5G & In-Building Wireless Convergence

Ensuring flexibility & future-proof infrastructure, despite the unknowns

A Disruptive Analysis thought-leadership eBook authored by Dean Bubley

Disruptive Analysis

iBwave

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5G will change in-building wireless

5G hype meets the indoor reality

There has been a lot of noise about 5G over the last two years or so, with early launches making 2019 a milestone in its development. Most commercial focus has been on fixed-wireless local access, plus some early handsets and mobile broadband.

However, much of the industry hype has focused more on the longer-term possibilities: ultra-reliable low-latency communications (URLLC), millimeter-band radios (mmWave) and visions of advanced IoT concepts like autonomous vehicles and wireless-controlled drones. Together with 4G, Wi-Fi and other technologies, expect acceleration in the trend for innovative wireless-enabled products, services and business models.

While Disruptive Analysis is sceptical of some hyperbolic visions (such as wireless surgical robots), the general trajectory points to a future where mobile and wireless connectivity becomes more pervasive, and applications ever more important and demanding.

Yet something is missing. There has been almost no discussion of the practicalities of getting 5G to work well indoors, especially for more-demanding use-cases. The author has regular discussions with device and solution-builders – and government policymakers – who simply assume in-building connectivity will evolve at the same pace as outdoor macro networks. Those assumptions are flawed. It will take a lot of time, effort, investment and planning. Even though timelines for 5G's benefits are long, work needs to start happening. Building owners and facilities managers should do ground-work now.

This eBook describes the challenges and opportunities of indoor 5G. Near the top of the "challenge" list is that 5G is still evolving, even as its first deployments are being made. There remain many variables and unknowns, about both the technical details such as spectrum bands and antenna configurations, and the business and funding models that could apply. There may be new service provider types, a variety of shared and private networks to support, and new regulations to comply with. This makes it much harder for those planning in-building systems to know which aspects to prioritize.

> ***"There has been almost no discussion of the practicalities of getting 5G to work well indoors."***

On the positive side, 5G's arrival coincides with a lot of other developments around in-building infrastructure, such as Wi-Fi 6, optical LANs, digital remote powering, smart-buildings and edge-computing. Taken together, ideally converged in planning and financing, we may see greater emphasis on designing "holistic" in-building networks, with deeper use of fiber and radio-propagation intelligence. There could also be new revenue streams, to offset the costs.

Readers need to understand that 5G – and other parallel technologies – are moving goal-posts. The "unknowns" will become clear only gradually over the coming years. Therefore flexibility & agility, to respond to the specific shape of future networks, is mandatory.

Expected 5G timeline in developed markets

2019
- Early Fixed Wireless Access deployment
- First 5G phones & hotspots
- 5G "Islands"
- 4G CBRS live

2020
- More 5G phones & Fixed Wireless Access
- Very limited coverage
- Wi-Fi 6 also expands

2021
- Early URLLC use cases
- OK urban outdoor coverage
- Indoor often problematic
- Private 5G emerges

2022
- 5G phones in consumer mainstream
- Advanced models like slicing, Multi-access edge computing
- Many unknowns

Source: Disruptive Analysis

The next sections of this eBook examine the following trends:

- 5G technologies and spectrum bands: knowns and unknowns.
- Use cases for indoor 5G wireless, including IoT solutions and consumer mobile broadband, and different types of building/site types. Offices, multi-dwelling units (MDUs), factories, sporting venues and stadiums, transport systems and industrial facilities are very different.
- Adjacent technology and market trends, that link to 5G in-building requirements and architectures, especially relating to fiber deployment.
- New players and business models becoming involved with in-building 5G. This includes "neutral hosts", building-as-a-service operators and vertical-industry private networks.
- What is required for future-proofing and flexibility, given the range of 5G variables and uncertainties.

5G knowns & unknowns

It is fairly straightforward to gauge what we can expect from 5G (or perhaps more broadly, the "5G era"), even if we dial down the industry hype:

- Faster throughput, in the gigabit-per-second range or beyond.
- More devices & device types – both personal and enterprise-focused.
- Multiple spectrum 5G bands being supported, with carrier-aggregation enabling them to be bonded together.
- Multi-carrier requirements indoors – even if enterprises sign up with a single network operator, there will be other users in the building using its competitors' services (because of BYOD "bring your own device" policies or embedded cellular in a variety of devices; on-site visitors, contractors and gig workers etc.)
- Lower end-to-end network latency, required for certain new use-cases.
- More stakeholders involved in building and operating 5G networks, especially given many policymakers' attempts to increase competition.
- Vertical sector customization. There are numerous attempts to tune 5G for different industries' specific requirements, such as manufacturing, automotive and so on.
- Over time, we will see new ways of operators selling network capabilities, such as "network slicing", optimizing combinations of virtual network functions and quality-of-service for particular customers or use-cases.
- "Massive IoT" (or MTC – machine-type communications, in 3GPP-speak) with very high densities of numerous, mostly low-power devices such as sensors.

All of these "knowns" help to set the broad parameters for 5G – but they are primarily defined by single-operator, well-controlled and mostly outdoor/macro-network scenarios.

When we translate these "5G knowns" into the implications for future in-building coverage solutions, everything becomes less certain. Building owners and infrastructure managers will need to cope with flexibility and numerous potential scenarios, especially relating to:

- Spectrum
- MIMO (multiple-in, multiple-out) antennas
- Interactions with mobile core networks, slicing and QoS
- Full building-wide coverage requirements
- Density of IoT devices requiring connectivity and power
- New use-cases and user types

Spectrum

In the 3G and 4G eras, we have seen a proliferation of spectrum bands used for mobile connections. However, the majority of frequencies used have been between 700MHz and 2.6GHz, and typically (outside China) used in FDD (frequency-division duplex) configurations, with separate up- and downstream bands.

There have been multiple options for building owners and carriers for delivering in-building coverage that fits requirements: active and passive DAS (distributed antenna systems), some small-cells and outside-to-inside propagation from the macro network. 5G changes this situation significantly. In broad terms, most networks are expected to deploy a mix of low-, mid-, and high-frequency bands.

Low Band <2GHz

The low bands currently expected to be used include 600MHz (for example T-Mobile US) and then a steady process of re-farming of other sub-2GHz bands, which vary depending on operator and country. For example, AT&T has signalled that it wants to switch off its 3G network over the next three years, likely shifting usage to 5G instead. Some network vendors are supporting mechanisms to run 4G and 5G in the same band, gradually shifting the balance over from one to the other. The timing of any given frequency will also depend on support from device/chipset suppliers.

Mid-Band 2-6GHz

5G is expected to use a lot of "mid-band" spectrum, especially between 3-5GHz. In Europe, 3.4-3.8GHz is a "pioneer" band, and is being released in most countries before 2020. China is supporting 4.9GHz. In the US, Sprint is expected to use its 2.5GHz band for 5G. There has been a lot of recent interest in 3.8-4.2GHz. The US and other markets are also looking at 6GHz as a future unlicensed band, with both Wi-Fi and 5G communities expressing interest.

High-Band / mmWave

A major focus for 5G is "mmWave" bands, such as 24, 26, 28, 32, 38 & 47GHz. These have huge amounts of capacity and are mostly clear of existing usage – but have very short range and poor propagation characteristics. There is also growing discussion of even higher bands, above 90GHz, especially for backhaul use in 5G. At the moment, most discussion about mmWave 5G is around fixed-wireless access (FWA) such as Verizon's early-roll-out in the US. However, some mobile devices will also support it – and it may become central to the highest-end networks aimed at applications with multi-gigabit speeds and ultra-low latency requirements. It seems unlikely that such uses will be outdoor-only.

The low bands should not be especially problematic for indoor-wireless systems to support, and in many cases (sub-1GHz) we should also expect decent outdoor-to-indoor penetration from the macro network. However, low band will not be effective for providing increased capacity-density to all points inside a building. Instead, mid-band small cells or ultimately mmWave radios could be more attractive alternatives for network densification and higher speed and QoS.

Mid-band, however, may prove tricky for existing in-building DAS systems, which have typically only been designed to work for frequencies below about 2.6GHz. Although various newer products are rated for 3.5GHz theoretically, most of the new higher bands are TDD-based and may not be able to easily co-exist with FDD 3G/4G radios. Thus, it seems likely that many sites may need dedicated small-cells for mid-band 5G, or at least significant reworking of existing DAS. (See also the section on MIMO, below).

Indoor mmWave 5G is still a largely unexplored domain. In the short term, it may only be used outdoors, for FWA and the highest-density mobile broadband needs. Ultimately, it seems likely it will be needed indoors as well, especially if multi-gigabit concepts like the "tactile Internet" come to fruition. (Essentially AR with extra functions like "tactile" touch-sensors and surfaces). The propagation characteristics also tend to favour "line of sight" connections. This is hard enough outdoors, with trees, vehicles and even snow in the way. Indoors, this is going to be exceptionally complex, even with new beam-forming / beam-steering techniques, and the potential to reflect off some surfaces. Furthermore, in-building network design for mmWave brings new modelling considerations in terms of wall penetrations, reflection loss and signal scattering due to varying material surfaces

Locations like sports stadiums and airports may come first – the high proportion of visitors may incentivize the telcos to invest themselves, to keep at the forefront of customer experience. At this stage of market maturity, it is probably enough to state this area of indoor mid-band/mmWave 5G will evolve massively over the next 3-5 years. Expect some disruptive innovations - one vendor has already suggested roll-able antenna "strips" that could even be stuck to walls or under floors, but that is still at the stage of lab-project.

One thing seems certain, however: whatever in-building systems eventually support new 5G spectrum bands, deeper fiber infrastructure is likely to be essential, as well as accessibility and "upgrade-ability" of the antennas. More pragmatically, Disruptive Analysis expects this type of problem to drive operators to refarm existing 3G/4G bands for 5G where possible, but that is still very early in the cycle.

MIMO

"Massive MIMO" (MIMO = Multiple In, Multiple Out) is a core part of 5G radio technology, using new multiple-element antenna arrays to create multiple high-capacity "beams". This should help some outdoor-to-indoor penetration issues from macro cell-sites, but also makes it harder to do "pure" indoor networks.

Existing DAS systems – or even small cells - may not be able to support the capability or will only be able to support low "orders" of MIMO (numbers of antennas per radio), rather than truly "massive" MIMO.

Worse, all this may mean multiple fibers are needed to each unit. If those access points are dense enough, it may not be necessary to have the highest-end MIMO implementations in-building, except perhaps in places like sports stadia or convention centers.

Core networks, QoS & network-slicing

One of the central expectations for 5G, promoted by standards bodies and industry trade groups, is that it will allow new business models for telcos. Top of the list is the idea of "network slicing", where operators can potentially sell virtualized partitions of their networks, with different characteristics. They may have guaranteed QoS, reliability levels suitable for business/health-critical uses, extra security, particular optimisations for specific use-cases and so on. The new 5G core network (which is being developed in tandem with the 5G new radio) has various design features expected to facilitate this.

Yet it is completely unclear how this may function with in-building networks, where the infrastructure will likely be (at least in part) owned and operated by the venue, or perhaps a neutral-host indoor operator (see below). Will traditional MNOs have the ability to monitor 5G QoS all the way down to the antenna? How will slicing and QoS guarantees work on networks shared not just by different customers, but by different SPs entirely? How can reliability guarantees be provided when someone else's fiber/copper/switches are in the signal path? Will the most demanding applications (for instance, something safety-critical) need multiple redundant paths through the building's infrastructure, with no single points of failure? How can any of this be validated and maintained?

Disruptive Analysis is somewhat sceptical of many of the claims around 5G QoS and network-slicing, partly because of these challenges, but also for numerous other reasons. Nevertheless, if "indoor 5G network slicing" is ever to become real, it needs to start being factored-into design decisions. The future potential/necessity/complexity of indoor 5G QoS could also prove a way to incentivize carriers to contribute to project funding.

New use-cases for 5G – and full-building coverage

Today, most in-building wireless is designed around the requirements of laptops (Wi-Fi) and smartphones (4G coverage, plus also Wi-Fi). Depending on the building, the locations are predictable as well – meeting rooms, lobbies, conference rooms, MDU apartments, corridors and so on. In essence, capacity is most needed in places where people walk, sit or congregate. Certain locations such as manufacturing plants are obviously different but have tended to use dedicated wireless solutions rather than cellular.

With 5G and related developments (Wi-Fi 6 and so on), this assumption has to change significantly. Network designers have to consider many more user-types, applications, devices and usage locations – as well as higher value (and in some cases liability) associated with high-quality wireless.

The 5G era brings many new applications & use-cases (also for Wi-Fi & 4G+)


AR & VR

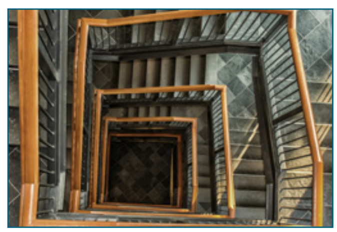

Cloud & XaaS


Automation & Robots


Machine Vision & AI


Life-Critical Systems


Multi-Carrier Devices


Voids & Stairwells


Exterior / Metalwork

Some of the indoor-wireless scenarios that can be imagined over the next 5-10 years lifetime of new or upgraded infrastructure includes:

- IoT and smart-building systems in ceiling voids, elevator shafts, or sub-basements.
- Robots and drones used for various purposes (e.g. industrial or maintenance).
- 5G connections that need to cope with metalwork or RF interference (eg welding).
- Active displays and touch-screens on any surface, perhaps enabling "ambient computing" for visitors or employees.
- New forms of distributed computing (edge servers, blockchain / cryptocurrency nodes, growing needs for high-availability cloud access etc).
- Medical and other life/safety-critical systems of various types.
- Regulatory demands for smart-energy monitoring and control, requiring thousands of sensors and control points.
- Connected or autonomous vehicles in underground parking garages, plus electric vehicle charge-points.
- In hotels and apartments, people expect to stream high-quality video or even VR content to wireless devices. The sheer density of capacity required may be orders of magnitude higher than in the past – for example, think about 1000s of people watching action replays, or feeds from different cameras, in a sports stadium.
- Future broadband public-safety networks may also require different patterns of coverage and therefore in-building infrastructure. It may be necessary to cover all areas/volumes of many structures, including rooftops and fire-escapes, with enough capacity not just for voice communications but also video and telemetry.

Industry and enterprise will have unique needs

A consequence of 5G's broad reach is that it will have very different implications for different industries and facility types. Some sectors' needs will remain largely centered on human mobile-broadband (smartphones, especially), while others are concentrating more on 5G for industrial automation, safety/security or content-streaming.

MDUs, retail sites, manufacturing plants, hospitals, transport hubs, universities and shared-office spaces and others will diverge even further in terms of both wireless requirements, and the network infrastructure required to support them.

Coupled with other adjacent technology changes (see next section), Disruptive Analysis expects to see "vertical-specific" expertise and integration/implementation to come to the fore.

It will become harder to create broad or generic templates, either in terms of cellular coverage needs (5G spectrum bands, device types and so on). A lot of detailed knowledge, thought, and planning will be needed – including a significant amount of future-thinking and imagination.

5G use-cases and stakeholders will vary widely by industry & building type

VERTICAL SECTOR	Multi-Carrier 5G MBB for employees / visitors	Uses for 5G ultra-low latency, high QoS	Opportunity for 5G massive IoT, LPWA	Private 5G, Neutral Host & new service models
Office Building	(green)	(yellow)	(green)	(yellow)
Multi-dwelling Units	(green)	(yellow)	(yellow)	(yellow)
Sports / Entertainement	(green)	(green)	(yellow)	(yellow)
Factories	(red)	(green)	(green)	(green)
Retail	(green)	(red)	(yellow)	(red)
Education	(yellow)	(yellow)	(red)	(yellow)
Rail / Air Transport	(green)	(green)	(yellow)	(green)
Hospitals	(yellow)	(green)	(green)	(yellow)
Oil / Gas / Power Plants	(red)	(green)	(green)	(green)

Source: Disruptive Analysis

Adjacent trends coinciding with 5G

Alongside 5G, various other trends are occurring in the telecoms / networking space that enterprises, property developers and in-building network managers need to be aware of.

Many of these overlap cellular networks in requiring deep-fiber infrastructure and may also bring new service providers and value-chain participants into a converged wired/wireless environment. They may even allow building owners and tenants to develop new revenue streams, which could help defray the costs. New uses for in-building / on-campus include:

- 5G (and 2G-4G) indoor coverage for multiple operators, mostly using active DAS and small-cells. This could be for either public or private networks (or public safety) and is covered throughout the bulk of this report.
- Connecting Wi-Fi access points, especially for Wi-Fi 6 and meshes.
- Remote radio-head siting linked to carriers' Cloud RAN architectures.
- Optical LAN.
- Smart-building connectivity.
- Edge / distributed computing.

Taken together, combinations of these could help justify the investments in more-dense fiber – and also become direct revenue-generators.

Wi-Fi 6

5G is not the only dynamic area for in-building wireless. Wi-Fi is also becoming more sophisticated and important in many locations, especially for enterprise offices, transport hubs and hospitality. Over the next few years, the latest version called Wi-Fi 6 – formerly known as 802.11ax – will become widespread. Together with other innovations (including meshes and multi-user MU-MIMO), this improves the coverage, efficiency and manageability of Wi-Fi. It will be able to deliver gigabit speeds – as long as the APs are connected with sufficiently-capable backhaul themselves to the main broadband or enterprise WAN.

This also mirrors the growing numbers of Wi-Fi devices in enterprise locations, and their data consumption. As well as laptops, smartphones and tablets, many businesses now connect 4K/8K display screens, assorted IoT devices, retail terminals, CCTV cameras, industrial systems and many other products via Wi-Fi. (This mirrors the trends seen in the home, where many households now have 15+ devices, and use them for streaming video and other demanding applications).

As with 5G cellular, we will see Wi-Fi 6 drive demand for more fiber and more-densely deployed access points. This could mean fiber directly to the AP, or more localized switches, with the last leg over copper (which can also support power-over-ethernet).

In future, we may also see new unlicensed spectrum bands emerging for Wi-Fi, especially at 6GHz, which may change the radio propagation models again. The FCC and other regulators seem enthusiastic. (Ignore those saying that Wi-Fi can be replaced by cellular technologies – it cannot, for numerous reasons, although we may well see 5G also using the same unlicensed bands, or hybrid Wi-Fi/5G small-cell + AP units).

60GHz Wi-Fi (formerly called WiGig) is also an interesting development for ultra-high bandwidth connections, although recent work seems to have focused more on outdoor fixed-wireless access and backhaul uses rather than indoor applications.

Cloud RAN

A key emerging trend which venues should understand is that of virtual or "cloud" RAN deployments (vRAN and C-RAN). These will add another "convergence" layer for future in-building wireless, as it may blend indoor infrastructure/fiber with macro/outdoor systems to create new hybrids. This could apply especially on new "campus" environments, or where entirely new mixed-use districts or whole cities are being developed.

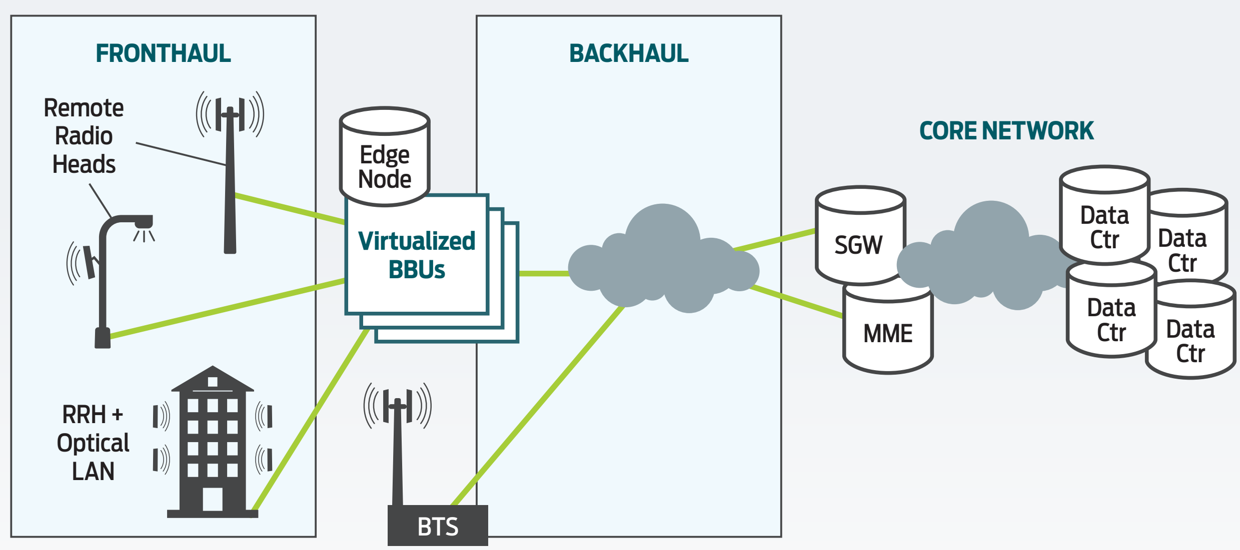
What's happening is an ongoing shift towards separating the processing electronics of a base station (called the baseband unit or BBU) from the radio unit (transceivers, amplifiers and antenna). Typically, these are connected with "fronthaul" fiber – in contrast to backhaul, which links the baseband to the core networks. This is actually fairly close to the model seen in DAS systems indoors, but usually just for a single network.

Initially, this type of architecture involved separating the BBU (at ground level), from the radio at the top of a mast or on a rooftop. This reduces the size, weight and cost of the antenna equipment installed. Then, the industry aimed to reduce RAN costs – and improve flexibility - by hosting multiple BBUs in a central "base station hotel", linked by fronthaul fibers to remote radio heads (RRHs) up to as much as 10-15km away. This allows capacity to be allocated more dynamically. Those RRHs are typically outdoor-focused, on rooftops, towers or poles.

The concept is now evolving further. The industry is starting to "virtualize" the equipment even more, by turning the hardware BBUs into applications running on white-box servers even further upstream in the network, at aggregation sites. This allows cost-savings, and core/transport capacity to be switched around according to demand, for example over the course of a day.

Ultimately, this may be integrated into an operator's overall NFV/SDN (network function virtualization / software-defined networking) architecture, either running in a central data-center, or at a regional "edge" location.

Future convergence between Optical LAN, Cloud RAN & Edge Computing



Source: Disruptive Analysis

Although it is still very early days, this will gradually lead to new hybrids with in-building wireless systems. One possibility is that the in-building fiber is directly connected to outdoor fronthaul fiber, allowing indoor RRHs. In a sense, this could be the indoor equivalent of a fiber-wholesale or dark-fiber rental business model.

This could mean new types of convergence between public (cellular) networks and private (venue-owned) infrastructure, and perhaps the emergence of new "neutral host" providers to facilitate it (see later in this document). It could also potentially integrate edge-compute functions.

Optical LAN

Historically, LAN equipment has involved using centralized switches/routers connecting to the WAN, plus small units connected with fiber on each floor, or for each workgroup. These have then used copper unshielded twisted-pair (UTP) wire, and RJ45 sockets to fan out to end-users' desktop computers, or other devices. The use of PoE (Power over Ethernet) combined with UTP wires has enabled the delivery of low-voltage electrical power for those devices over short distances. Over long distances, this requires deployment of additional switches and routers, plus dedicated electrical wiring – and therefore lots of expensive cable, support infrastructure, physical space, power and labour.

A number of buildings are now deploying "passive optical LANs" (POL), a technology which shares similarities with FTTB (fiber-to-the-building) networks. This can simplify or replace traditional structured cabling, with its multiple levels of switch and router aggregation. POL uses single-mode fiber delivered closer to users and devices, flattening the LAN, eliminating long-distance constraints and reducing the quantity of cabling required. It is also potentially more secure, and generally needs less maintenance. In addition, new composite cabling conveniently combines the distance and bandwidth capabilities of a single-mode fiber with much more electric power-carrying capability over longer distances.

Essentially this is end-to-end optical connectivity, intended for the most-demanding compute use-cases, such as:

- Workgroup switches connected over long distances (eg campuses or high-rises).
- High performance workstations (eg high-frequency trading, or complex data visualisations such as protein-folding imagery in pharmaceuticals)
- Industrial or medical equipment, especially where copper cabling can face RF or other electromagnetic interference.
- Servers.
- Large conferencing screens or other high-resolution displays.
- Wi-Fi access points.
- IoT sensors / end-points e.g. smart LED lighting systems.

Smart buildings

As well as normal wireless and wired connectivity for visitors' personal devices and tenant companies' systems, many buildings are also deploying their own internal infrastructure. There is a trend towards "smart buildings" which better manage their energy consumption, lighting, safety systems and so forth. While full details are outside the scope of this report, it is worth noting that these systems often require additional infrastructure (and therefore both fiber and electrical power cables) to connect new sensors, lighting, ventilation, security, fire-safety and other systems. The new "all in one wire" capability of modern optical fiber systems can greatly simplify any future upgrades, as growing numbers of wired/wireless end-points require connection and power.

Viewed holistically, in-building wireless could well be combined with a smart-building's own management needs, both technically and economically.

Edge computing

We may also see some sites turn into edge-computing nodes, as part of a parallel trend: while radio functions are being pushed "up" into the network from the antennas, the opposite is occurring for compute, with some data-center servers being moved "down" into the network. The physical locations will vary - maybe inside large buildings, private campuses or large-scale city development projects.

In some cases, edge-computing will itself be driven by (and integrated with) 5G or fixed networks – often referred to as MEC (Multi-Access or Mobile Edge Computing). Some telcos see themselves as latency/location-optimized alternatives to Amazon's or Google's hyperscale clouds, offering software or IoT developers ultra low-latency compute.

While some MEC deployments may occur at carriers' network aggregation points, other visions put such servers next to cell-sites or antennas. In theory, this could also mean integration with in-building wireless systems, in order to give better SLA terms to customers. This, in turn, could further drive fiber demand.

New players & business models

The previous sections have considered 5G in-building wireless through the lenses of both technology and use-case evolution, as well as its fit with adjacent market trends that impact indoor infrastructure deployment.

There is also another set of developments occurring in tandem, driven by new regulatory and commercial shifts. These will bring new stakeholders into the in-building marketplace, as well as potential new funding models for connectivity.

As well as new spectrum bands emerging for 5G, we are also seeing different methods for authorizing and allocating them. (This also applies to 4G and Wi-Fi networks).

Perhaps the largest change in the last 2 years has been a global shift towards considering shared, private and localized spectrum releases. This has been driven by a recognition by policymakers and industry bodies of two main factors:

- There are few unused / lightly-used bands, and it is becoming increasingly hard to clear and re-purpose existing bands in entirety. Incumbent users need to be accommodated, with 5G or other new networks fitting around them.
- National mobile operators have significant limits to resources and skills, that means they cannot cover everywhere, and provide suitable coverage / capacity for all the new use-cases. Indoor wireless is even more complex, as willingness-to-pay is even lower. So specialized or localized providers may be needed for particular industries' needs, or that have better economics and incentives for providing 4G/5G in indoor, rural and industrial contexts.

While a few countries (e.g. Mexico) have looked at state-owned wholesale mobile networks, most others have regulatory incentives for commercial deployments in such situations. Even a state-owned mobile network will struggle with indoor coverage. Some of the most important concepts that have emerged include:

- Localized mobile operators (also called "micro-MNOs") in specific places, with geo-limited spectrum allocations. These could cover individual buildings, universities or industrial plants, whole cities, or even county-level divisions. This could include private 4G/5G networks for locations such as sports stadia, ports/airports, hospitals and industrial facilities, oriented either towards their own employees/IoT systems, or for providing wholesale or retail capacity for visitors' needs. Different countries' regulators have proposed many different bands and mechanisms for such networks; it will probably be another 2-3 years before the most prevalent models become clear. The most well-known examples are the US CBRS (citizens' broadband radio service) at 3.5GHz, and the proposed German 5G industrial band at 3.7GHz. In the UK, Ofcom is looking at a variety of options, including low- and medium-power options in 3.8-4.2GHz.
- Neutral-host networks, either indoors or outdoors, which offer wholesale 4G/5G capacity to other service providers, typically either as "reverse MVNOs" or by permitting some form of in-country roaming. While various in-building providers have been called neutral hosts for some time, they generally haven't had their own spectrum and radio networks.

Various models of unlicensed (or lightly-licensed) frequencies for 4G and 5G networks. There are various technical approaches, including LTE-U, LAA (license-assisted access) and MulteFire. Typically, they run in the same bands as Wi-Fi and Bluetooth, especially in the 5GHz range. The US CBRS band also allows for both location-specific "priority-access" (licensed) networks, and a tier of users that are almost-unlicensed "general access" but need to query an availability database system.

- We may see a new breed of "Vertical Mobile Operators" – maybe set up as arms of industrial suppliers like GE or Siemens or Phillips or Honeywell, or which specialize in hospital connectivity, or which focus on MDUs.
- It should be noted that there are numerous other options here, including spectrum-leasing, sector-focused MVNOs, localized/private control of core networks (but not radio) and so on. Most of these are outside the scope of this report but will still need someone to provide coverage.

Future in-building wireless networks may therefore need to adopt different economic models as well. Today, the biggest question is "who pays?" for in-building infrastructure. But in future, we will be asking "what new revenue streams?" as well. Real estate companies might attain higher rents with certified "future-proof" coverage.

In a 5G world of neutral hosts and localized spectrum, various new firms might turn into providers of indoor systems, rather than staying as end-users. They may also be able to get direct revenues from end-users (in a similar fashion to Wi-Fi today), or perhaps cut wholesale deals with national (or international) operators.

One interesting strategic implication of localized spectrum is that it may shift the power-balance between venues and national MNOs. Either the latter will become more willing to fund the in-building capex – or else they will need to pay ongoing opex for in-building roaming or wholesale.

A related challenge will be hybrids of public and private infrastructure, as these boundaries between SPs, enterprises and venue-owners start to blur. This has huge implications for regulation (who is responsible?), economics (who pays, or gets revenues?), and operations (who builds, runs and maintains connectivity?). It is not obvious exactly where all the "demarcation points" will be in the future.

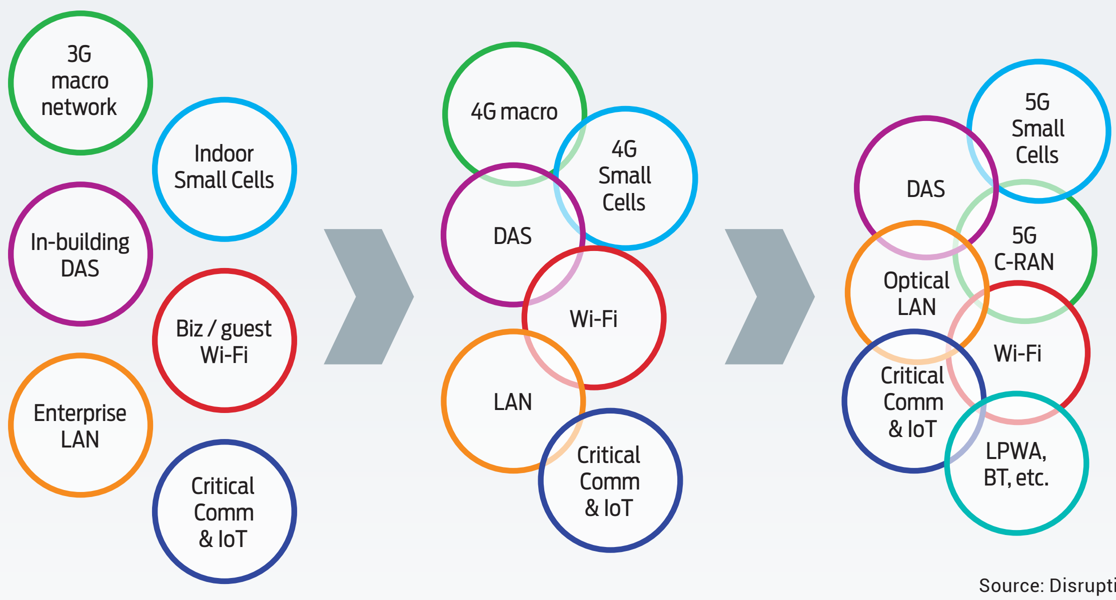
In particular, if telcos want to offer paid QoS and network slices for 5G, they will need to address their in-building requirements and obligations. If property/facilities managers can help the MNOs deliver on their promises better, then they may have extra leverage regarding commercial arrangements.

How can indoor systems be future-proofed for 5G?

We've looked at a top-level view of the changes ahead for in-building wireless networks. This eBook has covered a broad range of drivers – new technology, shifting regulations, the emergence of IoT, and a complex stakeholder landscape.

All participants need to plan ahead, and design "future-proof" infrastructure where possible, or at least have a good way to model different 5G radio and business-model options as they become clearer. That said, there will remain many "unknowns", so flexibility will be hugely important.

Separate network domains are converging, as they evolve in tech & biz model



Source: Disruptive Analysis

Deep fiber indoors

Today, more demanding active DAS, compute and Wi-Fi needs have meant fiber has been deployed "deeper" through newer buildings, in risers and wiring-closets and equipment rooms, although it is usually still not 100% end-to-end.

Disruptive Analysis believes that this drive will continue – despite all the variables around 5G spectrum and business models, one of the inevitable outcomes is a desire for more, deeper fiber. There are multiple future use-cases for in-building optical, which together are likely to require much deeper, more extensive and holistic deployments:

- Active DAS systems and cellular small-cells (including support for MIMO and much-higher frequency bands)
- Gigabit fixed broadband for MDUs
- Backhaul for Wi-Fi APs
- Reduced space, energy and maintenance associated with copper wiring
- Smart-building systems and IoT connectivity
- Optical LAN
- Connecting remote radio-heads for Cloud RAN
- Redundant cabling where future uses may be business/safety-critical.

Planning, insight and tools

In Disruptive Analysis' view, the 5G era – and its rapid evolution of new use-cases and business models – will mean that in-building systems need both better upfront planning and design, and continued market-scanning and updates.

Rather than a one-off, static design, it will be necessary to continually update, extend and enhance the infrastructure, especially given the likely future evolutions to 5G radio and use-cases over time. Ideally, there will be tight integration and shared blueprints covering the radio domain, fiber/ electrical connections – and perhaps also reflect the changing outdoor macro environment as well. In other words, in-building wireless (and its supporting fiber backbone) will become more of an opex rather than capex cost. Facilities managers and building owners may choose to either recruit specific expertise, or perhaps outsource to a new class of managed service providers.

New spectrum bands, new device and application types, new regulations and new user-expectations will be present in all industries and building types. It is still very unclear how future in-building systems will support 5G elements such as mmWave radio, or "end-to-end" network slicing.

Because 5G will be a continual evolutionary process, it is important to start improving capabilities without waiting for a defined end-point in standardisation or adoption. To adopt a software-industry phrase, the in-building network will need to become "agile" and improve its capabilities during operation, in an ongoing fashion.

> ***"Rather than a one-off, static design, it will be necessary to continually update, extend and enhance the 5G infrastructure"***

About iBwave

iBwave Solutions, the standard for converged indoor network planning is the power behind great in-building wireless experience, enabling billions of end users and devices to connect inside a wide range of venues. As the global industry reference, our software solutions allow for smarter planning, design and deployment of any project regardless of size, complexity or technology. Along with innovative software, we are recognized for world class support in 100 countries, industry's most comprehensive components database and a well established certification program. For more information visit: www.ibwave.com.

About Disruptive Analysis

Disruptive Analysis is a technology-focused advisory firm focused on the mobile and wireless industry. Founded by experienced analyst & futurist Dean Bubley, it provides critical commentary and consulting support to telecoms/IT vendors, operators, regulators, users, investors and intermediaries. Disruptive Analysis focuses on communications and information technology industry trends, particularly in areas with complex value chains, rapid technical/market evolution, or labyrinthine business relationships. Currently, the company is focusing on 5G, NFV, IoT networks, spectrum policy, operator business models, the Future of Voice, AI, blockchain & Internet/operator ecosystems and the role of governments in next-generation networks.

Disruptive Analysis attempts to predict and validate the future direction and profit potential of technology markets - based on consideration of many more "angles" than is typical among industry analysts. It takes into account new products and technologies, changing distribution channels, customer trends, investor sentiment and macroeconomic status. Where appropriate, it takes a contrarian stance rather than support consensus or industry momentum. Disruptive Analysis' motto is "Don't Assume".

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