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# Evolution to in-building 5G with CommScope ONECELL®


## Executive summary

5G presents a significant business opportunity, as 5G operator-billed services are expected to explode from $851 million in 2019 to $269 billion in 2025—a six-year, compound annual growth rate of 161 percent[1]. More than 400 uses cases for 5G have been identified, and many—such as industrial automation—are inherently in-building applications. To capitalize on these opportunities, operators must deliver reliable, high-performance 5G service indoors in a way that is economically sustainable. Historically, this has been a challenge.

At the same time, 5G radio specifications, use cases, business models and the timing of market adoption are all moving targets. Operators need to invest in flexible solutions that allow them to adapt to this dynamic environment.

This paper describes the challenges involved in meeting in-building 5G performance, capacity and deployment requirements. This includes the need to deploy and support LTE for the foreseeable future.

It examines different approaches to in-building wireless and their ability to meet these requirements. Through this analysis, we demonstrate that C-RAN small cells are uniquely suited to addressing the challenges—paving the way for a more ubiquitous in-building presence and laying the foundation for an in-building 5G business.


## The in-building 5G market opportunity

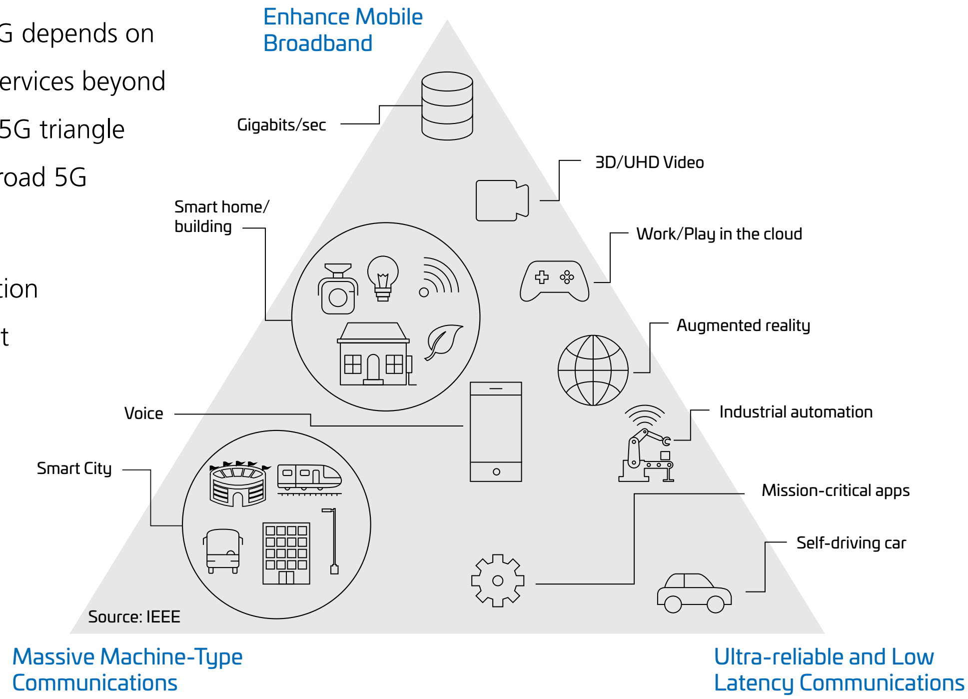
5G promises a feast of technical capabilities: multi-gigabit user data rates, millisecond latency, ultra-reliability on a massive scale and more. For mobile network operators, delivering on this promise will require a massive investment in infrastructure—as much as $250 billion in the U.S. alone[2]. Quantifying the return on that investment is difficult at best—although, typically, operator subscription pricing is not speed- or performance-based.

On the operations side, 5G offers potential cost savings through network functions virtualization and increased spectrum efficiency. However, these savings will take time to become significant, as will the penetration of 5G devices. Until these benefits reach critical mass, operators must continue to support their LTE, legacy 3G, and even 2G services for years to come.

1. 5G Market Strategies: Consumer & Enterprise Opportunities & Forecasts 2017-2025, Juniper Research, July 5, 2017
2. 5G: In search of a viable commercial and infrastructure model, by Sam Evans of Delta Partners in ITProPortal, March 26, 2018

Clearly, the return on investment (ROI) for 5G depends on operators' ability to offer new value-added services beyond connection and transport. The now-familiar 5G triangle defines high-value services for each of the broad 5G technical use cases.

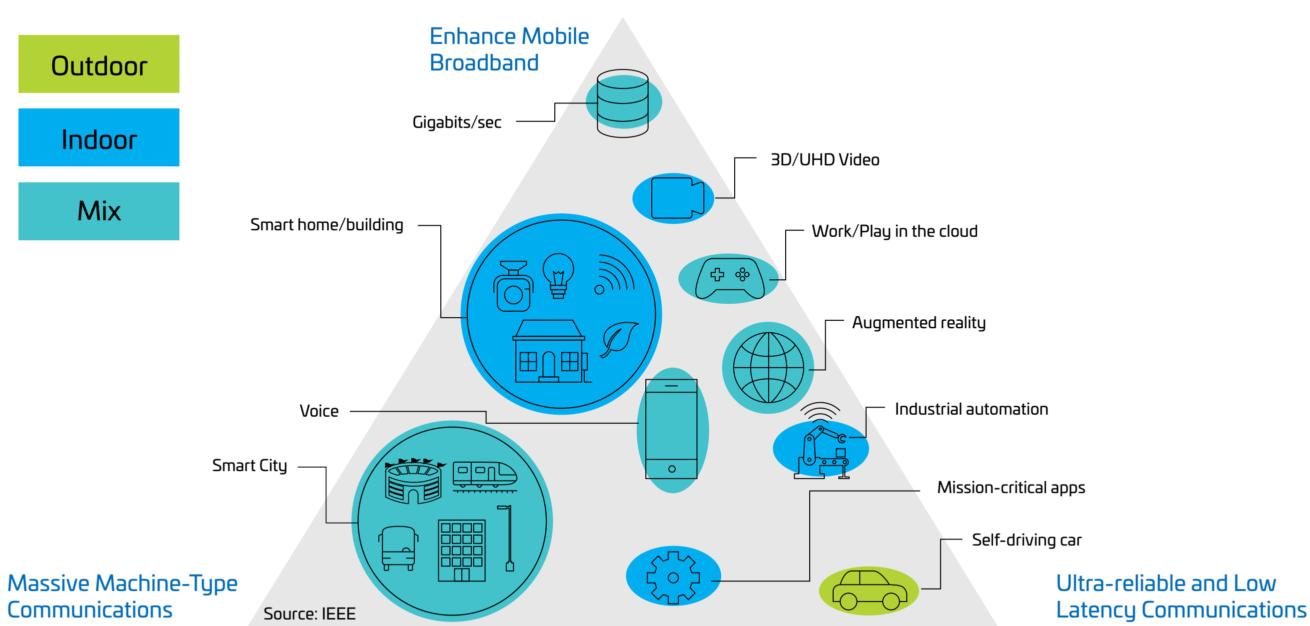
These services range from industrial automation to self-driving cars to smart buildings. The list of use cases points to the large number of applications that require 5G connectivity inside buildings. Examples include:




- **Ultra high-density (UHD) video:** While 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.
- **Augmented Reality/Virtual Reality (AR/VR):** These technologies serve indoor uses like training and product support that require high speed and low latency.
- **Industrial automation:** This includes real-time robotic controls, sensors and inventory tracking, all of which take place in controlled indoor environments.
- **Smart buildings:** This category is, by definition, an indoor one. It includes services such as access security, lighting and energy efficiency, and air quality sensing and monitoring.

The figure below shows the same 5G triangle—this time, coded by indoors vs. out.

For these reasons, the 5G business opportunity will be overwhelmingly indoors. Operators seeking to take advantage of the business opportunities will need to deliver reliable in-building wireless (IBW) service that is 5G enabled.




The majority of use cases identified for 5G will take place partially or exclusively indoors.

Those who cannot deliver it risk being “shut out”—literally and figuratively—as over-the-top (OTT) service providers using alternate indoor networks monetize the value instead.

## Key challenges for in-building 5G

### Performance challenges

Historically, RAN technology has been designed for outdoor use and then adapted for use inside buildings. The most common approach has been to use the neighboring outdoor macro network to serve indoor spaces on a best-efforts basis, a practice known as “outside-in”.

Among actual in-building solutions, Remote Radio Heads (RRH) extend the radios of an outdoor base station and then connect them over coaxial cables to a series passive antennas distributed throughout the building.

Alternatively, the RAN OEM vendor may connect their macro base station to a set of indoor antennas using a proprietary Common Public Radio Interface (CPRI) connection. The result is a distributed radio system (DRS).

Yet another approach adapts residential femtocells for use within the enterprise and large venues. The femtocells connect to a centralized controller that aggregates backhaul and coordinates functions such as handovers.

These approaches have proven somewhat effective for supporting legacy 3G and LTE applications. However, CommScope does not believe—for 5G to reach its stated performance objectives—that these adaptation strategies will be sufficient going forward.

### Migration challenges

The migration of mobile networks to 5G will happen slowly. The GSMA’s latest research suggests that, while 5G usage will begin in 2018, by 2025 it will represent only 14 percent of all global connections. Meanwhile, LTE connections will continue to grow throughout this entire time—accounting for nearly four times the number of 5G connections in 2025. Infrastructure investment, illustrated in Figure 2, is expected to follow a similar pattern.

The implication of this gradual migration is that, while operators will need to continue their LTE buildouts for years to come, they will simultaneously need to ensure their LTE systems are 5G ready. This requires the ability to be upgraded to 5G, easily and economically, while supporting mixed LTE and 5G operation. Complicating the challenge is the uncertainty regarding final 5G radio standards and the frequency bands each operator will use for 5G.

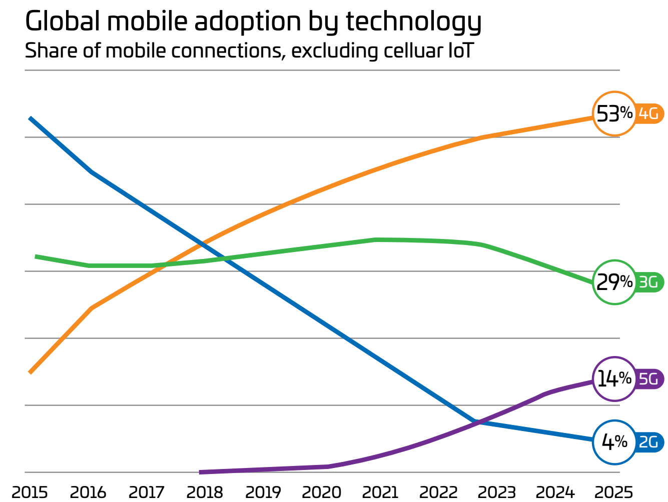



Figure 1. Source: GSMA, The Mobile Economy 2018

### Business challenges

An often-quoted industry stat estimates that 80 percent of mobile data is consumed indoors, which makes sense considering most people spend the bulk of their time indoors. As a result, mobile operators have invested in serving high-traffic, high-profile buildings such as airports, railway/metro stations and stadiums.

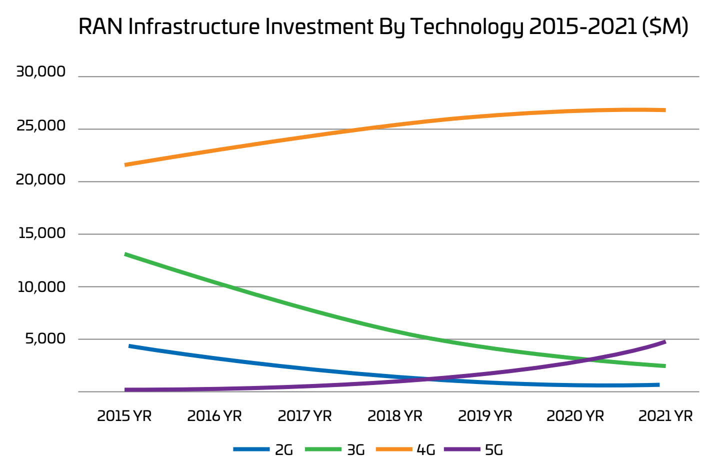



Figure 2. Source: Gartner, Communications Service Provider Operational Technology Worldwide, December 2017

The industry has made substantial progress in terms of in-building wireless penetration. But, to fully support the customer demand for—and enhanced performance requirements of—in-building 5G service, solution costs must come down further. To achieve this, deployment models must evolve to become more flexible. Greater flexibility and lower cost would allow enterprises and building owners, for example, to deploy systems on their own behalf, or enable operators to monetize small-cell-as-a-service offerings to enterprises.[3]

## Defining an architecture for in-building 5G

In establishing 5G radio standards, 3GPP and other industry standards organizations make no distinction between outdoor and indoor applications. In fact, the objectives of 5G are the same indoors and out. These include performance objectives such as ultra-high data rates and reliability, ultra-low latency and massive scalability. They also include operational objectives such as C-RAN centralization, virtualization, and graceful coexistence with LTE and legacy networks.

### Indoor is different

While the objectives are common, the methods to achieve them are not. For example, outdoor networks are characterized by large open spaces, while indoor spaces are small by comparison, and are divided into even smaller sub-spaces. Outdoor networks typically use dedicated fiber for backhaul and front-haul, while Ethernet is the de facto network indoors. The table below lists key differences between outdoor and indoor mobile networks.

Many of the enabling technologies being defined by 3GPP—massive multiple-in multiple-out (MIMO), 0 millisecond handover and lean carrier design—have an implicit focus on the outdoor environment. But, in designing a network architecture to optimize these technologies, the distinct characteristics of indoor networks dictate a different architecture.

3. 5G's network slicing presents an opportunity for operators to support differentiated premium services, something LTE and legacy technologies have not offered.

| Element | Outdoor | Indoor | Comments |
|---|---|---|---|
| Power | Medium to high | Low | Low power is needed for shorter distances and to meet safety requirements in human-occupied spaces. |
| Signal propagation | Mainly LoS | LoS and NLoS | High-frequency 5G signals cannot penetrate exterior walls; therefore, signals must originate indoors. |
| Front-haul | Dark fiber | Ethernet LAN | Ethernet/IP is the standard network infrastructure for enterprises and nearly all indoor spaces. Other formerly specialized overlays such as CCTV are increasingly IP based and joining the Ethernet infrastructure. |
| Mobility | Driving | Walking | Indoor users are slow moving or stationary. |
| Sectorization | By space | By user | Pure space-defined sectors are insufficiently dynamic to support user population shifts that occur inside buildings. |
| Traffic density | Low to medium | Medium to high | Indoor networks must serve many users in a small space. |
| Business model | Operator-led | Multiple | It is not economically feasible for mobile operators to invest in covering a critical mass of commercial buildings. Also, the enterprise or building owner has easier access to interior spaces and supporting infrastructure such as switching, ducting and power. |

## Keys to meeting 5G requirements indoors

CommScope defines four foundational principles needed to meet 5G objectives in the indoor environment:

1. **User-centric networks:** Capacity—and the cell itself—must be defined and designed around the users (or things, in the case of the internet of things [IoT]), 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. Through cell virtualization it dynamically matches capacity to user demand. This is critical to meeting 5G performance and latency objectives.

2. **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; and the ability to support emerging power over Ethernet (PoE) standards.

3. **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.

4. **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 3G, 4G and LTE technologies, networks must be able to adapt easily to support 5G NR (which is not yet fully defined), CBRS, Cat-M1 and other radio technologies. This requires radio access points that are field programmable—able to adapt to new technologies with a software upgrade instead of having to be replaced.

| | Meeting performance challenges | Meeting migration challenges | Meeting business challenges |
|---|---|---|---|
| **User-centric network** | • Eliminate handover and provide consistent user experience everywhere<br>• Cell virtualization for capacity<br>• Simplify macro coordination | • Minimize network upgrade cost to enhance user experience from LTE to 5G | • Ability to provide premium services and differentiation |
| **Ethernet front-haul** | • Ability to scale throughput at lower cost | • Ride Ethernet industry growth curve | • IT deployment model<br>• Shared infrastructure vs. dedicated overlay |
| **Edge intelligence** | • Enabler of cell virtualization<br>• Joint Tx/Rx<br>• Distributed MIMO | • No need to re-sectorize or re-plan the system to improve location accuracy or to meet increasing capacity demand over time | • Granular location sensing<br>• Ability to support emergency services and other location-based applications |
| **Radio adaptability** | • Guarantee optimal coexistence between 4G and 5G bands | • LTE-to-5G NR radio migration with no/minimal upgrade cost | • Flexibility in many-radio future<br>• Investment protection |

## Approaches to 5G in-building wireless

There are a number of alternative approaches to bringing 5G services indoors. Most of them involve adapting the outside macro network for use indoors.

### Outside-in

As discussed earlier, this approach uses the outdoor macro network to serve the in-building space. Solutions range from simply using nearby macro sites to cover as much of the indoor space as possible, to adding outdoor small cells in high-density areas—a process known as "densification."

Likewise, the effort and cost associated with the outside-in approach varies as well, from zero cost and effort involved in the macro-only solution, to multiple issues—site access, municipal zoning restrictions, availability of backhaul and power[6] —that must be considered in cell densification. Regardless of the approach, outdoor signal generation for indoor use has fundamental shortcomings that will increase as we move toward 5G:

1. **High-frequency path loss:** 5G signals tend to reside in higher frequency bands[7] that lose signal strength rapidly when attempting to penetrate exterior building materials. Additional losses occur as the signal moves deeper into the interior of large buildings.

2. **Energy-efficient building design:** Low-e window materials, increasingly in use, block RF signals more than traditional glass—further limiting RF signal strength.

3. **Macro capacity impact:** Serving indoor spaces from the outdoor network drains capacity from the macro cells. As in-building signals weaken, indoor users require more network resources to maintain connections. Under heavy traffic loads, this disproportionate demand from indoor users can impair the performance of the outdoor macro network.

These challenges have existed for 3G and LTE but, in many cases, have been tolerated in order to deliver best-effort voice and data service. With 5G running mission-critical and revenue-generating services—which require demanding latency and reliability requirements—the performance degradation all but rules out outside-in as an in-building approach.[8]

### Standalone small cells

In a standalone small cell solution, each access point is a unique physical cell. Since most operators have a limited number of channels to use indoors, standalone small cells operate on a common channel, creating interference among neighboring cells. For dense deployments in larger buildings, inter-cell interference limits performance, making standalone small cells unsuitable for 5G.[9]

With no coordination between cells, each small cell sees the user independently from the others—the antithesis of a user-centric network. Similarly, since each access point acts on its own, there is little opportunity for edge intelligence, apart from handover control.

While many other in-building wireless solutions require coaxial cabling and proprietary switching nodes, standalone small cells are deployed over Ethernet—a big advantage in terms of deployment simplicity. These systems also could, in theory, offer programmable radios. But, in order to keep the price affordable, individual radio access points—which contain the entire baseband processing stack—are built on cost-optimized consumer-class chipsets whose functions are static. The lack of programmability almost ensures they will need to be replaced or fully overlaid in the migration from LTE to 5G.

6 Outdoor densification can be an excellent strategy for meeting intense outdoor mobile coverage and capacity needs. CommScope provides a range of outdoor siting solutions for this purpose.

7 Here we are referring to sub-6 GHz bands that have been typically discussed for indoor 5G. Higher-frequency millimeter wave bands will almost certainly fail to serve indoor spaces from outdoors.

8 From KT reveals Winter Olympics 5G lessons, Mobile World Live, 26 April 2018: "During the Olympic trial, KT observed poor outdoor-to-indoor coverage penetration"

9 AT&T recommends a professional RF design for deployments exceeding 3 small cells: Source: AT&T MetroCell Technical Requirements, February 2016

## Distributed radio system (DRS)

A DRS uses a standard or pico-scale base station connected to multiple access points through a series of intermediate CPRI-fed nodes. The base station, intermediate nodes, access points and CPRI implementation all come from a single vendor.

The access points in a DRS offer little in the way of edge intelligence or user-centric behavior. This limits their ability to perform advanced functions such as joint transmit/receive or location sensing. They do offer digital front-haul over IT-style Category 6A or fiber cables; but, because they rely on CPRI, they cannot cost-effectively meet 5G bandwidth requirements nor can they operate over standard IP/Ethernet networks. Therefore, it requires a dedicated and costly network overlay.

In these systems, access points do not decode Layer 1 signals, preventing them from performing any intelligent functions. Instead, all Layer 1 decoding occurs at the base station without the contextual information from intelligent access points.

## Remote radio heads

A remote radio head (RRH) extends the coverage of a base station by separating the radio and baseband unit and connecting them via CPRI over fiber. In this sense, they are like a DRS, but lack in-building optimizations such as integrated antennas. Remote radio head systems leverage a passive coaxial network and antennas. This prevents location tracking and degrades uplink performance due to passive cable losses. It also presents significant frequency band limitations due to high coaxial/passive component attenuation at higher frequencies. Consequently, while an RRH system can leverage macro baseband units and form a single cell, its passive infrastructure prevents it from distributing the signal throughout a building with any of the intelligence required for 5G. In addition, all the limitations that apply to DRS apply equally to RRH.

## C-RAN small cells

C-RAN small cells, such as CommScope's ONECELL®, are designed specifically for high-capacity in-building environments. ONECELL performs baseband scheduling in a centralized baseband controller to create a single physical cell ID across multiple radio access points known as "radio points". This eliminates border interference and handovers, significantly improving throughput, latency and connection reliability—key performance attributes critical for support of 5G.

ONECELL also employs an architectural split that places some baseband processing intelligence in the radio points. This enables the radio points to operate in a coordinated fashion and provide several important benefits:

- **Cell virtualization:** ONECELL creates multiple virtual cells within a single physical cell to effectively reuse spectrum without inter-cell interference. Thus, it can increase the data rates to individual users well beyond the nominal capacity of the physical cell. The ability to detect and provide capacity based on user demand, instead of the physical characteristics around the radio point, is important for a user-centric network.
- **Joint transmit/receive and distributed MIMO:** Multiple radio points can simultaneously transmit to or receive from an individual user, enabling better signal quality and higher data rates. For 5G, the ability to support distributed MIMO will be critical indoors, where the high frequencies, high power and large antenna size associated with massive MIMO will be impractical.
- **Location sensing:** Each ONECELL radio point can detect and report the signal strength of a given 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.

ONECELL's architectural split is designed to allow front-haul over standard IP-based switched Ethernet networks. This allows it to leverage commercial switch products whose evolution will provide continual advancements in speed and power (PoE). It also enables facility and network managers to utilize an existing ecosystem of network integrators who can perform all aspects of design, installation and configuration.[11]

In its latest release, ONECELL introduced the RP5000 Series of programmable radio points. RP5000 Series uses a field-programmable gate array (FPGA) for baseband processing, enabling "future-proof" baseband processing that can be changed from LTE to 5G NR or other radio technologies, such as CBRS and Cat-M1, through a software upgrade. In its first version, in multi-carrier and multi-operator deployments, one RP5000 unit can host up to four radio modules to support up to four carriers and frequency bands in 2x2 MIMO configuration. RP5000 uses a multi-gigabit Ethernet interface to support the front-haul requirements of multiple simultaneous LTE or 5G NR carriers.

The RP5000 Series provides an attractive migration path to 5G. The entire signal distribution network—Ethernet switches, cabling and radio points—can be deployed for LTE, then upgraded with a software update to support 5G NR. In this way, it helps lower the cost to deploy and maintain the signal distribution network—by far the most expensive portion of the network.

## Summary of approaches to in-building 5G

The table below provides a summary of the in-building wireless approaches and the degree to which each meets the 5G criteria as established.

Based on this analysis, the C-RAN small cell approach, embodied by CommScope's ONECELL, is the only solution to deliver on the foundational principles for a viable 5G in-building solution. Outside-in, remote radio heads, and distributed radio systems all suffer in one way or another from their reliance on outdoor or macro-optimized architectures. Meanwhile, standalone small cells suffer from the reverse problem—they are based on consumer architectures that do not scale to the needs of enterprises or large venues.

## Laying the foundation of indoor 5G with ONECELL

The migration from LTE to 5G represents an opportunity for mobile network operators to expand their participation in the value chain by offering enhanced applications and services. Many of these offerings will require in-building connectivity with assured high levels of reliability and performance.

As evidenced by CommScope's ONECELL, C-RAN small cells are uniquely designed to meet 5G reliability and performance requirements while also providing an economical migration path from LTE to 5G. ONECELL's IT-style deployment methodology enables enterprises and building owners to take a greater role in leading and funding these deployments.

11 CommScope has more than 2,000 PartnerPro® partners globally who perform these services.

| | Outside-in | Standalone small cells | Remote radio heads | Distributed radio systems | C-RAN small cells |
|---|---|---|---|---|---|
| **User-centric network** | No | No | Limited | Limited | Yes |
| **Ethernet front-haul** | No | Yes | No | No | Yes |
| **Edge intelligence** | No | Limited | No | No | Yes |
| **Radio adaptability** | Yes | No | Limited | Yes | Yes |
| **Key implications** | Cannot meet 5G performance requirements indoors | Multi-cell impairs intelligence while system-on-chip (SoC) design means fixed radios | Distributes signal but adds no value | Reliance on CPRI forces proprietary front-haul; no edge intelligence | Meets all requirements |

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