoors for training and product support, as well as entertainment purposes.

Autonomous service vehicles

Autonomous service vehicles within subterranean locations, such as pedestrian or vehicular tunnels and parking garages, cannot be reached by outdoor signals. Such vehicles can also operate between buildings in enclosed pedestrian footbridges connecting hospitals, convention centers, hotels, and office buildings.

Outside-In: Bolstering 5G deployments indoors

According to Caroline Gabriel, principal analyst at Analysys Mason, the indoor quality of experience must no longer take a back seat in the 5G era if enterprise requirements are to be satisfied. As Gabriel explains, operators and businesses now have a "strong motivation" to invest in in-building wireless networks to the same extent as outdoor networks. For the first time, she says, networks will be deployed where the importance of the indoor quality of service is equal to that of the outdoor quality of service, rather than being an afterthought.

This goal can be achieved with the next generation of in-building cellular solutions: small cells and DAS. To deliver the bandwidth and latency performance needed to realize 5G's full indoor potential, these systems should ideally adhere to the following principles:

User-centric networks

Capacity—and the cell itself—must be defined and designed around users and applications, rather than the space within a larger single physical cell. When compared with densely deployed standalone small cell networks, the user-centric network eliminates border interference and handovers. With cell virtualization, it dynamically matches capacity to user demand, which is critical to meeting 5G performance and latency objectives.

Ethernet front-haul

Proprietary and dedicated network overlays are costly to design, deploy and maintain. 5G-enabled IBW solutions that can be deployed over Ethernet (the de facto in-building networking standard) enable use of commercial off-the-shelf switches. This approach also allows network and facility owners to ride Ethernet's robust growth. This means easier migration as access layer switches evolve from 1 gigabit to 2.5 and 10 gigabits, as well as the ability to support emerging power over Ethernet (PoE) standards.

Edge intelligence

A user-centric network requires performance-critical functions, intelligence and user awareness at its endpoints—the radio access points. The ability to respond intelligently to changes in user or device location and behavior enables delivery of value-added services. These include emergency services and AR/VR applications that take advantage of granular location awareness.

Radio adaptability

Multiple mobile radio technologies are already in play, while new ones are being introduced faster than the legacy technologies can be retired. In addition to existing LTE technologies, networks must be able to adapt easily to support 5G NR, CBRS, Cat-M1 and other radio technologies. This requires radio access points that are field programmable, meaning they are capable of adapting to new technologies with a software upgrade instead of having to be replaced.

C-RAN Small Cells

C-RAN small cell deployments can be tailored for high-capacity in-building environments, with small cells configured to perform baseband scheduling in a centralized baseband controller. Put simply, this creates a single physical cell ID across multiple radio access points to eliminate border interference and handovers, thereby significantly improving throughput, reducing latency, and bolstering connection reliability. As well, certain baseband processing functions can be shifted to the radio points, enabling them to operate in a coordinated fashion with a number of key benefits. These include:

Cell virtualization

Multiple virtual cells can be 'created' within a single physical cell to effectively reuse spectrum without inter-cell interference.

Location sensing

Each small cell radio point can detect and report the signal strength of a user device, allowing the system to identify the device's location more precisely than systems in which all intelligence resides in the centralized baseband unit.

Joint transmit/receive and distributed MIMO

Multiple radio points can simultaneously transmit to or receive from an individual user, bolstering signal quality and facilitating higher data rates. Supporting distributed MIMO is critical for bringing 5G inside, as the frequencies, high power and large antenna size associated with massive MIMO are impractical indoors.

DAS

In addition to small cells, a distributed antenna system is another option that can help bolster indoor 5G mobile connectivity. DAS is inherently an extension of third-party base stations typically designed for outdoor use, so it may not be able to support advanced features of indoor-optimized small cells such as cell virtualization. On the other hand, DAS are already installed in many high-use locations, so upgrading the DAS to 5G can still provide a substantially improved user experience, and therefore may be the most practical strategy.

Extending an existing DAS to support 5G may be as simple as adding a C-band-capable head-end RF interface module, or it may require an entire overlay system, depending on the DAS architecture. These include carpeted office buildings, hospitals, multi-building campuses, airports and stadiums. A typical DAS system generally comprises:

- A head-end located either on-premise or in a centralized RAN hub. The head-end takes RF and CPRI from service provider base stations and digitizes them for transport across the building's fiber or copper cabling.
- Distributed nodes that extend the signal throughout the building, venue or campus.
- Access points with associated antennas and passive devices that convert the digital signal back to radio frequency (RF) for over-the-air transmission.

Conclusion

Mobile operators are rolling out new 5G networks to support more bandwidth and enable faster download speeds that could eventually provide up to 10 gigabits per second (Gbps) and gigabit/s upload speeds. However, delivering reliable cellular coverage indoors remains an elusive goal, even though most people spend the majority of their time inside various buildings. This poses real-world challenges for a number of indoor high speed and low latency use cases that depend on reliable 5G connectivity such as manufacturing automation, edge computing and streaming ultra-high-density (UHD) video. Indeed, outside-in coverage is notoriously difficult to achieve with the higher-band frequencies utilized by many U.S. operators for 5G. To optimally bolster indoor mobile connectivity in the age of 5G, operators should consider adopting an 'inside-out' approach.