Wireless in the enterprise.
A deeper reach, a more active role for venue owners

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I. Analyst Report

The wireless enterprise

For a long time, we have channeled our attention onto the increasing use of wireless connectivity at the **individual** user level – either a consumer or business user, with the distinction between the two disappearing as usage models converge.

The increased reliance on wireless in the **enterprise** has attracted less attention, but it has grown steadily, through a massive, almost universal adoption of Wi-Fi. Single-handedly, Wi-Fi has nearly eradicated fixed access in the enterprise and created a healthy appetite for other technologies (using licensed or unlicensed bands) and new or expanded services (e.g., IoT), and opened the way for new business models (e.g., neutral host).

Even though we are at the beginning of a further major expansion in the role of wireless in the enterprise, it is increasingly clear that wireless connectivity is no longer just an amenity for visitors or a productivity enhancer for employees. Wireless has become operationally crucial to running the business efficiently. Most enterprises cannot function without at least the minimum level of wireless connectivity expected by their customers. Connectivity failures can cause delays, disruption in internal communications, a need to revert to manual operation, and an inability to monitor and track processes.

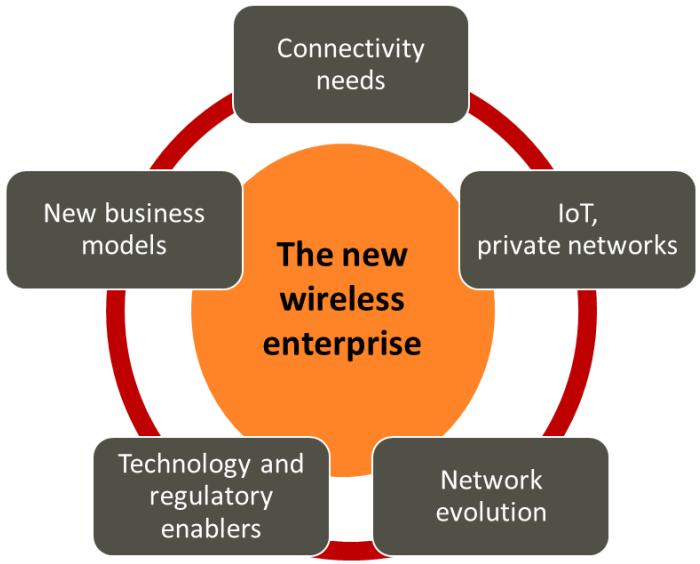
As the awareness of the role of wireless increases within the enterprise so does the willingness – or indeed the need – to take on a more active role in funding, managing and controlling it.

At the same time, the enterprise cannot effect this change unilaterally, and it has no desire to do so. Wireless is a tool to support business, but it is typically not an enterprise core capability. Hence the enterprise is keenly looking forward to working with mobile operators, other service providers, and neutral hosts to avail itself of the infrastructure and services it needs. The openness of the enterprise to cooperating becomes an opportunity for mobile operators to address this market in more effective ways than in the past, and to gain a stronger foothold. It also gives neutral hosts a path along which to expand a nascent set of new services they can provide, beyond the DAS deployments that are the main service they provide today.

Why now?

The role of wireless infrastructure in the enterprise has been steadily expanding since the introduction of Wi-Fi – so for about two decades. In some Asian countries, operators have deployed in-building infrastructure in the enterprise for a long time, driven by high indoor usage and buildings with challenging signal penetration.

Recently the enterprise has become a hotter topic, because of a confluence of drivers that increase both the value of wireless to the enterprise and the ability of wireless solutions to meet the enterprise requirements. Surveys repeatedly show that enterprises across the board – different sizes, verticals, markets, requirements – share complaints about bad coverage, insufficient capacity, expensive equipment, and lack of support for the services necessary to address high expectations and needs from within their organizations.



Source: Senza Fili

The most foundational driver is the increase in connectivity needs, as wireless has become the default access medium, replacing wireline connectivity. In office buildings these days, it is difficult to find an Ethernet outlet, and some new laptops ship without an Ethernet port.

IoT drives the requirements for connectivity further. Enterprise networks have to support new services and applications, and keep connected to a denser, more diverse set of devices with wildly different performance requirements.

The network evolution both benefits from and supports a more active role for the enterprise. Venue ownership becomes more valuable with densification, and operators need the support of venue owners to densify their networks.

New technology spawned by LTE Advanced, Gigabit LTE, and 5G, along with spectrum sharing initiatives such as CBRS, creates an environment in which both enterprises and service providers can control the infrastructure they need and can integrate different networks with ample flexibility.

Finally, new business models are essential to enable the enterprise to provide access to their premises to multiple operators and to deploy private networks that they own and control, or to avail themselves of cloud-based services on a XaaS framework.

The rest of the report looks at these factors driving the transformation of the role of wireless in the enterprise – keeping in mind that the transformation goes beyond the enterprise. Indeed it will require significant support from service providers eager to offer a better experience to their subscribers and reduce costs.

Definitions: enterprise, venues

When talking about the **enterprise**, images of office space or a warehouse are the most likely to come to mind. But there is more variety to the enterprise – and its diversity creates a fragmented environment that makes it challenging to devise and deploy a common wireless infrastructure, as we will see in the rest of the report. Enterprises vary widely in function, physical environment, size, and ownership.

In this report we include under the enterprise umbrella:

- Office buildings, campuses, factories, warehouses
- Outdoor business facilities – e.g., mining, utilities and transportation sites and assets
- Retail and entertainment venues – e.g., malls, stadiums, restaurants
- Public or semi-public venues – e.g., colleges, hospitals, hotels, airports

What sets enterprises apart is that they have control over the real estate where they are located, and access is for a broad range of users (e.g., employees, visitors, students, patients, renters). The enterprise may have control over the venue even if the venue is leased and not owned, or a third party may manage and control the venue (e.g., in a building with multiple business occupants, or a residential high-rise building).

We do not consider residential single-occupant or small multi-unit buildings as enterprises – even though the occupants have control over the premises – because in these environments access is limited to house residents and their guests.

We use the term **venue** (from the French *venue*, past participle of *venir*, to come) to refer to an indoor or outdoor location where people convene to work, to travel, to study, or to participate to events and social activities.






The evolution of wireless in the enterprise

As wireless in the enterprise becomes more prominent, its fundamental role and characteristics are changing. Wireless has evolved from a restricted access technology to the dominant one. The graph on the next page outlines the phases of this evolution.

The changes have been occurring at multiple levels:

- **Fixed and mobile convergence.** Initially, wireless access was mostly limited to mobile access, with employees using the mobile phone when away from their desk. Today, they use wireless as the default technology, regardless of location, even in fixed-access scenarios (e.g., sitting at a desk).

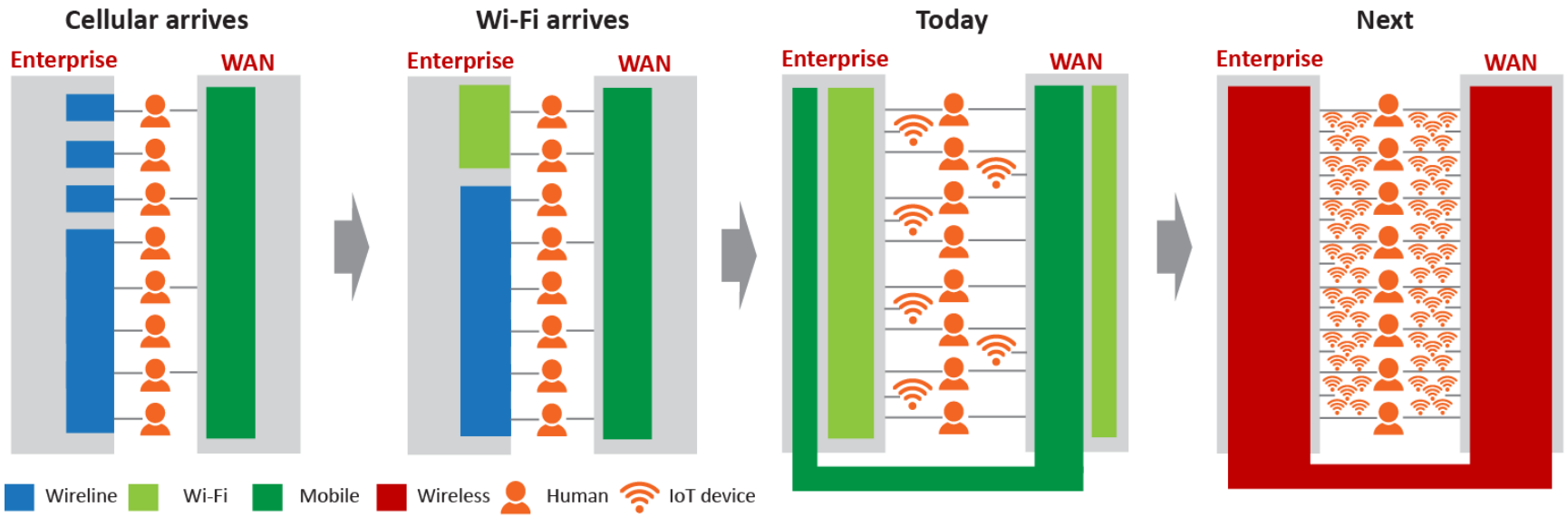
- **Access technologies.** Wireless networks both within the enterprise and outside it are increasingly agnostic to access technologies, and they leverage the mix of technologies available to improve network performance and QoE.

- **Operational depth.** Wireless still provides what we consider basic connectivity – e.g., voice, email, text, internet access, OTT applications – but it has also started to insert itself deeply into enterprise operations such as manufacturing, automation, or tracking and monitoring the movement of goods in a warehouse.

- **Devices.** Initially, mobile phones were the only option, and those who had one typically had only one connected mobile device. Today, most users have many wireless devices and, with IoT, the number of devices not directly operated by humans will skyrocket. And this will add complexity and strain to enterprise networks.

- **Relationship with wireless WAN.** The separation in ownership and control between public wireless WAN and private enterprise WLAN will not go away. Devices, however, will be able to seamlessly access the network that offers the best performance for the application being used (e.g., Wi-Fi for downstream video, but LTE for conversational video, because LTE is better for the uplink, but Wi-Fi has more capacity).

- **Ownership and service models.** The enterprise will expand ownership of the infrastructure, but it is not likely to want (or be able) to operate all the networks. So there is a wider role for operators and third-party integrators and neutral hosts to empower the wireless enterprise.



Source: Senza Fili

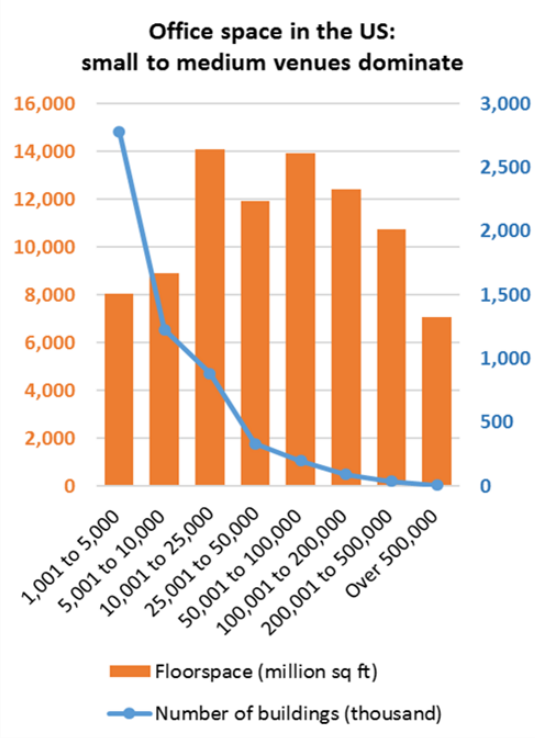
During the early days of cellular, wireline access dominated in the enterprise – and even wireline access was limited in functionality and availability. Not all employees had mobile phones. The enterprise and wireless WAN had completely separate technology and devices.

Wi-Fi marks the entry of wireless into the enterprise to provide widespread connectivity to employees and guests. Initially, enterprises deployed Wi-Fi selectively in areas of high demand, but eventually they extended coverage and capacity, often to include the entire venue. At the same time, the portion of traffic transported over Wi-Fi increased to the point of surpassing wireline access.

Wi-Fi is the access technology that carries the most enterprise traffic, and it has become the default access technology in work environments for both employees and applications. Mobile connectivity is mostly provided by networks external to the enterprise, with indoor connectivity through DAS, small cells, and hybrid systems. The IBW networks are mostly owned or controlled by mobile operators or neutral hosts. In addition to devices operated by humans, there are an increasing number of IoT devices, some connected to enterprise networks, some to mobile networks. Mobile operators may own Wi-Fi networks, but they are typically separate from those owned by the enterprise.

With 5G and in preparation for it, wireless networks will widen the range of access technologies and spectrum bands they use, but they will increasingly integrate them to provide seamless or flexible access to user or IoT devices. Even though ownership and control of networks may be split between enterprise and operators, networks will be able to coordinate traffic management to optimize resource utilization and user QoE. With the growth of IoT, the number of devices not directly controlled by humans will grow rapidly. Within the enterprise, Wi-Fi will keep its prominence, but other technologies will increase their presence to meet a wider range of requirements.

Serving the enterprise (and the middleprise)



Source: U.S. Energy Information Administration, Office of Energy Consumption and Efficiency Statistics

It is widely recognized that the enterprise is underserved and that, at the same time, it is a very attractive market for mobile operators and third-party players like neutral hosts. Why is it so?

Historically, mobile operators have grown their networks to serve subscribers – i.e., individuals using their network across their footprint – and that has been their way of improving revenues. Because wireline technologies provided most voice and data connectivity, initially mobile operators concentrated their efforts on expanding coverage first and increasing capacity next. They used their macro networks to target primarily outdoor locations, which were the places where their subscribers did not have connectivity otherwise. Indoor coverage was valuable too, but by and large not targeted by a separate part of the wireless infrastructure. DAS in large venues such as stadiums was the exception, but it addresses only the top venues.

To date, many services that mobile operators offer to the enterprise are services for the employees who work across their network or their applications, but those services are often not specific to a venue.

To address the new needs of the enterprise, mobile operators have to develop services and solutions that target the specific locations where enterprises operate – and that have the flexibility to address a wide range of venue types. This requires getting inside these locations and working closely with the enterprise, or with neutral hosts or third parties that rely on or manage the enterprise networks (and, in the latter case, sharing the access footprint with other operators). Most operators will rely on a mix of these options, depending on the type of enterprise.

Until a few years ago, mobile operators were extremely cautious about – or even opposed to – installing hardware in venues they did not control. (Again the exception was massive venues such as stadiums, which attract too many people to ignore.) The operators viewed venue-specific and in-building infrastructure as too complicated and time-consuming to install and operate. That has changed, because of the need to densify the network and the fact that 80% or more of the traffic comes from indoor locations. Operators have realized they have to find a way to enter enterprise venues.

Still, deploying and operating enterprise networks can be challenging and expensive for mobile operators, especially if each operator builds its own network within the same venue. The business case is difficult, especially as the size and attractiveness (i.e., the density of subscribers) decrease.

In large venues – stadiums, airports, big malls – good coverage and capacity are a must, for both the operators and the real estate owners. Both parties are ready to invest in the infrastructure. Many of these venues have a DAS in addition to a dense Wi-Fi network for guests and employees.

As we move to smaller venues – the middleprise, with venues of less than 500,000 sq ft – the financial attractiveness of the deployment decreases for operators. These are small deployments, but they still require considerable investment and planning, yet they offer limited revenue opportunity for the operators. Also, there is a huge diversity among these venues, based on vertical and function within the vertical (e.g., factory, warehouse and headquarters offices within the same enterprise). Operators have to invest substantial resources to plan a network that meets the specific venue requirement.

As a result, the middleprise is the most underserved enterprise segment, despite most enterprise venues and most enterprise footage falling into this category (see graph showing the distribution of buildings by size).

A top priority for the entire wireless ecosystem is to find ways to provide the coverage and performance the middleprise needs, in a cost-effective and scalable way. There are multiple technologies, and there have been many regulatory and market changes, that will make it easier to meet the middleprise challenge, but a crucial enabler is the growing willingness of the enterprise to pay for the wireless infrastructure. This approach reduces the cost of the network because the enterprise can integrate all wireless and wireline networks and has complete access to the venue. As added benefits, the enterprise can select the desired coverage level, capacity, and other performance characteristics, as long as it is willing to pay for them – and mobile operators are spared the effort of estimating performance and cost requirements that are difficult to determine from outside the enterprise.

Enterprise priorities

Wireless is now penetrating more deeply into the enterprise. It is doing this by transforming itself from an access technology for voice and data coexisting with wireline, and by becoming a tool essential to running a business, managing a property, or providing services to people in the venue.

Some in the telecommunications industry even consider wireless to be a new utility. However, treating it as such underestimates its role. Utilities typically provide resources on an even basis to all assets that require them. Wireless provides connectivity to all people and assets that can connect, but it also can manage connectivity in highly sophisticated ways to make sure each connected device has the resources it needs, when it needs them, and for the services it uses. Wireless can add intelligence to baseline connectivity, and this allows for an efficient use of network resources, which in turn improves performance and reduces per-bit costs.

For instance, an enterprise LTE private network may give priority to voice traffic, which is highly sensitive to latency and jitter, over data applications that can accommodate delays in transmission more gracefully. Another enterprise may use uplink video for mission-critical applications and assign priority to it. For some businesses – e.g., in the financial sector – specific security requirements affect how the enterprise chooses how to manage traffic. Virtually every enterprise needs the flexibility to customize a wireless network to meet its requirements and preferences.

As a result, the priorities of the enterprise vary across multiple dimensions – vertical, size, venue type, business processes and wireless strategy – and they go beyond coverage and capacity. Enterprises need the flexibility to support multiple services and applications side by side on the same network and, conversely, the same application or service on multiple networks. As it tries to optimize performance and resource utilization, the enterprise needs to take into account traffic distribution and requirements to allocate traffic flows to the best-suited network. Multiple networks will coexist, and they have to be integrated to strengthen each other. The awareness that network diversity not only increases capacity but improves the performance of individual applications and services replaces the perception of competition among technologies or networks.

The complexity of this many-to-many approach increases the need for the enterprise to have full visibility into and adequate control over the networks' services in real time, as well as have the corresponding SLAs – even if it does not own or operate those networks.

Basic needs

Coverage

Gone are the days when enterprises deployed Wi-Fi only in the lobby and meeting rooms. Today, Wi-Fi and mobile access are expected throughout the building, with the possible exception of some remote garage areas. And coverage no longer means only that devices can connect to the network, but also that they can reasonably run voice and data service with an acceptable QoE, without the user having to walk to the window.

Outdoor macro networks still provide most of the mobile connectivity within the buildings. But because the signal has to go through windows and walls, good indoor connectivity is difficult to achieve, and indoor traffic requires more network capacity than outdoor traffic does. New building codes designed for energy efficiency have the unintended effect of making indoor coverage more difficult (and expensive in terms of resources). When we consider that 80% of traffic comes from devices located indoors, the case for adding IBW infrastructure in the enterprise becomes compelling. In many cases, this is the only cost-effective way to provide the coverage needed inside buildings.

Capacity density

As wireless has become the default access technology, the enterprise needs wireless networks that not only provide good coverage and capacity, but also scale with increased usage and number of devices. It needs a high capacity density – the capacity per area unit (e.g., Mbps per sq m) – to accommodate a high number of devices in a given area.

This is where densification comes in: it does not increase the throughput of a single cell, but rather increases the density of cells to support more devices within the same area. Wi-Fi and small cells are very effective for adding capacity density and flexibly accommodating different capacity requirements. The enterprise can densify gradually, by adding new elements as demand grows.

In turn, mobile operators benefit greatly from IBW networks. They relieve pressure on congested macro stations. Because of the high per-bit cost of capacity in a macro cell, operators and enterprises jointly gain from operating indoor mobile networks using either licensed, unlicensed or shared bands.

Latency

Latency has grabbed a lot of mindshare lately as we consume more video and as voice has become embedded in data traffic. Both voice and video traffic are exquisitely sensitive to latency – sluggish high latency dooms QoE even on a network with outstanding capacity. To some extent, low latency is necessary to protect the value of capacity.

At the same time, it is crucial to appreciate that the impact of latency varies greatly across traffic types. Latency requirements can be relaxed for non-real-time traffic – e.g., best-efforts data traffic, including many IoT applications. That gives some leeway in enterprise networks to manage traffic, for instance with network slicing, to optimize latency. This way enterprise networks can use their resources to optimize QoE – e.g., tolerating higher latency for non-real-time applications in order to free resources for real-time traffic.

The need (and expectation) for extra-low latency increases with 5G, with some IoT services that run in real time, and with new applications such as VR and AR. The enterprise will play a significant role in pushing for low latency.

Pervasive connectivity across networks

Pervasive connectivity is a corollary of the stringent coverage, capacity density, and latency requirements. No single frequency or network is likely to be sufficient to support the required QoE and performance across the entire venue. In locations where one network does not provide sufficiently good coverage, devices should be able to connect to networks that have better coverage. When one network is congested, devices should be able to switch to networks that are less loaded. When licensed bands are at capacity, networks should be able to leverage unlicensed spectrum, using technologies such as LAA or LWA. This flexibility enables a pervasive type of connectivity that uses spectrum and network resources opportunistically.

Intelligent allocation of resources

Pervasive connectivity requires, and its benefits are amplified by, the ability to intelligently manage resources and traffic demand end to end. While this holds for all wireless networks, in enterprise networks, intelligence has to be applied case by case to the specific enterprise's wireless environment, including devices, networks, services and applications, and to the specific enterprise's priorities.

While this intelligence is applied only within the venue, it will have an impact on the end-to-end network and may be at odds with the operator's approach to allocation of network resources.

Policy is an example of this. The operator may have a network-wide policy that differs from the one that an enterprise wishes to apply within its venue. The policy can be enforced locally at the edge, but the divergence between the two policy approaches has to be reconciled and requires flexibility from both the operators and the enterprise. Network slicing, edge computing and security are other areas where the enterprise is likely to have requirements that are divergent from the operator.

Intelligence in resource allocation is not a binary concept, and we should expect a gradual evolution as requirements become clearer, IoT applications more widely used, more commercially solutions, and enterprises and operators more comfortable with automated tools using artificial intelligence or machine learning. But the transition is toward real-time traffic management at the application level in virtualized networks that can host functionality in both centralized and distributed architectures. It is a major transition for wireless networks, so expect that it will take some time for commercial networks to employ full-fledged real-time traffic management.

Local content, ubiquitous reach

Ubiquitous reach is vital for the enterprise. Employees may work remotely, and they need secure access to enterprise applications regardless of where they are.

At the same time, in many venues much of the traffic is local – i.e., directed to other people in the venue, or using content or data that is stored or generated within the venue. In this case, there is no need for the traffic to go back to the core. The additional trip to the core increases latency, makes it more difficult to share applications across local networks if operated by different entities, uses backhaul resources needlessly, and may unnecessarily expose the enterprise to security challenges. A local breakout that allows the enterprise to store selected content and host its own applications within the venue is one of the contributions of edge computing that will help address this need. In a private network, local breakout is organically built in. In an enterprise network that is part of a public network, the enterprise will expect the operator or other service provider to provide local breakout functionality.

Security

The deeper the reach of wireless into the enterprise's inner workings, the greater the need for security and the wider the scope of security within the venue. Not only does the enterprise need to protect itself from the network side, it also has to protect itself from the device side. Devices are already a growing area of concern, with employees and visitors often using multiple connected devices. But it will become a more complex challenge with the addition of IoT devices, because of their number and multiple form factors, and because they are not actively monitored by (or in proximity to) a human user. IoT devices may become the target of attacks directed at the enterprise. They may be in locations easily accessible by unauthorized users, and in many cases it will not be possible to physically protect them from malicious access.

Reliability and resiliency

Security, reliability and resiliency become more important as wireless connectivity becomes an integral component of business processes. This is already the case with Wi-Fi in many enterprises. If Wi-Fi connectivity goes down, productivity suffers, and some tasks break down. Even without IoT, mobile connectivity is essential to most employees. With IoT, reliability and resiliency will become even more crucial to the enterprise. At the same time, the coexistence of multiple networks that are integrated with each other will improve the overall wireless reliability and resiliency by providing redundancy.

The rise of IoT, CBRS and private networks

With the rise of IoT and private networks, wireless in the enterprise ceases to be only an extension of public WAN cellular networks to get better coverage and more capacity, or a substitute for wireline connectivity. Wireless networks in the enterprise assume a venue-dependent role tied to specific IoT and other applications that is complementary to providing connectivity to employees and guests.

The attractiveness of IoT comes from the opportunity to leverage connectivity – predominantly wireless – to improve the quality, efficiency and reliability of business processes, to increase outputs, and to reduce costs. But this comes at a cost that is not purely, or primarily, financial. In addition to deploying the wireless infrastructure and the applications required, IoT forces a deep change in the way enterprises run their business. While this change is expected to bring value in the long term, it creates operational and cultural challenges in the short term that will require time and the adoption of the right business model to address. IoT will not change the enterprise overnight – but the wireless infrastructure foundations have to be in place to enable a gradual introduction of applications. This relaxed pace will give most enterprises the ability to adapt to change, while keeping disruption under control and building confidence in automated and real-time processing in IoT applications.

The new role for wireless infrastructure, coupled with the financial and cultural changes it creates, changes how much the enterprise is willing to invest in wireless, and what it demands in terms of performance and control. It also brings to the forefront the question of who owns and controls the wireless infrastructure, and who builds and runs the IoT applications.

We will discuss ownership and control over wireless networks and services in the section below on business models. In preparation for that, here we review the enterprise's options for harnessing wireless networks to support IoT applications.

Applications that use wireless technology to support business processes or provide security are nothing new. There are multiple mature, proprietary solutions that are specific to verticals (e.g., utilities, transportation, military). Most use narrowband spectrum allocations. These applications do not qualify as IoT, because the "internet" component is usually not part of them. Wi-Fi, however, has introduced many applications in the enterprise that can be treated as ante-litteram IoT. They have been deployed widely across verticals and have been effective in improving performance cost-effectively.

Wi-Fi will undoubtedly continue to be a primary platform for IoT. However, as the range, the requirements and the sheer number of connected devices grow, there is a clear need to expand the wireless infrastructure to other technologies and spectrum bands. Public mobile networks continue to host more IoT applications, too, especially those used in the WAN; transportation and smart-

city applications are good examples of verticals where mobile networks are the best solution.

But there is more than Wi-Fi, and more than public mobile networks. Private networks are a new and powerful way to address the needs and challenges of venue-based IoT applications. Because of this, they have quickly become a hot topic and stirred the discussion on what business models are viable or necessary to enable IoT in the enterprise.

The idea of private networks is not new either. Wi-Fi networks are the quintessential private networks today – mostly owned, controlled and operated by the enterprise. LTE private networks have been considered, too, but it is difficult for the enterprise to have access to licensed spectrum for such networks.

Even with LAA, an enterprise-controlled LTE private network is a difficult proposition. LAA uses the unlicensed 5 GHz band for the data plane, but it still requires anchoring to a licensed band for the control plane. As a result, an enterprise can deploy an LAA network, but only in partnership with a mobile operator with licensed spectrum assets.

MulteFire addresses this issue by enabling the enterprise to deploy LTE in the 5 GHz band as a stand-alone network that does not require anchoring to a licensed band or a mobile LTE core. Both MulteFire and Wi-Fi operate in the same 5 GHz band, though, so if an enterprise chooses to deploy both, it has to determine how to balance spectrum sharing between the two. (We assume that enterprises will retain Wi-Fi when deploying MulteFire.) MulteFire may play a role in rolling out some IoT applications that benefit from the performance advantages of LTE (e.g., a better uplink). However, the reliance on the 5 GHz band – a band heavily used already for non-IoT access – limits its ability to support all the IoT in an enterprise in the same way as Wi-Fi.

The most promising and innovative opportunity for private networks comes with CBRS in the US. CBRS uses the 3.5 GHz band. If, as an initial proof point, CBRS is successful, it can be extended to other bands to provide the foundation of a spectrum-sharing platform available across the globe.

CBRS's entirely new regulatory framework tries to balance the advantages of licensed and unlicensed spectrum while sharing both with legacy users (i.e., military, satellite operators and WISPs). Legacy users retain priority access to the spectrum. When they do not need it, licensed spectrum holders can use LTE, 5G or any other technology of choice in their spectrum allocation. For a detailed overview and assessment of CBRS, see the report "Learning to share. CBRS in the 3.5 GHz band changes how we use spectrum."

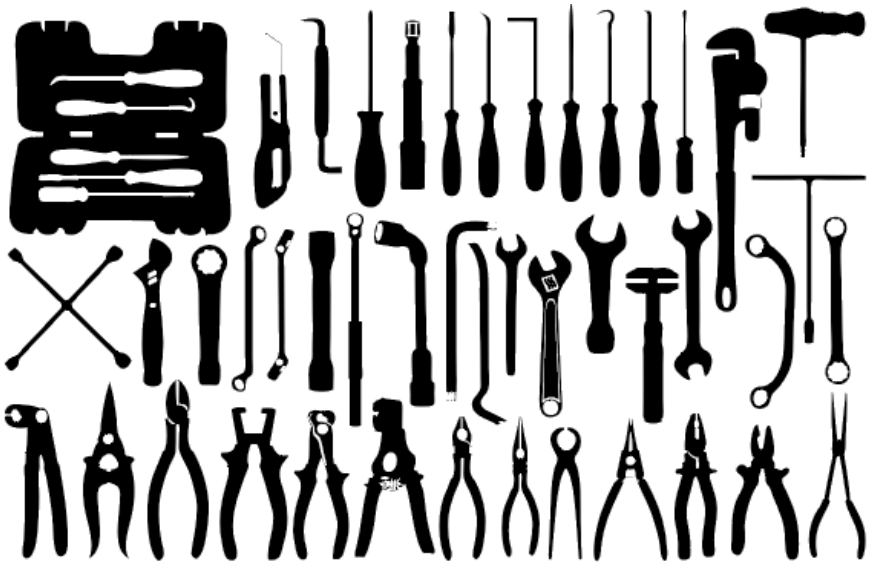
The most innovative part of CBRS is that any entity can use a part of the 3.5 GHz band, plus any spectrum channel that is not actively used by legacy and licensed users, on an unlicensed basis under the GAA umbrella. The interested party has to register its intention to use the band, and it can use it when authorized to do so by a SAS, an entity that coordinates use among CBRS users.

Service providers and network operators are likely to pursue licensing for access to 3.5 GHz spectrum, but enterprises will be able to gain access to CBRS spectrum under the GAA provision because they control the real estate where they operate. That means that an enterprise that has control over a building or a campus can use the GAA spectrum without much competition in most environments. In this context, the more limited propagation of the 3.5 GHz band, compared with that of licensed cellular bands, acts as a protection for an enterprise private network, because it reduces the impact of interference from sources outside the venue.

CBRS is a crucial booster for private networks in the US. It gives enterprises the ability to deploy and operate an LTE network within their premises, with up to 150 MHz of spectrum, using a standards-based technology like LTE (and eventually 5G) that gives them a choice over infrastructure and device vendors and delivers the cost benefits of LTE's economy of scale.

While encouraging the deployment of private networks, CBRS also encourages deeper cooperation with mobile operators and other service providers. They can use the CBRS infrastructure owned by the enterprise to either provide their subscribers access (e.g., at a mall or college campus), or to deploy and manage the CBRS infrastructure on behalf of the enterprise.

Technology enablers



Densification

When the topic of densification in the enterprise comes up, a common question is whether and when small cells will finally take off. That question misses the significance of the bigger trend toward densification and, within the enterprise, IBW. Densification is much more than small cells, and much more than DAS – at least in the small cell and DAS architectures that dominate in existing deployments.

DAS and, to a lesser extent, small cells are the most common IBW solutions deployed today, but they cover a very small fraction of enterprise venues. Within the overall mobile networks, they still are niche solutions, often targeted at specific venues (e.g., stadiums, airports, large enterprises).

As we look ahead, a good environment for densification is developing. It arises from the strong need of the enterprise – and specifically the middleprise – to have venue-based wireless networks to complement Wi-Fi, and from mobile operators' increased acceptance of IBW and their push to expand it.

New solutions are becoming available that make densification easier, more scalable and cost efficient, adaptable to different business and ownership models, and supportive of a multi-operator presence within the venue. Both small cells and DAS deployed today fall short of at least some of these targets. Traditional DAS works for large venues but does not scale well downward to the middleprise with regard to cost and complexity. First-generation small cells are not as cheap or easy to install as initially expected, or as needed to support a single-operator deployment model.

Vendors have taken note of this, and have been developing new solutions that are either evolutionary or hybrid models of today's DAS and small cells. None of those is set to become a winner-take-all solution, but taken together they create a powerful toolbox for operators, enterprises and neutral hosts to select the solution they need in a given venue. Flexibility and choice in cost/performance/complexity tradeoffs are the strengths of this approach.

These new solutions vary along multiple dimensions, including distributed/centralized architecture, backhaul/fronthaul requirements, power, complexity, cost, performance, support for multiple access interfaces, planning requirements, efficiency of spectrum use and reuse, and support for unlicensed spectrum.

Virtualization

The link between densification and enterprise networks is more straightforward than the one between virtualization and enterprise networks, but virtualization is nevertheless a powerful enabler of the evolution of wireless in the enterprise. Virtualization adds flexibility, automation, and real-time allocation of resources to wireless networks. This enables mobile operators to more easily accommodate the requirements of enterprises, including the tight timeframe of some enterprises, and to do so for enterprises of different sizes and operating in different verticals.

Of specific relevance to the enterprise is the virtualization of the RAN. A virtualized RAN can reduce the deployment cost of small cells or other venue-based solutions, thus making densification financially more attractive for both operators and enterprises.

From a functional perspective, a cloud RAN virtualized architecture can improve operators' support for (virtualized) small cells in small and medium enterprises with the BBU location shared across venues. At the other end, larger enterprises may keep the BBUs all within their premises, and co-locate them with edge computing servers to extract cost savings and leverage the synergy of RAN virtualization and edge computing.

Edge computing

Moving core functionality toward the edge is another, indirect benefit of virtualization. Edge computing does not require a virtualized wireless network, but a virtualized network makes it easier (and cheaper) to push functionality to the edge. Virtualization not only decouples software from hardware, it also separates location from function, encouraging operators to choose the best-suited location in terms of cost and performance.

Edge computing enables local breakout, so enterprises can keep their processing and content within their premises. Local breakout also lowers the latency, gives the enterprise more direct control over its applications plus additional scope to step up security, and reduces the requirement for backhaul resources and thus their cost.

Network slicing

Network slicing makes it possible to manage traffic and allocate network resources more efficiently and according to the specific requirements of traffic, application, user or policy rule. If the enterprise owns the infrastructure or has a service arrangement with an operator or a third party to use it for its applications, it can use network slicing to decide how traffic should be managed within its premises.

5G

The evolution of enterprise networks does not depend on 5G, but the enterprise will benefit from many 5G features. The timing works well as both 5G and venue-based wireless will take a few years to reach full market potential. Meanwhile, the enterprise can already start deploying networks that can be upgraded to 5G.

Among the features of 5G that will benefit the enterprise are the increased capacity, lower latency, and improved reliability. They are valuable to all use cases, but they are particularly relevant to IoT applications that have tight requirements. Many of these improvements, however, will become available gradually ahead of 5G, with LTE-A and Gigabit LTE, so 5G will not mark a sharp discontinuity but instead be the target that mobile networks have already started to aim at.

A 5G-specific feature that will benefit the enterprise is the expansion to mmW, which has large amounts of spectrum, some of it in unlicensed bands that are accessible to the enterprise. The enterprise may use mmW for fixed connectivity – e.g., between buildings in a campus or to backhaul outdoor small cells – or for access in indoor or outdoor environments at locations where there is a need for high capacity density, but not for long-range connectivity.

Another 5G feature that will have a high impact on the enterprise is 5G's inherently multi-access approach, which sets it apart from previous Gs. While 5G standards include NR as the new interface, 5G networks are designed to integrate multiple access technologies, both in licensed and unlicensed bands (including Wi-Fi), and to expand support for unlicensed access for NR.

Wi-Fi evolution

In parallel with the mobile evolution from LTE in 4G to NR in 5G, Wi-Fi is also evolving to provide better performance – comparable to 5G in mobile networks.

The introduction of Wi-Fi ac and 802.11ax increases the capacity of Wi-Fi and its ability to support IoT applications. Wi-Fi is also introducing new features designed to integrate Wi-Fi and mobile networks more effectively than is possible today.

WiGig expands Wi-Fi availability from the sub-6 GHz bands to mmW spectrum in the 60 GHz band. WiGig has a smaller coverage area than Wi-Fi in the 5 GHz, and hence the use cases will be different to some extent. The limited coverage area will inevitably limit the IoT services that WiGig can support, but, at the same time, it increases spectrum utilization.

Business models

The biggest obstacle that has slowed down the adoption of mobile networks in the enterprise has been the lack of robust and scalable business models, and for two reasons. The first is that available solutions – DAS and small cells – have been too expensive for many enterprises (especially medium-to-small ones) to justify a deployment, whether funded by the enterprise, a mobile operator or a third party. The second is the prevalence of the model in which the operator owns, operates and controls the infrastructure. This model holds even in the case of a neutral-host DAS, where the neutral host or the enterprise may own the in-building equipment, but the operator has full control over the BBUs – and hence over managing the RAN.

Wi-Fi is different. The business case for Wi-Fi is straightforward, and Wi-Fi networks are virtually ubiquitous in the enterprise, although there is great variability in their quality and performance, depending on how much the enterprise is willing to invest in the network.

As a result, wireless access within an enterprise venue is frequently split between the enterprise-owned Wi-Fi and the operator-owned mobile network, most frequently through outdoor macro cells, because of the limited number of venues with DAS or small cells.

This arrangement does not satisfy either the enterprise or the mobile operators. The enterprise does not get the mobile coverage and capacity it needs in most venues, and it lacks control over what gets deployed and how the network is run. Mobile operators want to reach out to the enterprise, but building indoor infrastructure in small venues has been difficult to justify financially and complex to manage. Furthermore, it is a missed opportunity for neutral hosts and third parties, which have also found it difficult to address the needs of the middleprise.

As we have seen earlier in this report, this is changing with the pressure of both enterprises and operators wanting to improve venue-based infrastructure, and their increased willingness to try new business models that are more attractive.

Multiple models are being assessed and becoming a commercial reality. Some will prove to be more successful than others, but multiple models will coexist to meet different enterprise and operator needs and preferences. The high-level trend, however, is toward more active participation by the enterprise in funding the infrastructure, paying for services, and expecting transparency and some level of control over the enterprise network.

The operator-owned and enterprise-owned models will survive and will continue to work in some environments. But increasingly, ownership and operational control will be split along a continuum of points.

The enterprise may choose to create, pay for, and operate a private network. Ownership and operational control allow the enterprise to use network

resources for connectivity and applications as it sees fit. That also gives the enterprise more leeway in how it integrates the mobile network with other wireless networks, primarily Wi-Fi, within the premises.

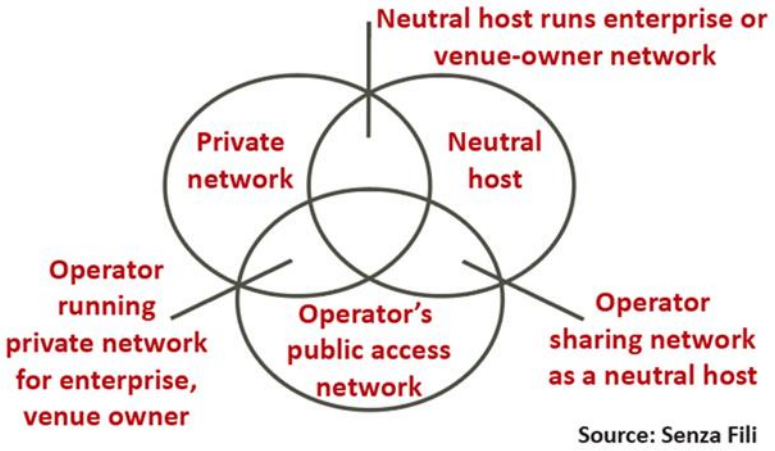
The enterprise may allow operators to lease access to its private network on a wholesale basis to serve the operators' subscribers within the venue and offload the macro network, without the operator having to finance the network deployment directly. This allows mobile operators to share the infrastructure without having to share spectrum or their own network infrastructure, and thus keeps the costs of providing venue-based connectivity under control.

Many other enterprises may not have the resources to own the wireless network directly, or may prefer to avoid managing one. In this model, they may have a neutral host, an operator or another third party manage the private network infrastructure they own. The enterprise still controls how to allocate network resources, and it may still lease access to operators.

These are scenarios that CBRS will encourage in the US (see figure), but that can be replicated worldwide in licensed bands with the operators' consent, or in unlicensed bands. However, mobile operators will not allow use of licensed spectrum they are actively using in a private network, unless they have control over it and it does not affect macro coverage in the area. In this case, they may manage the enterprise-owned network or own it entirely, and reverse the relationship with the enterprise and sell access to the enterprise on a XaaS basis. Operators may be willing to allow the enterprise to use their spectrum in remote areas (e.g., mining sites) or in areas where the operators have spectrum they do not actively use.

These new ownership and operational models will facilitate a more widespread deployment of wireless infrastructure in the enterprise. They will also enable both the enterprise to deploy its own applications, and operators and third parties to provide services to the enterprise. The latter option – using cloud-based application offered by the operator or a third party – is going to be particularly attractive to small- and medium-sized businesses that need cost-effective, off-the-shelf solutions that require only limited customization.

Innovation in business models with CBRS



Source: Senza Fili

Pervasive networks in the enterprise

The more active role of the enterprise in owning, managing and controlling its own infrastructure has effects that go beyond the confines of the enterprise. That growing role makes a central contribution to the evolution of the entire wireless infrastructure and ecosystem. In turn, the ongoing evolution of wireless networks from atomic networks to pervasive networks (see table below) is in line with and supports the evolution of the enterprise networks. (See "Massively densified networks. Why we need them and how we can build them" for a description of what I call atomic and pervasive networks).

Today's networks have an atomic, discrete architecture in which cells are the edge access elements and are all connected to a common core. The confluence of densification, virtualization, edge computing, real-time traffic management, focus on QoE, and 5G is deeply changing wireless networks, making them pervasive. Pervasive networks are distributed and user-centered.

With RAN virtualization, the cell as the fundamental self-contained element in the RAN ceases to exist. A multi-layer, multi-band, multi-access set of antennas connected to a remote baseband replaces the stand-alone cells. Devices within this model can connect to more than one antenna, and more than one access network. This enables pervasive networks to allocate network resources more efficiently and extract more value from the infrastructure already deployed.

The increased flexibility in pervasive networks benefits the enterprise at multiple levels. RAN virtualization, expansion to new licensed frequencies and to unlicensed ones, and new RAN topologies make mobile networks more attractive to the enterprise and better suited to meet its needs.

New IBW topologies, the more intensive use of unlicensed (Wi-Fi, LAA, MulteFire) and shared spectrum access (CBRS), and multi-layer densified networks bring to the forefront the role of enterprise as the entity that has control over the venue. Spectrum ownership is no longer sufficient for cost-effective densification efforts. And venue owners cannot on their own manage increasingly complex mobile networks. The success of densification efforts depends on the cooperation of mobile operators and the enterprise to jointly explore and rollout business models that are beneficial to both.

	Atomic networks	Pervasive networks
Network model	Network-centric: subscriber adapts to the network (e.g., goes to the window to make a phone call).	User-centric: network adapts to subscriber demand (e.g., ultra-dense wireless infrastructure in stadiums).
RAN	Discrete elements: cells (antenna and baseband).	No-more-cells, phantom-cells approach, with antennas as access points in a multi-layer topology, connected to a remote baseband.
UE-RAN connection	One-to-one connection from the UE to the cell. Handoffs required for the UE to move association from one cell to the next.	UEs can connect to multiple antennas, use multiple bands. Flexible modes of connectivity coexist: dual connectivity, device-to-device connectivity, Wi-Fi offload. Subscribers can establish multiple concurrent connections: multiple devices (including non-SIM and IoT devices) on the same plan. The distinction between RAN elements and devices is less sharp because devices connect to each other and act as access points to the RAN.
User and control planes	User and data planes allocated to each access channel (e.g., sector).	Control plane can manage traffic for multiple access channels, so some access channels do not require a separate control plane (e.g., LTE in unlicensed bands, LWA, mmW). Short-range mobility can be managed without handoffs.
Densification targets	Coverage in the wide area, capacity in high-traffic areas, with most of the RAN infrastructure in outdoor locations and large venues (e.g., stadiums).	Vertical capacity increase and coverage extension driven by location-specific traffic or service requirements (e.g., service tied to a venue; IoT service).
Layers	Single macro-layer, possibly with limited small-cell hotspot deployments, and with Wi-Fi offload.	Multi-layer networks, with extensive indoor and outdoor coverage with small cells, DAS or femto cells.
Spectrum	Cellular frequencies below 3 GHz.	Wider range of higher-frequency bands (3.5 GHz, 5 GHz, mmW), with the inclusion of unlicensed spectrum.
Core/RAN	Separate location and equipment, with RAN equipment located at the edge and core equipment in centralized locations.	Boundaries less strict, with RAN becoming virtualized and centralized, and some wireless core functionality moving to the edge (e.g., MEC, CORD). Location of function (distributed versus centralized architectures) is a strategic decision.
Testing, monitoring, optimization	Testing and monitoring based on network KPIs and historical data. Limited optimization functionality.	QoE metrics based on the performance of UEs are tied to network KPIs to test, monitor and optimize networks in real time.

	Atomic networks	Pervasive networks
Performance yardstick	Capacity per RAN element.	Capacity density (e.g., per sq km) and latency.
Traffic management	Maximize throughput. Capacity determines service availability.	Real-time traffic management, at the application or service level. Network slicing used to extract more value from network resources.
RAN equipment location	Telecom assets (e.g., macro-cellular towers, building rooftops), mostly in outdoor locations.	RAN equipment gets closer to subscribers and devices – closer to the ground and indoors.
Network ownership	Operator owns the network, often leasing space on a cell tower or other assets. Limited network sharing.	Venue owners increasingly pay for infrastructure, even though they do not (and choose not to) operate the network. Multi-operator, neutral-host model, in which some network elements (e.g., backhaul) are shared among operators.
Control	Operators control end-to-end network.	Operators retain control of the RAN, but other players – venue owners, residential users, neutral hosts, and system integrator – get more visibility into the networks and have a stronger role in determining how the network resources they paid for are being used.

Implications: striking the right balance

The enterprise wireless connectivity needs are expanding beyond connectivity for employees and guest, with the growth of IoT and the deeper penetration of wireless in the enterprise processes.

Wireless connectivity in the enterprise is becoming access-agnostic with multiple technologies integrated, multiple coexisting service models.

Serving the venue-specific needs of the enterprise has become a top priority for mobile operators and neutral hosts.

The enterprise is becoming more active in owning, controlling and managing the wireless infrastructure to ensure it meets its requirements. This is especially true in the middleprise, which is the biggest but also harder to serve market segment for mobile operators.

Private networks have emerged as a driver for a wider role of the enterprise in mobile networks. CBRS will be a crucial testing ground for private networks and the new business models they enable.

The evolution of wireless in the enterprise does not stop within the enterprise: it will contribute to change the way we think of and use spectrum rights and the impact of venue ownership in the deployment and operation of mobile networks.

As we move from atomic to pervasive networks, the enterprise will benefit from the increased role of venue ownership, the wider choice of RAN topologies, and the technological advances that will culminate in 5G.

II. Profiles and interviews

Profile

CommScope

A leader in telecom infrastructure for more than 40 years, CommScope provides both the enterprise and service providers with a wide range of wireline and wireless products, and solutions that support the convergence of wireline and wireless in public and private networks. The company has grown in size and scope with the acquisition of companies such as Avaya Connectivity Solutions, Andrew Corporation, TE Connectivity's Broadband Network Solutions and Airvana.

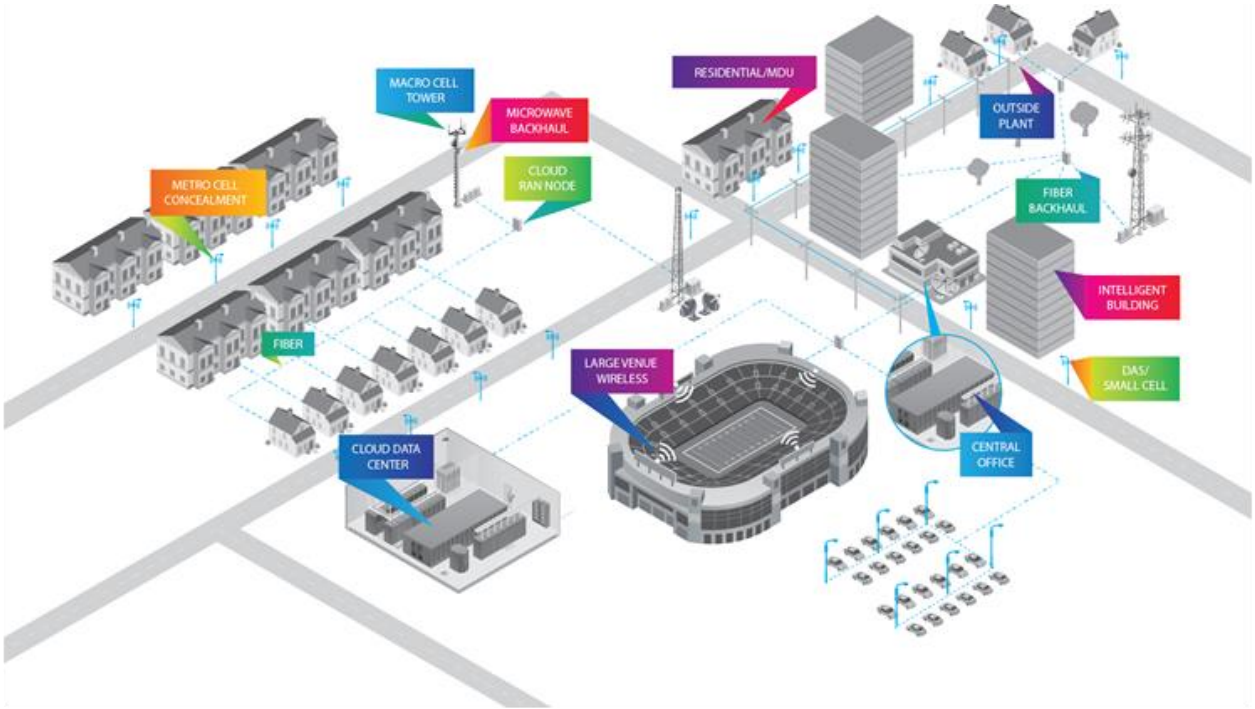
The CommScope Connectivity Solutions Segment offers solutions for indoor networks – in enterprises and public venues and in network core locations, such as data centers, central offices and cable TV headends – and outdoor networks, for access and edge connectivity.

The CommScope Mobility Solutions Segment offers solutions for outdoor and IBW that include:

- RF connectivity for macro cells, metro cells, small cells and DAS.
- Telecom equipment for tower sites, rooftops, street poles and street furniture.
- DAS and small cells for indoor and outdoor deployments and transportation systems.

CommScope has a wide set of solutions to serve the wireless enterprise market, either directly, through partners or service providers:

- ION-E, an enterprise DAS solution which aims to make DAS affordable to medium-size venues by leveraging existing, standard infrastructure, such as Cat 6B and fiber, for in-building connectivity, and by sharing the infrastructure with services such as Wi-Fi and IoT networks.
- OneCell, a small-cell solution based on a C-RAN architecture and targeting dense deployments where interference and handovers challenge stand-alone small cells. The combination of OneCell baseband and radio units creates a super cell within which there is no need for handovers and no interference among its radio units.
- Structured Cabling Solutions, to manage enterprise connectivity for multiple services, including IoT, mobile networks, cloud computing, audio/visual systems, security, building automation – all of which are included in what CommScope calls the universal connectivity grid (UCG). Within the UCG framework, the enterprise can share a converged cabling infrastructure for wireline and wireless access, and to support multiple-enterprise IoT and other applications. Products include SYSTIMAX GigaSPEED X10D cabling, offering up to 10 Gbps capacity, fiber optic solutions with capacity in excess of 100 mbps, and PoE solutions.



CommScope core markets *Source: CommScope*

CommScope

What does the enterprise need for its wireless infrastructure?

A conversation with JP Compagnucci, Market Development Global Leader in Enterprise Mobility, CommScope

Enterprises have become more eager to take an active role in the on-premise wireless infrastructure, from ownership to operations, either on their own or with partners. To do so, they need support in navigating what for many enterprises is a new technological environment, and they need solutions that address their needs and speak their language. In this conversation, I talked with JP Compagnucci, Market Development Global Leader in Enterprise Mobility, about how CommScope addresses the new role of wireless within the enterprise.

Monica Paolini: JP, could you tell us what CommScope is doing in the enterprise, and what your own role is within CommScope?

JP Compagnucci: CommScope is a global communications infrastructure company. We are wherever the networks are; we design and build the connectivity for the most advanced communications networks. From wireline communications networks to wireless communications networks, from data centers to buildings and venues, with a wide range of network infrastructure solutions: BSAs, metro cells, FTTX, DAS, small cells, high-performance structured cabling and software management solutions, to name some.

My role at CommScope is to lead the IBW market development initiative for the enterprise. The goal is to drive the global integration of our IBW offering into the enterprise space.

Monica: There is a lot to do. The role of the enterprise is changing, and you've been working on that for a while. What's your view of what's changing and why?

JP: A lot of things are changing. From the users' perspective in the enterprise spaces, there is now a universal expectation that there should be wireless connectivity throughout all the buildings, in every part of the building, not just in certain areas. Wireless is truly becoming the fourth utility.

At the same time, wireless connectivity has an impact in the enterprise business, and in different verticals, as well. There is a correlation now between indoor wireless connectivity and office productivity, tenant retention strategies, property value, to name a few.

Recently we did a survey of 600 building professionals in the US and Europe, and we asked how wireless connectivity was affecting their business.

More than 80% of them said wireless connectivity was imperative in all areas of the building – that it was improving workers' productivity, and also increasing the property value. Wireless connectivity has a big impact on the customer mindset.

At the same time, there are some challenges as well, because the coverage we have from the outdoor networks does not extend well inside the buildings, because of signal propagation.

Signals attenuate with the walls, and even more with the high-performance or high-efficiency glass windows. Really, the right solution is to install an indoor wireless infrastructure to provide optimal coverage and capacity inside the building. And since you're using licensed spectrum, you need to go through the carrier approval process – you need to have the carrier's permission to do that.

That has also been changing. In recent years, wireless service providers have been focused on installing IBW solutions for large venues – tier one stadiums, big arenas, and tier one airports, where high capacity is needed because of the high concentration of subscribers who demand services there.

When you move into the enterprise, the situation is different. MNOs are not willing to invest in DAS unless they obtain a suitable ROI. That's one of the reasons we are seeing a fundamental shift in the funding models. The carriers' goals, and consequently their investments, are changing. They're now looking at initiatives like fixed broadband, IoT, virtualization and more spectrum.

The enterprises need some help to solve those indoor connectivity challenges, particularly from the ecosystem that feeds them, and we are perceiving a shift in the ownership models, where enterprises want to take more control.

Monica: This is interesting, because it used to be that you just assumed the mobile operator would take care of everything: it's the responsibility of the mobile operator to provide coverage. Now the venue owners, the enterprises, are saying, "No, no, hold on. We need good coverage."

They're taking a bigger role. But how does that change the relationship they have with the mobile operators, or the role of the mobile operators in all this?

JP: Operators are always going to have an important role, because the enterprises are dealing with licensed spectrum for commercial cellular. Enterprises are also finding new models to fund the IBW solutions, with different levels of involvement.

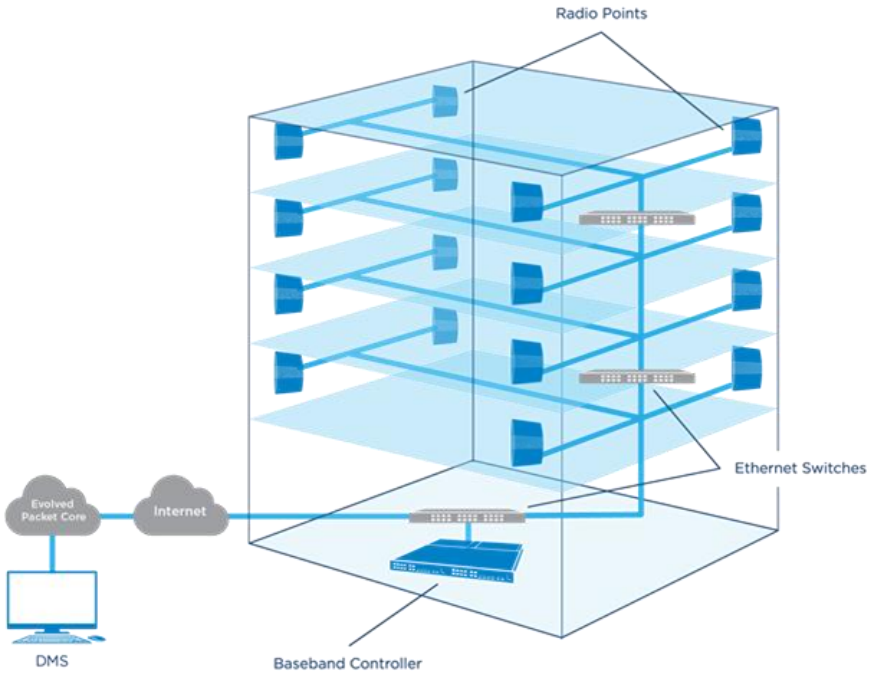
Originally, we have the traditional carrier-funded approach, where the carriers take ownership of the active part of the DAS, the passives, the signal source, and the backhaul. That's what has happened mainly for the large venues in the past.

We are seeing other models, as well – for example, the neutral-host model, where a third-party company takes control and ownership of the DAS system in agreement with the MNOs. This is attractive for the enterprises, as they perceive less investment needed from their side, as well as some reduced operational needs.

Maybe the challenge for the NH model is the fact that there should be enough subscribers and usage to produce a good ROI for both the neutral host and the carrier, to justify this model.

Then you have the enterprise funding model, where the enterprise takes control and ownership of the DAS infrastructure: the actives, the passives and the distributions. Then they work, usually with the help of some players in the ecosystem, on the carrier approval process, to get the backhaul and signal source from the MNOs.

Those are the three main business models that are available, but we are seeing also some mixed business or funding models. For example, a carrier can fund the active part of the DAS, and the enterprises can own the passive infrastructure, or some shared-cost models depending on the region.



CommScope's OneCell network in an office building ***Source: CommScope***

The number of enterprise funding deals is growing. The relationship with the carriers is still really, really important. In other regions of the world, it's coming, but not as aggressively as in the US market.

We are seeing some traction in Latin America, Europe, the Middle East and Africa, and Asia. But the big growth we are seeing is in the US.

Monica: The growth you're seeing in the US or in other places, is it because the enterprise is willing to fund the network infrastructure? Because even if you have a neutral-host model, the enterprise might provide the funding for the infrastructure.

Why is it changing? Is it because they realize that the mobile operators are not going to be able to make the investment? Or are there other reasons?

JP: There are a couple of reasons enterprises want to fund the IBW system. The strongest might be that they want to take control of their own infrastructure.

Sometimes they can't wait until the carriers provide an optimal solution – they want to decide and understand what type of solution fits their needs. Sometimes they want to have a multi-carrier solution, maybe not to support a lot of

carriers, but more than one – because they have some shared or public spaces.

In many cases, they want to take control because they want to understand a priori what is going to be installed, and to make sure it's ready for the future. They want to own a scalable DAS solution. The simple answer is that they really want to control that. It varies according to the different scenarios or verticals, but in most cases, it's because of that.

Monica: What about the neutral-host model? We've been talking about neutral hosts for a long time, but the carriers are sometimes a little bit, let's say, careful about embracing a neutral-host model, because they feel like they have to share the infrastructure. Maybe they don't want to do that. Is that changing from the enterprise point of view?

JP: The neutral-host model is really interesting for the enterprises, because it reduces their investment and makes some operations easier for them. Even if the NH owns the passives, the actives, or both, they need to have a good relationship with the carriers.

What type of enterprises are going to benefit from that neutral-host model? We are seeing some traction in the enterprise space, but it can't serve all of that market. Maybe in the middle, between carrier-funded deals (high-capacity venues, etc.) and mid-size enterprises. Remember, the number of subscribers and the amount of usage are important here, because for the neutral-host model to work, it should provide a good ROI for the neutral host and for the carriers.

That is not the case for most of the enterprises we were talking about, and that's why we are seeing more building owners willing to invest, themselves, in IBW and take control. Of course, the NH is still a very valid model.

Monica: Another thing that has always amazed me is that we know most of the usage comes from indoors. Now it's getting even more difficult, as you mentioned, to get indoor coverage, because of the new building codes. It's even more difficult to get indoors coverage at higher frequencies.

Why don't we have more in-building coverage already? Why didn't it start a long time ago? Although, in Asia there is much more indoor deployment than in the US.

JP: It's a combination of factors. It's such a good question that we included it in our building professionals survey. What challenges were they facing in trying to achieve optimal in-building wireless coverage?

They mentioned a lot of challenges, but maybe the four most important were the cost of the overall solutions, the complexity of the technology, the carrier-approval process – they mentioned, "Hey, carrier approval is an obstacle for us" – and then the lack of skills.

When they say "cost," they say, "You know what? Traditionally, DAS solutions were designed for high-capacity bandwidth use – big, high-powered projects – and not for enterprises." Really, they were not scaling down economically to serve the enterprises or larger buildings.

Where they said "complexity," they were mainly referring to their unfamiliarity with those traditional IBW systems.

Remember, we are dealing with the IT people, IT departments. With the IT teams, there is an environment that works differently for DAS and its RF complexity – the path loss, RF calculations, commissioning, coax cabling, understanding the different cards of a headend. Some of the complexity was hard for them to incorporate into their IT environment. Of course, the lack of skills was attached to that.

And the other challenge was really the relationship with the carriers.

They were feeling that the carriers were not capable of reaching every enterprise in the way they expected. At the same time, they recognized they don't understand how to interact with the carriers, particularly in regard to the approval and coordination processes. Even if those are clearer today, they are not the same from carrier to carrier, adding complexity to the equation.

Those were the main challenges we saw. We believe that, in part, that was because the ecosystem was not ready to help the enterprises.

Monica: I guess there are different factors coming together to enable it now. At CommScope, how do you help the enterprise address this challenge? It's still somewhat difficult for the enterprise to deploy indoor coverage. How can you help them?

JP: It is still difficult for them. We are working on two things: making the next generation of DAS and small-cell solutions friendly to the IT environment,

and how to enable the ecosystem to better serve the enterprise.

It's not only about the solutions. Both the solutions and the ecosystem are really important. We are working with both of them very hard.

For example, what we call the next generation of DAS solutions – the digital DAS or enterprise DAS that we call ION-E – is really a new platform designed for the enterprise. In addition to being a multi-operator, multi-technology, multi-band solution – really a neutral-host solution – it has features that let an IT manager treat it like another piece of IT infrastructure.

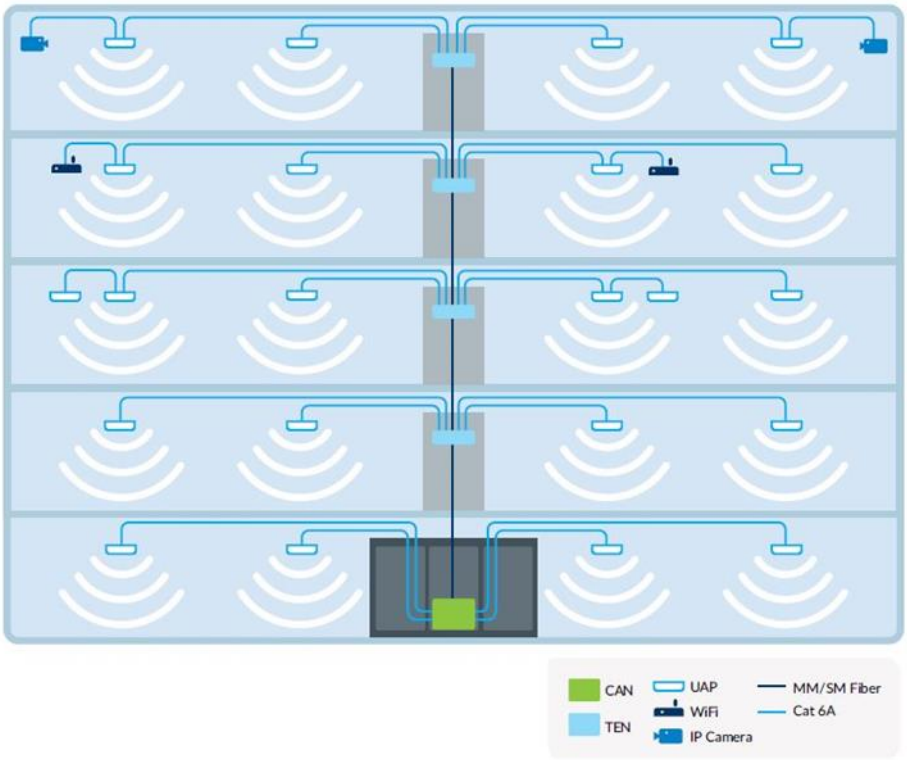
For example, you may have a compact headend with cards that are agnostic to the frequency, with auto-detection, very similar to a blade switch or a server – any IT piece of infrastructure. Then you have a universal access point that is like a DAS remote, but very flexible, in that it supports a wide range of frequencies.

Also, it's all digital. You have fronthaul that, instead of coax cabling, uses Cat cabling – Category 6A, for example – and remote powering, which also allows you to share the same cabling infrastructure to connect another IP device to the remote, like an IP camera, that also uses standard optical single-mode or multimode fiber. All of that with a very friendly software management tool.

It makes the DAS solution IT friendly, scaling it down economically, so enterprises can manage it almost the same way they manage Wi-Fi or another piece of IT equipment.

Also, we are working on small cells. "Small cells" is sometimes a broad term, because you have stand-alone small cells, networked small cells, DRS, C-RAN small cells. What we are working with is the next generation of small cells – what we call OneCell, a C-RAN small-cell solution.

Every stand-alone small cell is a mini base station, where you have the baseband unit, the radio, the antennas. They create small or discrete cells of coverage. The problem with this type of small cell, which was designed for houses or small offices, is that when you put a bunch of them together, it creates an overlap of borders.



CommScope's ION-E for the unified wireless infrastructure ***Source: CommScope***

In those borders, you have interference. You have bad throughput, bad voice quality, and even dropped calls. You can minimize that, of course, by careful design, by adjusting and controlling the power and the placement of the small cells, etc. But it's a process that you need to do carefully, and it's not always easy.

With C-RAN small cells, you can have a lot of them in a building space, but since all the processing from the radio points is coordinated by a baseband unit controller, a super cell of coverage is created that has no borders.

That eliminates the handovers and the interference, and that's great because it simplifies the RF design. At the same time, cell virtualization is enabled by cloud RAN: you can have a virtual sector of capacity inside that super cell without having any borders in it, because there is a tight coordination between the radio points and the users.

In addition, C-RAN small cells use structured cabling and PoE, making them even more friendly to the enterprise environment.

Monica: That's actually a lot of learning for enterprises to do, because they're used to Wi-Fi, and they need to deal with the complexity of a DAS even though they usually don't install it themselves.

Sometimes you hear the argument that if enterprises have Wi-Fi, why do they need any other wireless network? They can do voice on Wi-Fi. They can do data, video. Why do they need something else?

JP: That's a really good question. We don't believe Wi-Fi is the enemy here. We think unlicensed Wi-Fi and cellular technologies are going to coexist inside the buildings.

Both cellular and Wi-Fi technologies are well–established, with enormous user bases and a mature ecosystem. Everybody is talking about Gigabit LTE and 5G now, but also Wi-Fi has a strong roadmap for evolution, if you think about the recent 802.11ac Wave 2, and the future 802.11ax.

Wi-Fi is something that is going to coexist with other wireless technologies. Venues that are primary workplaces, particularly, will use Wi-Fi, in most cases to access data, but also as an extension of the corporate network and to access the internet.

Most venues are private, but they have visitors, guests, and patients, and some shared spaces. That's where the situation changes. LTE and cellular service are becoming truly more efficient to serve those spaces. Wi-Fi is not enough on its own.

Scenarios where you start having greater subscriber density in a location, or you need to support BYOD to serve different types of users and visitors, or even to support reliable voice connectivity, cellular services and LTE are much more efficient at handling those environments. Again, we believe they are going to coexist, and that the enterprise will need both for different use cases in buildings.

Monica: I guess that's also the trend in the industry: putting different radio access technologies together. It's not a question of fighting with each other, but what's the best way to integrate them, to get them to exist together.

Which raises another issue. The enterprise is getting more and more involved with wireless, but wireless is changing. How is the enterprise doing in terms of keeping up with the changes with Gigabit LTE, 5G? What does the enterprise need to do there?

JP: Because all those technologies are emerging and are going to take their place in the enterprise space, we believe enterprises should start considering wireless connectivity at the design phase of the building process, by considering the wireless connectivity earlier – not only Wi-Fi, but also DAS and small cells. If you think for a moment about wireless in the building, and you also think about the internet of things, there is a convergence there in terms of connectivity: the DAS, small cells and Wi-Fi, all using structured cabling, standard IT cabling, copper and fiber – particularly copper – with PoE to connect all those devices.

At the same time, other devices are using the same connectivity – security cameras, sensors, building automation systems and so on. The convergence in terms of connectivity is not only because of the bandwidth, but also because of power – how to power those devices inside the building.

As all that convergence is happening, enterprises can really save a lot of money and headaches in the future if they plan for mobility in the design phases – if they have a common architecture that includes all those technologies from the beginning.

Once you have that, then if you need other small cells in the future with different technologies – LAA, CBRS, or whatever – or you are going to scale the Wi-Fi networks, or you are going to bring in another type of devices, or another type of sensor for IoT, you will have an architecture that will answer to those changes in a flexible way, with minimal interruption to the office operations.

We have a design approach, called the universal connectivity grid (UCG), that helps with exactly that. It's based on the concept of zone cabling. Rather than a desk-centric approach and looking to support the connectivity needs in the ceiling, the UCG provides the capacity and flexibility needed inside buildings.

We believe these types of approaches are something that enterprises should consider from the beginning.

Monica: Especially if they have a greenfield network, so they can design it properly, and not be bound to legacy technologies.

Let me ask you a final question. What are you working on at CommScope right now? What's going to be ready, and what should we expect in the next five years?

JP: One of the things we are working on is the next generation of DAS and small cells. That's something we are putting a lot of effort into and we're very proud of.

The other thing we are doing is working to enable the ecosystem to better serve the enterprise. As I mentioned before, it's not only about the IT people inside the building, or the technology. It's also the ecosystem that feeds the enterprises. It's not only about the wireless carriers, but the consulting firms, the system integrators, the cable contractors, the distributors, the building owners. We are working really hard on that.

We are also looking closely at future technologies, like CBRS, LAA, MulteFire – all those technologies that we believe could have an impact on the enterprise world in the near term, or in the short to medium term. We are looking at those closely.

About CommScope

CommScope helps design, build and manage wired and wireless networks around the world. As a communications infrastructure leader, we shape the always-on networks of tomorrow. For more than 40 years, our global team of greater than 20,000 employees, innovators and technologists have empowered customers in all regions of the world to anticipate what's next and push the boundaries of what's possible.

About JP Compagnucci

Juan Pablo Compagnucci leads the enterprise in-building wireless market development initiative globally for CommScope. Previously, he served as solution architect for CommScope's Intelligent Buildings team in the Caribbean and Latin America region. Before that, he worked as a technical manager for CommScope in different countries within CALA. JP has 12 years of experience in the networking and telecommunications industry. Prior to joining CommScope, he worked as a wireless application engineer and RF consultant for two global wireless telecommunications vendors. He started his career as a professor of statistics and probability. JP holds a telecommunications engineering degree from the IUA Institute in Cordoba, Argentina.

Profile

Intel

The wireless enterprise plays a central role in Intel's strategy to accelerate 5G and to empower IoT through new products, support for the underlying ecosystem, and standardization efforts. Intel envisions 5G as a heterogeneous network, in which LTE, Wi-Fi, mmWave and NB-IoT will be integrated with the new 5G air interface, NR.

Intel's work on 5G covers the end-to-end network, including virtualization, security and IP networking. Of particular relevance to the enterprise is the focus on edge computing and IoT.

With edge computing, service providers can deploy services at the edge of networks, and keep both data and processing local to the enterprise – without having to transport all the data to the network's core. Intel's commitment is to increase the computing power, bandwidth and storage at the edge, and thus to lower the latency, improve QoE and strengthen security in enterprise services and applications.

IoT can play a crucial role in expanding wireless connectivity in the enterprise. To succeed at that, service providers and enterprises have to integrate multiple technologies, services and devices, and operate within a complex, diverse ecosystem of vendors and service providers. To get IoT off the ground, Intel is working on multiple trials with ecosystem partners such as Nokia, Ericsson, AT&T and Orange.

Intel's products to support wireless in the enterprise – and specifically 5G, IoT and edge computing – range from base stations, to vCPEs, to SD-WAN, to network appliances. Intel has recently announced engagements with NTT Docomo, Telia and China Mobile to accelerate 5G deployments.

Launched in 2016, Intel's 5G Mobile Trial Platform strengthened the development of 5G products and demonstrated interoperability among vendors.

In January 2017, Intel announced its 5G Modem to speed the development of 5G devices capable to support high throughput and low latency, using NR technology in a variety of bands, from sub-6 GHz to mmW. The modem supports low-latency frame structures, advanced channel coding, beamforming and massive MIMO, reaching speeds of more than 5 Gbps, according to the company. Intel expects to sample the modem by the end of 2017.

Complementing the 5G modem is the 5G RFIC, working in the 3.3 to 4.2 GHz and 20 GHz bands and supporting 50 MHz to 800 MHz transmission with 2x2 and 4x4 MIMO.

Support for edge computing comes from products such as:

- Intel® Ethernet Network Adapter XXV710, supporting 25 Gbps speeds.
- Intel Atom® processor C3000 product family, designed to strike a balance among cost, performance and power consumption.
- Networking Series for the Intel® Xeon® processor D-1500 product family, supporting rates up 40 Gbps.
- Intel QuickAssist Adapter family, supporting up to 100 Gbps of crypto, compression and public key acceleration.

Intel's view of the impact of 5G on society and the economy ***Source: Intel***

Intel

Embracing Wi-Fi, LTE and 5G – licensed and unlicensed – in the enterprise

A conversation with Asha Keddy, Vice President of Next Generation and Standards, Intel

Wireless is nothing new to the enterprise. The role of Wi-Fi has expanded: it has become the default technology, to the point that, in some companies, Ethernet outlets are difficult to find. Yet there is an increasing interest in wireless technologies such as LTE and 5G, in both licensed and unlicensed bands, that complement Wi-Fi in rolling out a wider range of services, including IoT.

In this conversation with Asha Keddy, VP at Intel, we talked about the evolving role of wireless in the enterprise, with the increased connectivity needs and adoption of IoT in parallel with a gradual transition to 5G.

Monica Paolini: Asha can you tell us what you do at Intel?

Asha Keddy: At Intel, I run a team that's called Next Generation and Standards. My main focus is to look at what's around the corner – for example, what is 5G: the standardization work and the trials that go along with it, and the business development among these new areas that enable new technologies, including 5G.

Monica: The enterprise has a strong interest in 5G. What is changing there as we move to 5G, and before that, with Gigabit LTE? What's changing in the enterprise from a technology point of view?

Asha: As you know, 5G is all the things we do to enable, as NGMN says, a fully connected, mobile, intelligent society.

I paused on each of these words, because when you talk about a society that's fully mobile, intelligent, and connected, what happens is that you need ambient compute, communications, and other things – all as a part of your business.

Whether it's my sister, who is a housewife, or an enterprise, or a small business, you need to be able to access this fully connected mobile society to be competitive.

By taking an interim view, in 5G in particular, we can start not only customizing the devices and the applications that the enterprise uses, but also, we can start looking at how the network works. How can we customize it into the mobile edge? What can we do?

For example, we have done some analysis, with our partners in research areas, which shows that you can customize things, where you can have content and applications cached on the mobile edge for that particular enterprise.

With caching, you can download things faster. You can have better customer service or better service within the enterprise, including B2B, because you are focusing on those particular applications.

Monica: There are multiple ways in which the enterprise is going to be affected. The first one that you pointed out is the flexibility. Can you talk about how we achieve the flexibility to meet the enterprise's flexibility requirements?

5G as a critical element of the new data economy *Source: Intel, Cisco VNI*

How is 5G going to help by moving content and applications to the edge, and having more flexibility, customizing the network?

Asha: Two ways. One of the things with 5G, as you know, is that it's about billions of connected devices. In a lot of these cases, the devices are talking to each other. We are moving away from where the majority of the connections are between the human and the computer, such as a PC or a phone.

The ITU has three different angles at which 5G is defined. One is the evolution of mobile broadband, which is something we know well, but how do we evolve it? For example, 8K videos, VR, entertainment, and all.

Another one is around ultra-high speed and low latency. For example, what can we do to enhance VR, remote surgery, autonomous driving, or even industrial automation in factories – things that require extremely high precision and low latency?

At the other extreme is the evolution of NarrowBand IoT towards massive, machine-type communications, around maybe an industrial factory, where a lot of processes are operated by sensors. How do you turn up and maintain all of these things together?

With 5G, you're not only designing a technology that is forward-compatible from an air interface point of view, but you also are conditioning the network, having it evolve to become a software-defined network, and having a mobile edge where you can cache, and network slicing, where you can differentiate types of traffic.

As an enterprise, I can say some types of traffic are much more important than other kinds of traffic because they are more important to the quality, or reliability, or such.

When you start taking into consideration the design of 5G, where you have these different use cases combined with data and with network virtualization, you can start customizing the solutions to your enterprise.

Even within an enterprise, you might have different kinds of use cases that have different latency and sensitivities, or a band of sensitivities.

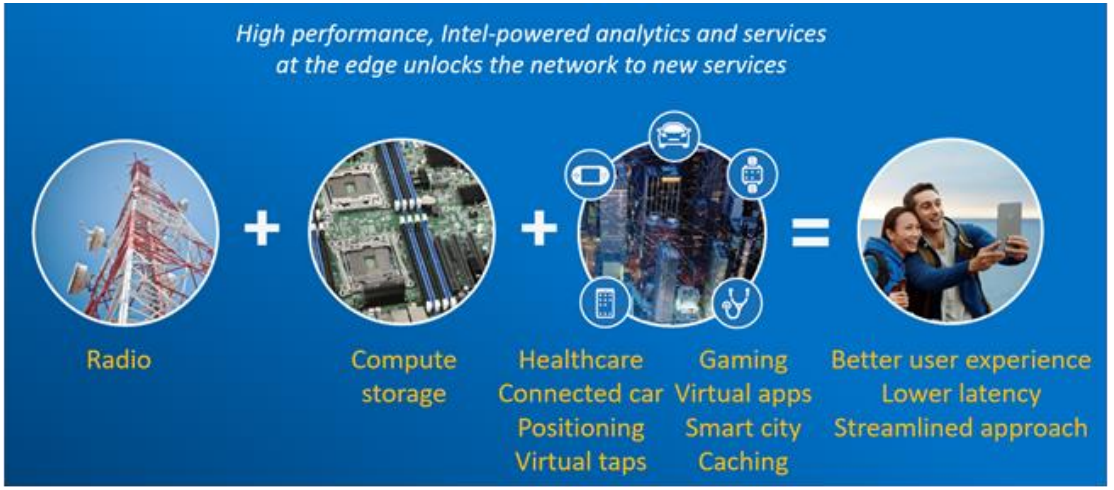
Monica: Let's talk about both edge computing and network slicing. Can you give us some examples of trials you've done or use cases you have seen where the enterprise benefits, or needs those technologies to develop some services they need?

Asha: I'll give you an example that we have been starting to model, and then how we can take it to the enterprise. One of the things we have focused on is autonomous driving. In autonomous driving, it's very important to differentiate, for example, if I'm going into a flooded area or if, like right now, we have a lot of wildfires here in Oregon.

I need something that goes beyond just autonomous driving, where a connected car can start helping me know what are some of the fire hazards or some of the flood plains, and some of the safety hazards ahead and around my route.

That kind of information can be critical to planning – and to not being stuck for hours on the road. We can differentiate that kind of traffic from, let's say, downloading the next Game of Thrones. We are starting to look at those sorts of things, especially in a mobile autonomous area.

Now, if you go to something that's more on the business edge, I can start looking at how much I'm paying for a particular kind of transaction, or the volume, and start customizing it.



5G extends the cloud to the mobile edge *Source: Intel*

For example, if I'm a small business, then I might be able to know what loyal customers do, and figure out, around a sale, how do I get those customers prioritized versus something that is more generic.

Monica: That's very interesting. Another thing there is a lot of talk about is the local breakout that edge computing allows. Do you see the enterprise being interested in that? What is the value the enterprise sees in that?

Asha: You bring up an interesting point. One of the things about edge computing is that, by moving the computing to the edge, you are taking a lot of information down from the cloud towards the consumer, or towards the enterprise in this case.

That allows for a few things. You get faster turnaround time because it is all at the edge. You don't have to take it all the way. You also can customize which data goes to the cloud. There may be some privacy, some sensitivity issues.

In addition to being able to handle the data at the edge as we look at the conversions, you can start adding things that are particular to your enterprise. For example, if you are doing a venue-based service at a stadium, once there's a touchdown you can have it cached at the edge, because you know that after every touchdown, there'll be a lot of people downloading.

There's also the inverse happening. We see a big uptick on uplink communication, not just downlink. You can have all of these different models where, based on the uplink, you can route it to a different part of the enterprise or the branch, based on the decisions and the calculations you do at the edge.

Monica: This attests to the fact that the requirements of the enterprise, and venues as well, have become stricter. As you move to 5G, the network is going to be more powerful, but also the requirements are going to be more stringent.

It used to be that the enterprise mostly needed some basic coverage. Now, coverage is still essential, but it's not enough. You also need capacity and low latency. Can you say something about how these requirements are evolving in the enterprise?

Asha: In the enterprise, you're talking about coverage capacity. When we talk about network slicing, we talk about quality of service. Right now, where we are headed is a world where every enterprise has to have an online component. It is the way of doing business.

We are working to increase the amount of spectrum available. When you have different kinds of spectrum – unlicensed and licensed, and even hybrid models – you are enabling different ways for the enterprise to have access to it. Essentially, we're building more highways and different kinds of highways, if you will. That's one aspect.

Another aspect is capacity. This is changing with higher-order spectrum. In the older days, the base stations used to be out in the field, they used to be waterproof. Now we are flattening the network. A lot of it is more general-purpose. We are reducing the capex, where you can use more off-the-shelf Xeon processors, for example, to do the computing. You're separating the radio heads from the software network. We have all these new concepts, like small cells.

Density is becoming crucial. A lot of the data consumption comes from places such as stadiums, enterprises and homes. In all of these areas, we can use small cells that are very low-cost, but their density can be extremely high.

When this is combined with the flattening of the network, with a network architecture where the data may go directly between devices or go to the mobile edge and the devices, versus all the way to the cloud and back, you have a way of increasing capacity. At the edge, the capacity is going to be much higher than at the core.

Monica: This triggers another change, which is towards moving a lot of the infrastructure indoors, where most of the users are. Isn't this a different way to build the infrastructure and virtualize it?

Asha: Yes. Actually, you hit on a very good point. Most of the traffic consumption is indoors. I talked a little bit about licensed and unlicensed. As you know, there's quite a bit of footprint on Wi-Fi. Then there are also efforts such as Licensed-Assisted Access, LAA, and all that the LTE community is doing in 3GPP that will evolve into other assisted forms in 5G.

When you have so much indoors, it also provides for applications that are more controlled, where you can have a combination of licensed technologies and unlicensed technologies.

This is the case with mission-critical data. For example, in factory automation, I could use licensed technologies that are more reliable for mission-critical operations, whereas I can have some unlicensed areas to augment that for data inventory or spreadsheets – applications that may

not be as mission-critical from a latency point of view.

Monica: You mentioned Wi-Fi. It's a very interesting and hot topic as well, because as we move to 5G, Wi-Fi is also evolving to meet basically the same requirements.

You hear two arguments at the same time. Some argue that since you have Wi-Fi, you don't need much else, because Wi-Fi meets all the requirements. Others say that once you have 5G, you're not going to need Wi-Fi anymore. What's your view on that?

Asha: The truth is in the middle, and it depends on the applications. My view is that both will coexist. Here is why. At the end of the day, most of the traffic today is over Wi-Fi – the data traffic. It's entrenched.

When you go to a hotel or when you go home, you have Wi-Fi. It's very difficult to displace an entrenched ecosystem. It has a lot of users, especially consumers – cameras, for example; we all connect our devices on Wi-Fi.

On the other hand, in a cellular-based network, there tends to be a quality of service, a reliability, that you do not have from unlicensed spectrum. And the licensed spectrum is starting to offload into unlicensed areas.

For example, as I mentioned, you have Licensed-Assisted Access, but both LTE and Wi-Fi continue to increase. We don't have enough spectrum for LTE, so we are doing 5G. With the evolution of Wi-Fi into 802.11ax, we will have more Wi-Fi installs, more Wi-Fi deployments.

Enterprises are going to have to look at how much do they want to use unlicensed spectrum, and at whether they want to manage it, or do they want to work with the service providers, such as AT&T or Verizon in the US? How do they get their services from them, and how do they offload to unlicensed?

I truly believe there is room for both, and depending on the use cases, you will be predominantly focusing on one or the other.

Monica: What about using LAA, and then eventually 5G, for unlicensed? You can have cellular technologies in unlicensed bands.

Asha: Correct. LAA has started it. Unlicensed in LAA follows the same coexistence protocol as Wi-Fi, which is listen-before-talk. What happens is that LAA enables entities that use LTE to have access to the unlicensed area.

With MulteFire, you use unlicensed spectrum without an anchor in LTE. The whole MulteFire technology is completely unlicensed. To answer your question, I think that there will be growth in these areas, but Wi-Fi has an entrenched ecosystem.

The real question becomes, if you look at MulteFire and its evolution, how much that will take off, compared to the two ecosystems that already exist – Wi-Fi with its own evolution, and LAA anchored in licensed LTE and operated by a service provider.

Where does the enterprise get service from? If it gets it from an operator, it tends to have an access-control plane that is anchored in licensed, with unlicensed for augmentation.

Monica: In the enterprise, there's a lot of interest now in CBRS in the 3.5 GHz band in the US. What do you think about CBRS? Is it attractive to the enterprise?

Asha: Time will tell. It's quite a large amount of spectrum, 150 MHz. Right now, we have this three-tiered system in the US. If it works out, it provides an alternative area where we have a hybrid mechanism working towards solving spectrum availability problems. As of today, the utilization of spectrum has not been completely fulfilled.

As with any new technology, including LAA, or even if you look at the history of Wi-Fi, it took a long time for it to evolve. We are still in the early days of CBRS.

Remember, back in the day, traditional service providers used to dismiss Wi-Fi as they saw no need for unlicensed. Then when they ran out of spectrum, they had to do something, so now they're very much in the middle of unlicensed.

As we start overcoming these barriers, we have to get over the notion of not sharing spectrum, and then start to utilize it. It's a question of time and the use cases that will drive it.

Monica: Depending on who is providing the solution, you might use different technologies. And this is tied to how the relationship between the enterprise and mobile operators is evolving.

So far, it has been a difficult relationship, but now, finally, both ends are more willing to work with each other.

Asha: You said it very nicely. The real question is, why is it difficult? While you say enterprise, if you look at 5G, you really are talking beyond phones and tablets. We're talking about whether it's CPEs, or cars, or factories and automation.

The reason for the difficult relationship is that it's two worlds that may not have fully lived on each other's side. It's a question of control. If you look at LTE, we had so many different variants, including Cat-1, Cat-0, Cat-M. There are a lot of paths to getting into the right ballpark for IoT kinds of devices.

The reason for the two ecosystems to start to figure out solutions is for both to understand each other. The ones that will eventually win are the ones that know how to transform into services.

The more that traditional cellular service providers understand how to transform from a voice center, to a data center, to a services-oriented company that is more affordable, and how to solve the needs of the enterprise, the faster that coalition will happen.

But many enterprises don't want to have to rely on a traditional service provider, and its fees, all that. It's a transformation that needs to solve the pain points of the enterprise. And that's what drives the enterprise to look at solutions that are more in unlicensed or other areas.

Monica: Who is going to pay for the infrastructure? The enterprise is used to pay for the Wi-Fi infrastructure. Will it also pay for the indoor mobile network? Or will the mobile operators pay for it?

Asha: Both, or there could even be a third option. Let me give an example. One of my favorite quotes is that technology is predictable, human behavior is not. If you look at every evolution, five, six years into the middle of it we completely changed what we built it for.

3G was built to replace 2G and voice, but then when smartphones came out, it completely changed what we did, and "There's an app for that" happened. In 4G, there was this whole thing that was built ahead of its time, called IMS. We don't use much of IMS, because the OTT guys took over when we unleashed those capabilities.

Even 10 years ago, I didn't think that we would be having a conversation where Airbnb or Uber would be a part of it and some of the biggest providers in their categories. We thought that taxi unions would be there for another thousand years.

This evolution happened quickly, and cost as a motivation is an interesting thing. For example, if I have a very high density of cars, and cars go electrical, why wouldn't I, for example, have an electricity provider lease some of these – just like you can look at spectrum leasing?

It could be the mobile operator that provides the service in some certain geos. It could be the consumer of the service, because they don't want to share it. Or, there could be a third one, especially depending on how much we get regulated.

For instance, an electricity provider can build small cells on the bridges that they have and lease them to a service provider, or they can work with a car manufacturer on car leasing.

Monica: It's difficult to predict, because some might work in some areas, but not in others, or some environments.

Asha: And different countries.

Monica: We've only briefly touched upon security so far. Security has always been an issue, but it becomes crucial when wireless communications become mission critical in the enterprise.

How does the enterprise deal with the security issues that are, to some extent, new to them? When you get more networks, more interfaces and more services, managing security becomes more complex.

Asha: Security will become the core of what enables things. It's at multiple levels. There's hardware security, there's security in the policies we use, what data we can transmit. Related to security, and as important, is privacy. The two go hand in hand.

This is a problem that has to be solved at multiple levels. It has to be solved by the enterprise knowing what risks it wants to take, by the service provider knowing how to protect the data, having the controls in place to make sure that maybe the data doesn't leave the enterprise, if that's one of the policy requirements they have.

We can do something such as metadata that protects the individual user.

From an Intel point of view, we have invested in security solutions with our McAfee acquisition. We also look at our hardware platforms and software platforms and enabling hooks around security that we continue to evolve.

As security becomes more important, we as enterprise users or enterprise owners will have to start paying for it. Once we pay for it, we can tune to the desired degrees of freedom. We have to solve it like an onion – in many different layers.

About Intel

Intel (NASDAQ: INTC) expands the boundaries of technology to make the most amazing experiences possible. As the leader in the PC industry, Intel is powering the majority of the world's data centers, connecting hundreds of millions of mobile and Internet of Things (IoT) devices, and helping to secure and protect enterprise and government IT systems. Our manufacturing advantage—fueled by our pursuit of Moore's Law—lets us continuously push the limits of performance and functionality and expand what experiences can be made possible. Intel has a growing portfolio of products and technologies that deliver solutions to help communication service providers transform their networks, bringing advanced performance and intelligence from the core of the data center to the network edge. Intel's commitment to network transformation is long and deep – with years invested in delivering reference architectures, growing a strong ecosystem, and partnering with end-users. We are also deeply committed to 5G which represents the true convergence of computing and communications. 5G is a fundamental shift for the industry where networks will transform to become faster, smarter, and more efficient to realize the potential for the IoT and mobility, enabling richer experiences throughout daily life – augmented reality, smart cities, telemedicine, and more. Information about Intel and the work of its more than 100,000 employees can be found at newsroom.intel.com and intel.com

About Asha Keddy

Asha R. Keddy is Vice President in the Client and Internet of Things Businesses and Systems Architecture Group and General Manager of Next Generation and Standards at Intel Corporation. Ms. Keddy has more than 20 years' experience leading and managing wireless and mobile broadband areas and holds multiple patents. She is responsible for investigating and delivering the technologies, business use cases, collaborations and trials that will usher in the era of 5G wireless connectivity as well as broadly fostering innovation in mobile communications and ecosystem intelligence for future products. Ms. Keddy is also responsible for wireless standards at Intel, including 3GPP and IEEE. The organization's focus areas include prototyping, standards, ecosystem development and incubation of the advanced technologies and use cases towards new products and business growth. Ms. Keddy travels extensively for ecosystem partnership engagements as well as for speakerships on topics related to 5G development and the path to deployment, and diversity especially in the high-tech workforce. She believes in the importance of fostering diversity and inclusion in engineering, and mentors individuals as part of the effort to reach the ambitious goal of full representation of women and underrepresented minorities in the U.S. workforce by 2020.

Profile

Nextivity

Founded in 2006 and headquartered in San Diego, Nextivity provides cellular coverage solutions under the Cel-Fi brand to mobile operators and enterprises worldwide. They cover indoor environments, and both fixed and mobile use cases.

Cel-Fi products use a proprietary, application-specific integrated circuit that optimizes the distribution of cellular signal in indoor environments – from mobile and residential to enterprise – that experience poor cellular coverage.

Nextivity products include:

- Cel-Fi GO M for mobile use cases, including trucks and other vehicles, fleet management, RVs, and boats/marinas. The system supports multiple users and multi-carrier access.
- Cel-Fi PRIME is a cellular coverage solution for dense urban residential and small-business buildings, with a coverage range of 1 to 2 rooms.
- Cel-Fi PRO and DUO offer a larger footprint than PRIME, and are ideally suited for homes and small business. They provide coverage up to 15,000 sq ft.
- Cel-Fi GO X is ideal for industrial and remote environments, or any building or structure that lacks an indoor signal. It offers 15,000 sq. ft. of in-building coverage.

Cel-Fi QUATRA is the product that specifically targets the enterprise, where it can cover middleprise verticals such as healthcare, hospitality, commercial enterprise, real estate, transportation, and industrial. It is an active DAS hybrid that is self-organizing and self-optimizing. QUATRA uses Ethernet to transmit the RF signal, and PoE for power.

According to Nextivity, QUATRA is highly optimized and faster to deploy than traditional DAS, and has less stringent network planning requirements.

Cel-Fi QUATRA can be deployed as a stand-alone system (off-air configuration) to improve in-building coverage, or tethered to small cells to increase capacity as well as improve coverage.

When deployed in conjunction with small cells, Cel-Fi QUATRA creates a Supercell™, in which one small cell can be connected to multiple QUATRA coverage units (CUs) to extend the capacity provided by the small cell uniformly throughout the venue. The Supercell behaves as a single cell, so there is no need for handoffs as users move from one area to the next within the same Supercell.

Enterprises have the option to initially deploy Cel-Fi QUATRA off-air to get indoor coverage and then add small cells and/or additional QUATRA systems to incrementally increase capacity and coverage as the enterprise grows. This provides flexibility, and enables enterprises to spread out the CAPEX over time.

Nextivity's Cel-Fi product line by market segment *Source: Nextivity*

Nextivity

A hybrid approach to IBW, beyond DAS and small cells

A conversation with Werner Sievers, CEO, Nextivity

Most enterprise wireless infrastructure is indoors – offices, warehouses, factories, retail outlets. The big venues are mostly covered, and they are often celebrated as models of the success of IBW. The biggest challenge for IBW today is in the middle-sized enterprise – also referred to as the middleprise. I talked to Werner Sievers, CEO at Nextivity, about how Nextivity strives to meet the requirements of the middleprise and of the operators trying to serve it.

Monica Paolini: Werner, could you give us an introduction to what Nextivity does for the wireless enterprise?

Werner Sievers: Nextivity has obsessed about in-building wireless coverage, technology, and solutions for the past 10 years. We're into our fourth generation of product. That product ships worldwide to at least 200 operators, to thousands of enterprises, and in some instances, for large numbers of carrier-subscriber residential applications.

Our technology is primarily used to resolve the challenges associated with the degradation of signals as they penetrate from the outside macro network into a building, or, if there is an in-building signal source, how we propagate those signals uniformly in-building throughout the venue.

Monica: Indoor coverage has been around for a long time, especially in Asia, but only recently it has become a hot topic. To date, the coverage is mostly focused on big venues, but most of the buildings in the US and the rest of the world are middle size. Those have been more difficult to penetrate.

Can you tell us what the specific needs are of what we've started calling the middleprise?

Werner: Everything ultimately turns towards cost. As you point out, the bulk of the opportunities, the bulk of the venues nowadays are all in the middleprise.

The middleprise has a reasonably broad definition. It's anywhere from 15,000 sq ft to 500,000 sq ft. It's a large footprint, but it's significantly smaller than the classic large venues where, historically, networks have been installed by and on behalf of operators.

In the middleprise, there are a number of classic challenges. Those relate to the number of systems and the number of venues being installed. For example, there are fewer large-size venues than mid-size venues, so the frequency of installs is obviously significantly less. And while the complexity of large buildings is great, the frequency of installs is lower.

As we move into the middleprise, however, the challenge is, how do you muster a skilled workforce that can go out and successfully install many, many, many in-building solutions? To do that, a number of benchmark challenges need to be met.

Of course, historically, all the big venues are multimillion-dollar contracts and deals. As one moves into the middleprise, that range of cost spreads from tens of thousands of dollars to perhaps a few hundred thousand dollars.

In that circumstance, the caliber of technology needs to be intelligent, smart, and capable of doing the challenging task that's associated with the venue, but it needs to do that at a per-square-foot cost that makes it possible for the venue to shoulder that expense.

Historically, the cost of this technology has been way too high for the middleprise. What we've done at Nextivity is bring a class of technology that has only been seen in big venues down to the middleprise. Also, if you refer to the model today for in-building wireless installs – in other words, high-frequency building installs – these are all being done by skilled system integrators or installers.

For the integrators and installers to produce or turn over these installs at a high rate, they need to be able to draw on a different skill base – perhaps a skill base that isn't specific to radio frequency technologies – from the larger pool that encompasses the low-voltage community and the IT community. A technology that's able to optimize the rate of large numbers of installs by skilled installers is obviously a significant advantage.

In terms of technology, we've elected to use non-coaxial cable or fiber cable. There are levels of complexity and cost associated with those. We've

elected to use Cat 5 Ethernet. Over time, that enables the IT skill base to grow into this big middleprise opportunity for in-building wireless installs that we can see burgeoning right now. This year and the next few years present significant opportunity for in-building wireless in the middleprise.

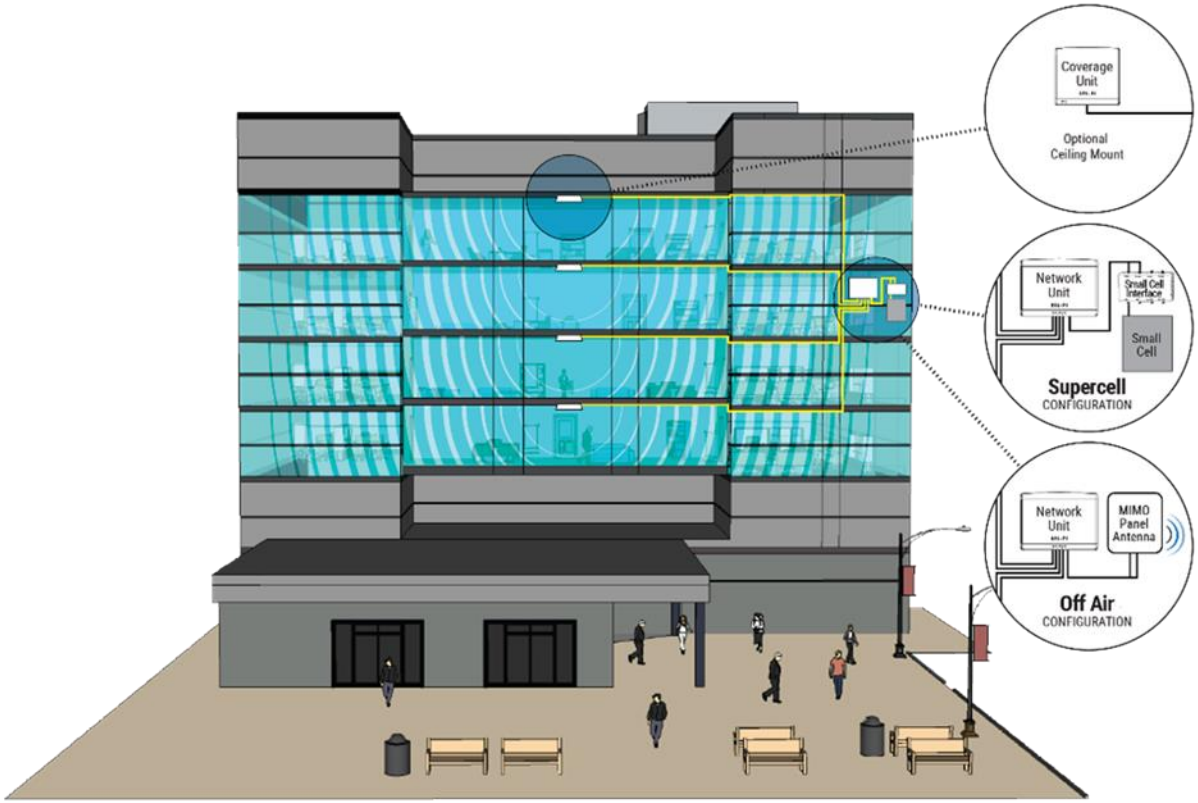
Monica: With the emergence of new solutions, what are the options for the middleprise? Wi-Fi has been deployed widely. What else is available?

Werner: In wireless, there's never exclusivity. It's always a companionship. There isn't yet one class of technology that absolutely does everything to the exclusion of other classes.

There is now a higher rate of adoption of cellular technologies outside of the classic business model of the operators (i.e., mobile phones). Plus, with the IoT sensor community and related devices, and with machine-to-machine applications, we see all of that unfold with greater and greater dependency on cellular. It's evident that cellular most likely won't unseat Wi-Fi in any way, but it is the dominant player for the future.

Cellular becomes the big deal. How to propagate cellular in the most cost-effective, high-performance, intelligent manner is the challenge.

What are the options in cellular? There's a class of technologies referred to as smart boosting technologies. There's a class of technologies called passive DAS, or distributed antenna systems. Then there's a class of technologies called active DAS, which is a more digitized, intelligent version of a DAS. Of course, then the capacity partner to those three technologies is small cells.



Nextivity's QUATRA Supercell topology

Source: Nextivity

We've elected to put ourselves outside of these technologies and introduce a new, hybrid solution that combines all the benefits of smart boosting technology and active DAS technology.

Monica: How does this hybrid solution relate to both active and passive DAS, and how is it different from them?

Werner: Let's start with passive DAS. Passive DAS is a coaxial architecture that has a head end, and then it has passive antennas spread throughout the venue. It takes a lot of cabling, a lot of engineering. It's all coaxial and it's very static, in a sense. It doesn't have the intelligence to adapt to the environment. It's seen more as a legacy technology. It's being unseated over time by a class of more intelligent systems.

Active DAS is a highly digitized system which encompasses both coaxial cable and fiber. It's very costly upfront, and heavily burdened by its ability to scale to a very large venue size.

A passive DAS has certain limitations in terms of its ability to scale, largely because of the significant signal loss that takes place over the coaxial cable as it is split multiple times into different directions in the venue. Every time it is split down farther and

farther away from the head end, there's a significant amount of signal loss.

There is no question that the active DAS is the preferred route to go. However, it is overburdened with a high degree of upfront planning, certainly at very high costs, and in some instances, even a high cost of ownership or maintenance.

Cel-Fi QUATRA – our product – is a hybrid that's taken 10 years' worth of smart-boosting experience that we've evolved and developed, and that we coupled with an intelligent antenna system.

We have an intelligent head end in QUATRA, and our remote antenna units are all super intelligent. They have the ability to sense around themselves, to be self-organizing. They're not limited by the same degradation or loss of signal over greater lengths.

As a result, you're able to build a very dynamic and very flexible infrastructure that can serve virtually any kind of building construction, in terms of structure and construction material as well as the architectural layout of a building.

Some buildings are much more difficult to solve with less cable or shorter cable runs. Some are far more complicated to serve, and you're forced to go to much longer cable runs.

With a highly digitized system like ours, which isn't subject to these great signal losses, we provide a very flexible, pragmatic and affordable solution that delivers all the functionality one would like to see from an active DAS system.

Monica: How does Cel-Fi QUATRA compare to small cells?

Werner: That's probably the most important question. A small cell's responsibility in a venue is to add capacity. It contributes to a venue that is deprived of capacity.

How might that occur? The macro signal serving that venue at that point in time might be over-tasked by an excessive number of devices in that particular venue. The type of data that's being transmitted or communicated from these devices has put a significant bandwidth limitation on the macro network.

When that happens – and of course, there are installers, there are confident people who can make that determination – what one then wants to do is have a signal source that emanates from inside the building, instead of trying to use the macro network, which needs to enter the building from the outside.

As you can appreciate, when you're coming from the outside in, there are all these losses that get created by the building material, whereas if you're emanating from inside the building, you still have loss, but you don't have the same extent of loss.

The small cell becomes, for QUATRA, the ideal partner. We like to build what are called Supercells™. These Supercells are created when you bring in an enterprise-grade small cell via DSL line or through some communal ISP pipe into the building, and we marry this small cell with our QUATRA system.

This enables us to take the capacity that the small cell now provides and uniformly distribute that throughout the building so that, literally, one is able to cover every nook and cranny in the building.

QUATRA makes its biggest contribution when there's capacity deficiency – but I should add that there are many, many off-air installs. In fact, the majority of installs done today for in-building wireless are most definitely off-air installs.

The demand for data, particularly over cellular, has increased – as opposed to voice. We all know operators face a challenge nowadays, inasmuch as the ARPU has declined, the voice usage has flattened off, while the data increase is significant.

We're expecting that there will be an 8 to 10 times greater data burden placed on cellular networks over the next decade. That causes a conflict: how does the operator draw revenues by relying on voice? It's not a plan that has any future.

When a lot of the in-building IoT and other sensor-type devices first came out, they were only Bluetooth or Wi-Fi. Many of them are now migrating to cellular technologies. In that instance, you elevate even to a greater extent the amount of data that's being communicated.

In those data contexts, versus the purely voice context, all of a sudden, the capacity immediately comes into question. It is important to determine whether there is a capacity and a coverage deficiency, or whether you're just facing a coverage deficiency.

Monica: As we try to address both the capacity and coverage challenges, it seems like you're introducing an entirely new and different concept of what a cell is. Traditionally, you have a discrete

set of cells. Each one is tied to an antenna. But in your system, you appear to have a cloud of coverage, where it is no longer single cells – well, it is a Supercell. This is not the traditional concept of a small cell.

Werner: Exactly, and there's really a good reason for doing that. It's not as though we woke up one day and felt that that would be the way to do it. Obviously, interference still is a primary consideration in in-building wireless. Very definitely, inside of the building, lots of issues and circumstances contribute to an ideal, interference-free environment.

One of the challenges associated with, say, putting three small cells into a single venue is that it's difficult for an installer to identify the interference considerations that three overlapping small cells might create.

The model that carriers universally, over time, will want to adopt is one that's self-serve, self-help, self-install – where someone in the IT department requests a small cell from the carrier, and the small cell is delivered to the subscriber's premises. Together with the support people from the carrier, the IT person would deploy that small cell.

The challenge is if you do that three times over. You need to be able to locate the small cells so that not only do they not interfere with one another, you situate them optimally from a distribution-of-coverage point of view. And at the same time, you try and conform to the enterprise's requirement to have critical assets like small cells and QUATRA systems in a secure environment.

If you're aiming to put a small cell in a secure environment and have it positioned in such an optimal manner that the fewest number of small cells are needed to entirely cover a building, there are a number of challenges. Ultimately interference among small cells creeps in.

When you have a single small cell that is supersized – in other words, we create a Supercell – our remote units simply go into the outlying areas of the venue and ensure that we're taking that single small cell's capacity and making it available to every nook and cranny in the building, and there is no risk whatsoever of any interference.

The great thing about that is that the amount of planning it takes, the amount of energy it takes, the amount of time it takes to do a quality install are all greatly reduced.

The benefit is that the installer community, who are now under pressure to roll out far higher numbers of these installs, are greatly advantaged. We empower them to take on more of these installation jobs, and therefore meet the densification challenge, or at least get close to meeting the densification challenge that now all carriers, all enterprises, all businesses face.

Monica: You raised an important issue, which is not really a technology issue. It's a deployment issue that I hear all the time from operators: in order to keep the costs down, you need to be able to install any infrastructure very quickly, without relying on RF engineers.

It's a question of time, cost, and also, people's skills. The middleprise is potentially a huge market: most buildings are in the middleprise category. Are you helping operators in the enterprise to meet their costs, and to do the installations on time, despite the limited availability of RF engineers?

Werner: Absolutely. I would venture to say that we're at the forefront of doing exactly that.

We all know there are limitations to our communal ability to deploy many, many, many capacity points – in other words, outdoor and indoor small cells.

At Nextivity, we focus specifically on indoor –that's our business, that's our game. It's a trying circumstance to get all these buildings planned and executed. The number of experienced installers in North America today is far below what is required to meet the densification challenge, take advantage of it, and roll it out.

The reality is that by enabling a new skill set or skill pool to draw from – those skilled IT people within the enterprise environment – the challenge becomes more tenable. As the operator relies on the self-installed small-cell model, you can see how immediately and automatically the IT team is involved.

If you're an installer and you require additional resources, the best place to draw from would be the IT environment. This way you empower people from the IT community and encourage them to step up.

Monica: What are the advantages of using Ethernet in QUATRA?

Werner: QUATRA is structured as an Ethernet-based system, powered over Ethernet and with no remote power consideration. If we want to site our remote radio heads or our remote units, we

can do so. The primary driver to that is an optimized location so we can achieve the best coverage. We don't need to make a determination about whether there's a power outlet close by. We can install it in the ceiling. We can install it on the wall. We can drop it down an elevator shaft.

There are many things we can do creatively to ensure that this particular remote unit is being optimized purely for coverage purposes and not for any other considerations like power.

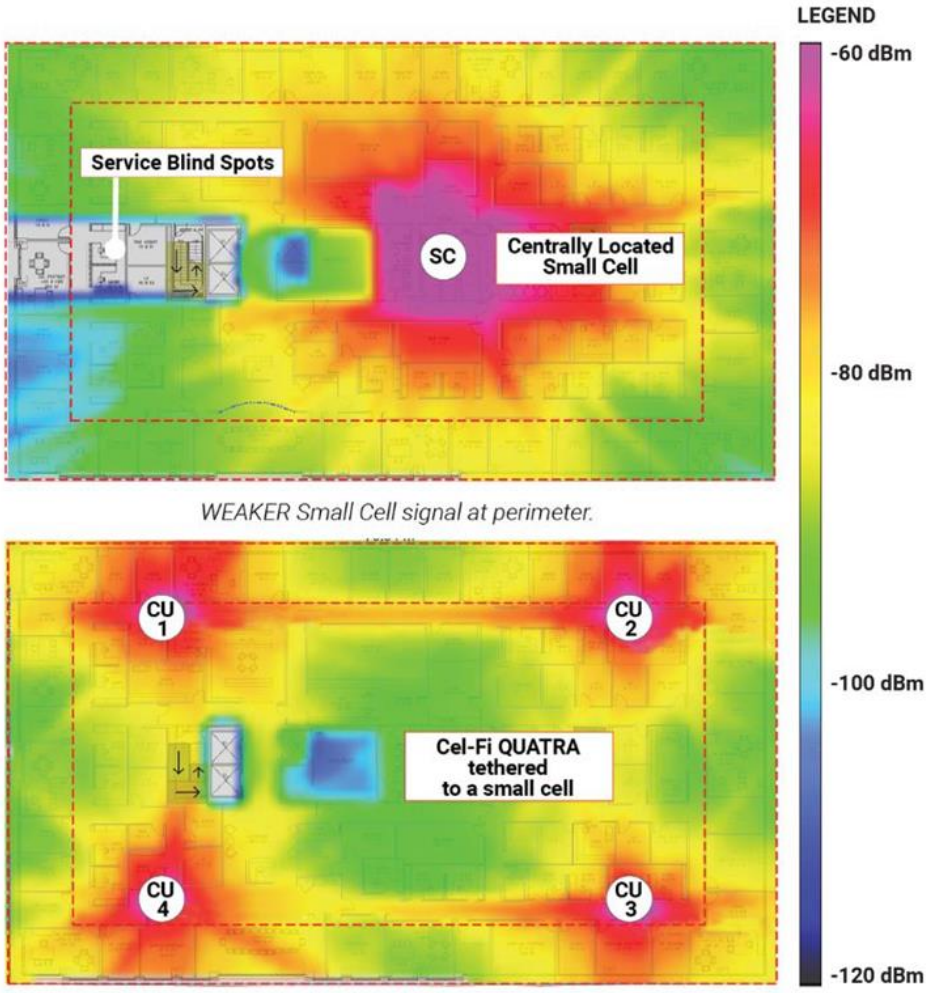
Merely by using Ethernet, we're aligning much better with the IT environment or resource pool than if we were, for example, using purely coax or fiber.

That's one of the circumstances we bring to bear that really enables this deployment to be more – I don't want to say rapid, because in some instances, it's not necessarily rapid – but it's highly optimized, compared to what it used to be. This high level of optimization simply enables installers to do more jobs in any one period of time than they could before.

Of course, that's really what QUATRA is aimed at. It's aimed at scaling the ability of our installer community to do higher-volume installs as opposed to fewer, very-large-venue installs, which really don't exist today anymore.

Monica: How do enterprises manage a QUATRA system?

Werner: We have a number of tools that are IT-like in many ways. They enable somebody who is familiar with the UIs that are readily available within the IT tool set – the IT management systems – to drive the planning of our product, sizing our products very pragmatically and with a low intensity in terms of skill set.



Top: The small cell placed by itself in the center of the building is overpowered by the macro signal at the building perimeter.
Bottom: When Cel-Fi QUATRA is tethered to the small cell, there is uniform distribution of the small cell capacity right to the building perimeter and to all the nooks and crannies where construction obstacles may block the signal.
Source: Nextivity

Essentially, we can plan bills of material. We don't have to use all the costly, legacy-based planning tools. We can use a new generation of planning mechanisms and tools to plan a venue, and then

also execute the install pragmatically from a central location once the remote radio heads or units have been installed.

Then, of course, the added significant benefit is if you compare this to a passive DAS system, which – being static – becomes a real problem. If anything changes with the carrier's network, it's reflected immediately inside of a passive system as interference signal quality or customer experience consideration.

With QUATRA, because it's completely dynamic, it will shift and move with network change. It's completely self-organizing.

And it enables maintenance to be conducted or carried out from a remote venue. The installers don't always have to roll a truck to a venue because there's, perhaps, an antenna head or a remote spot in a building that suddenly is deficient in terms of coverage that, a few days prior, was doing fine.

Those coordination issues, those coordinated circumstances, are what align us really well with an installer base that now is growing and pulling in a skill base that is IT oriented. That said, of course, the bulk of the installs today still get done by those with RF skills.

Monica: What should we expect to hear from you over the next five years? What is it you're working on right now?

Werner: You did a marvelous paper, I must say, on the Citizens Broadband Radio Service. CBRS and bands and technologies that enable private LTE networks are going to become really important. We want to make sure our infrastructure can support the evolution of this private LTE infrastructure.

We're highly motivated by LTE. Our engineering team, our whole being, has grown from the GSM base, all the way through GPRS and wideband CDMA and HSDPA, all the way up through LTE, LTE Advanced. It's a technology path that we followed, that we're intimate with.

We will continue to build technologies that support the leveraging of LTE, whether it be private or public. Also, of course, we are looking at how a platform like QUATRA can provide ideal flexibility for the middleprise and how that serves IoT.

How best does an infrastructure like ours rise to the challenge of the IoT? Of course, in that sense, the route we will follow will most definitely be narrowband IoT and Cat M – Cat M for the higher-speed applications, higher-bandwidth applications, and narrowband IoT for the lowest speed.

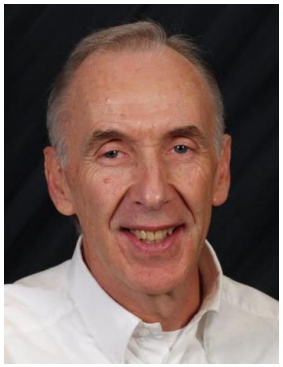
Simply integrating those technologies into our current platform, as well as looking at some of the TDD technologies that have become very relevant in Asia and other areas (and that to a slightly lesser extent are relevant in the United States), provides advantages for data-carrying capacity.

Looking at TDD, looking at IoT, and considering what the world is going to look like with private LTE networks is really where we are focused.

About Nextivity

Headquartered in San Diego, Nextivity Inc. develops the multi award-winning Cel-Fi family of cellular products for delivering best-in-class in-building wireless coverage solutions for diverse venues within the healthcare, hospitality, commercial enterprise, real estate, transportation, and industrial verticals. Authorized for use by more than 200 leading global mobile network operators in 98 countries, Cel-Fi products leverage advanced signal processing and intelligent antenna design to create highly optimized, self-configuring, and environmentally aware indoor coverage solutions.

About Werner Sievers



Werner Sievers, President and Chief Executive Officer of Nextivity, is a wireless industry expert and experienced leader of technology-centric, venture-backed start-ups. Werner is a serial entrepreneur who has consistently delivered returns to investors and employees across a series of international communications, semiconductor, and wireless companies. He previously headed Broadcom's Broadband Cellular Group, following his successful sale of Zyray Wireless, Inc. to Broadcom in 2004. Prior to Zyray, Werner served as CEO of Centera Ltd. He was also the Founder and CEO of Dimension Data Ltd., a company acquired by NTT DoCoMo. He holds a bachelor's degree from the University of Johannesburg.

Profile

SOLiD

SOLiD offers both outdoor and indoor DAS installations that target a wide range of locations, from large venues with high capacity-density requirements, to slightly smaller commercial buildings – which SOLiD calls the middleprise. In the past, middleprise venues have been challenging for DAS deployments because of the complexity and cost of traditional DAS. SOLiD's goal is to change this and make DAS attractive to smaller venues as well as to large ones.

The ALLIANCE Multi-Carrier DAS platform is SOLiD's flagship DAS solution. It supports neutral-host deployment models, and works in frequencies ranging from 150 MHz to 3 GHz. Remote units are available at different power levels, each suited to a different venue and topology. Lower-power ROUs are well-suited for smaller venues and public safety networks. Higher-power ROUs are most commonly deployed outdoors or in venues with high traffic loads. The ALLIANCE platform also includes:

- The ALLIANCE eBIU, the headend that filters traffic to the base stations.
- The ALLIANCE DMS, used to manage the DAS.
- The ALLIANCE OEU, an optical multiplexing device to expand coverage to additional buildings.

SOLiD also offers the EXPRESS Single-Carrier DAS, a multi-band solution for a single operator, and EXPRESS Public-Safety DAS for the public safety market.

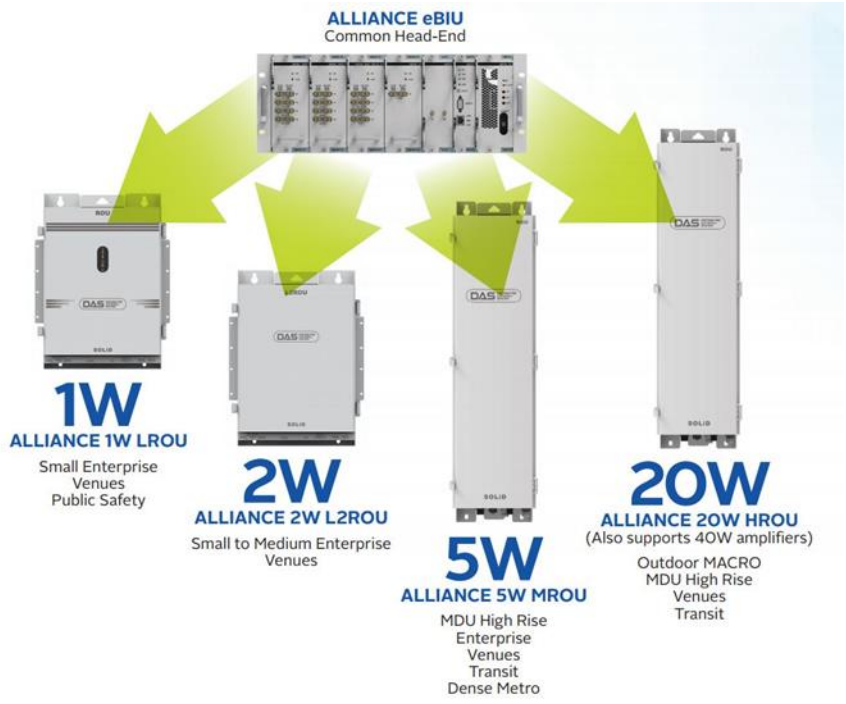
In 2017, SOLiD released the GENESIS platform, designed specifically to meet the middleprise's requirements by using a multi-band, multi-operator vRAN architecture. GENESIS was developed on what SOLiD calls a "supply meets demand" model, in which the enterprise owns the indoor infrastructure and enables multiple wireless service providers to access it.

GENESIS includes four elements:

- GENESIS RAX, the Radio Access eXchange, for the vRAN signal source.
- GENESIS DAS, a next-gen DAS solution.
- GENESIS CLOUD, a management system for the platform elements.
- GENESIS MARKETPLACE, a cloud application that enables enterprises/building owners to establish wholesale relations with wireless service providers in an automated way.

In the optical backhaul and fronthaul area, SOLiD has been a leading proponent of DWDM, which splits a single fiber strand into multiple bidirectional channels to increase the capacity of the fiber, multiplying the capacity of the link. Linear add/drops enable the operator to use the same strand to serve multiple small cells, and to provide both fronthaul and backhaul.

The DWDM solution, INFINITY ACCESS, supports multiple protocols (e.g., CPRI, OBSAI and Ethernet) and can simultaneously support multiple access technologies (e.g., LTE and Wi-Fi) in the same strand. Operators no longer need to add a new fiber link when they add a new RRH or a small cell. Moreover, because DWDM allows operators to gradually add new links to the same strand, they can reduce their deployment and operating costs as they expand their networks.



SOLiD ALLIANCE multi-carrier DAS *Source: SOLiD*

SOLiD

The middleprise will pay for wireless networks if its needs are met

A conversation with Ken Sandfeld, President, SOLiD America, SOLiD

The enterprise's wireless requirements are growing, as wireless coverage, capacity, services, and specific applications become crucial to ensuring productivity. But is the enterprise willing to pay for the in-building infrastructure it needs? What needs to happen to get the enterprise to fund the in-building infrastructure? And will mobile operators be willing to use networks they do not own? SOLiD has been working on solutions to this challenge, with a focus on the middleprise. In this conversation, I talked with Ken Sandfeld, President at SOLiD America.

Monica Paolini: Ken, we've talked about this many times before, but for our listeners, can you tell us what you do at SOLiD? And what does SOLiD do for the enterprise?

Ken Sandfeld: SOLiD is in the business of developing and building coverage and capacity solutions – most significantly, DAS solutions. Our distribution has more recently been developing solutions that supply capacity, as well as a full, turnkey solution. That's the business we're in, making sure people can use their devices inside buildings.

Monica: Most of the wireless usage comes from indoors – and enterprises and venues account for a good portion of that. It's a huge market. It used to be considered a niche market, but in terms of the number of buildings and square feet, it's definitely not.

It's not a uniform landscape. There are big venues. There are small venues. There are middle-size venues. How do you manage them all?

Ken: We focus on what we like to call the middleprise. You may have heard that term before. We've been using that term for a number of years. The middleprise is a portion of business, or the building category, that is really underserved.

The middleprise typically occupies buildings that a wireless operator would not like to invest a lot of money into. It typically means a lot of problems, a lot of demand for services. It's also typically a market segment that doesn't have very good public safety coverage.

It's the highest-growth portion of the market, and it's the most underserved for lots of reasons, which we'll go into.

The middleprise differentiates itself most importantly from the larger-venue projects in terms of the investment from the wireless operator, which does not want to invest a large amount of money into it. Typically, middleprise wireless networks are going to be owned by the building owner or a third party, depending on the project.

Monica: The middleprise is an attractive market because, like you said, it's underserved and yet it's the biggest IBW segment in terms of total square footage, total number of buildings.

You mentioned public safety. What are the public safety requirements, and how can you help operators and the enterprise deal with them?

Ken: With public safety, it really is multifold. Having your cell phone work in an emergency is critical for public safety. Even commercial cell services play a public safety role.

However, when we refer to public safety, we're mostly referring to the ability of first responders to communicate inside a building. More importantly, we're talking about first responders being able not only to talk, but to access data – lifesaving information that allows them to do their jobs inside that building.

That is, obviously, what FirstNet is all about. Organizations like the Safer Buildings Coalition are all pushing in that direction to make sure buildings are safer. Middleprise buildings are large enough that they absolutely require some safety enhancement.

If they're newer facilities, it's a guarantee. They need some type of public safety enhancement, as well. It's no longer "Well, maybe we can get by. It should work OK." It's not acceptable. Nowadays, especially with everything that's going on, it's absolutely something that should not be an afterthought. It's something building owners have to look at.

Monica: When an enterprise has a need, it is not willing to just wait for the operator to come in and

solve the problems on its behalf; it wants to be part of the solution. Isn't that something new?

Ken: Yes. The days of the building owner, basically, just waiting for something to happen are coming to an end. There're two reasons that's happening.

One, the wireless operators have acknowledged that they just can't afford to fix everyone's building. This is not just in the US. It's globally. This is a global situation.

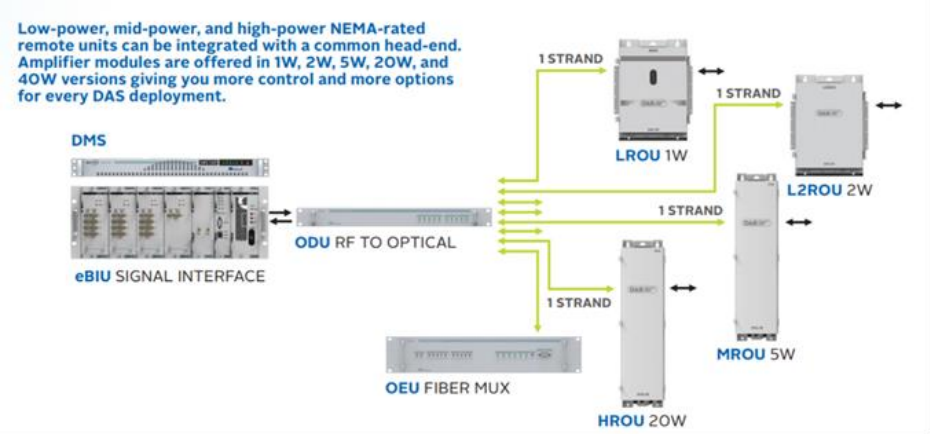
Operators realize they're going to have to work with the building owners and with vendors, like SOLiD, to come out with solutions that are affordable for everyone and solve everyone's problems. That's the biggest change.

Two, building owners are more proactive about solving for these things. They recognize it's going to require some investments, and they recognize that those potential investments have ROIs. They're looking at how that's going to increase the return on investment on their building, as well as how to make them safer.

Monica: Another driver of change in the wireless enterprise is IoT. There are more and more IoT applications in the enterprise. Clearly that's another area where the enterprise wants to have its say, because they have their own applications to run.

How is that changing the relationship between the enterprise and the wireless infrastructure, and with operators?

Ken: IoT is another area that is going to provide a positive ROI for the infrastructure. The more applications you can use to create a return on investment for your infrastructure, the better. Both IoT and Mobile Edge Computing – or as I like to call it, on-premise or in-building services – will contribute to the ROI.



SOLiD ALLIANCE topology *Source: SOLiD*

Services that are, potentially, functions or applications that are served on-premise will be critical, because doing that absolutely provides a return on investment for the building owner. That's why the in-building infrastructure becomes so critical: it enables the building owner to justify the spend.

Of course, the wireless operator becomes an integral part of that, because it's providing the mobility outside the building and the need to provide that extension into the building, as well. So that partnership continues.

Monica: In terms of the solutions available, in a big venue, traditionally, you have a DAS, or you may have small cells. Are the same solutions going to work in the middleprise – just scale them down? Or is the middleprise fundamentally different?

Ken: It's fundamentally different, in a lot of ways. Is it still RF? Yes, it's still RF. Is it still a radio connection? Yes, it is. However, two parts need to change drastically for all this to make sense.

First and foremost, the building owner is being asked to invest in infrastructure. Today, most of the infrastructure technologies, including some from SOLiD, are a little bit too expensive for the middleprise.

Also, half-inch coax and other technologies are not very flexible or future proof. They don't necessarily provide a roadmap for 5G, which building owners are learning about. The wireless infrastructure needs to become an integral part of the overall value proposition that the building owners look at.

The other difference is the connection to the carrier's network, or any other technology that enables that functionality. Ultimately, carriers need an infrastructure that can flex and scale, as well as provide the services the building owner wants.

If there's any part of the equation that sounds like you have to wait months and months and months to have one of the operators connected, or that you are not going to be able to connect to them, then that's a complete failure, and it absolutely will not sell. It will hold our industry back if that isn't solved.

Ultimately, the IBW solution has to be a combined, holistic approach, an end-to-end approach to solving for those service coverage and capacity needs in that building.

Monica: How about solutions like C-RAN? They have attracted a lot of attention. Is that essential for the middleprise?

Ken: There are different forms of C-RAN. C-RAN is cost effective for the operators, because they're pooling their resources. With the dawn of virtualization, the cost of supplying the equipment on premise has come way down.

This year, we launched a technology called GENESIS RAX, which brought the cost of vRAN, for all operators and all services, down to a price at which the building owner wouldn't even flinch about spending the money for the hardware and the software.

Locating the radio resources centrally, or in a cloud, or in an intermediary location – like a third-party owner's location – or on premise, it doesn't really matter in the end. Ultimately, it's whatever works best for all parties.

There're many ways to do C-RAN, as well. You could pool the radio resources, or you could backhaul from the CO and have everything located at the central location. Then you could transmit multiple sectors to that building, and still have everything at one location.

SOLiD GENESIS supply-meets-demand model *Source: SOLiD*

There're many ways to slice and dice that split point. We think the best way is to locate the equipment on premise and have the building owner responsible for the maintenance and growth of that solution, in conjunction with the wireless operator working with SOLiD.

Monica: Depending on your topology, you may have different functional splits. In some cases, you do need fiber, in some cases you don't. What's the best solution for the enterprise in that respect?

Ken: I believe the backhaul should be provided by the wireless operator for the middleprise projects. For some lower-capacity sites, it will be provided by the building owner, but for the most part, the wireless operator, or the operators in general, want to remain sticky with the building owner. They're going to want to provide pipes to the building.

CPRI or Ethernet or MPLS are all possible solutions. CPRI is not ideal to feed a building, because it means the operator has to allocate radio resources at a central point. Again, that becomes costly. It's fine when you're talking one or two building, but not when there are a hundred buildings.

When you're talking tens of thousands of buildings, that becomes a big burden on the wireless operator. It's going to have to figure out where to put all this stuff. Do we push more of it to the cloud? Do we push some of it to the enterprise? That's not completely settled.

CPRI is not the most efficient way to serve the middleprise. Future enhancements to CPRI may change that. What we see right now is that Ethernet is more than capable of serving the middleprise fronthaul, as well as a proprietary means of serving RF.

Long-term, the carrier-managed cloud is going to make it easier for the enterprise to take advantage of C-RAN and drive the costs down even further. Already, the on-premise solution is absolutely attractive.

Monica: To date, I would argue that one of the reasons we don't have a lot of coverage in the middleprise is cost. And specifically deciding who's going to pay for the indoor infrastructure. The operator, typically, does not find it cost effective to deploy indoor infrastructure in all middleprise buildings.

As you mentioned, the enterprise is more willing to pay for it, but when it does that, how is the TCO

different from the big venues? What is special about the middleprise TCO?

Ken: When the middleprise owns it, it has to justify it, which means it needs a positive return on investment. That's precisely why DAS has been struggling in the middleprise.

The DAS infrastructures need to change. They need to fit into structured cabling. We're promoting a fiber approach out to the active devices. We're doing that mostly to support 5G and other types of technologies that are coming in the future. The fiber approach is absolutely the most future-proof method that we have available to us at this time. Building owners are looking to the future. They want to know that the solution can flex and grow for all those things.

The infrastructure needs a change, but the biggest thing that affects the middleprise's ability to fund the in-building infrastructure – the only way it makes sense – is if all operators are able to play on day one.

That is the biggest obstacle in this industry. It can no longer be a solution where we've got one operator or two. That's not acceptable. You're leaving lots of people out, if they come into this building and have no service.

The only way to arrive at a solution is to standardize – to have a solution where the operators approve of the technology. It has to fit into their future roadmap of their core networks and how they create gateway solutions that allow people to get approved and connect to their network.

The operators need to have full control of those resources. Even if the resources are owned by the building owner, maintained by the building owner, and the building owner has an SLA with the operator, the carrier still has full control of its licensed-band services.

That's the way we see it, and that's what our middleprise customers are telling us: "Ken, we don't have an issue paying for the system, but it's got to work for everyone." If it leaves any particular operator out, or it doesn't allow the enterprise to scale for a future service, they're never going to be able to spend the money.

That's really what we see going on in the market. That's why you see SOLiD investing so heavily in a radio solution that supports everyone and that can scale for the future.

Ultimately, 5G is going to drive this. 5G is an opportunity and an inflection point in the business that allows both operators and OEMs like SOLiD to create solutions that will not only solve for 5G, but solve situations in the market that are at complete loggerheads with being able to provide service to those buildings.

Monica: What does SOLiD do to address this issue?

Ken: For a few years, we've been working on the infrastructure as well as the connection to the core network.

On the infrastructure side, we're working on solutions that lower the cost of installation to the point where the network is deployed a lot like Wi-Fi. You've probably heard that term before.

It's a solution that is enterprise friendly. It's something the enterprise knows how to deploy. It doesn't require a fleet of RF engineers to come and figure out how to get a PIN diode situation solved. The system will, basically, take care of all that.

We already mentioned fiber. The reason fiber's important is that it gives you a roadmap towards other solutions. In order to be 5G ready, you need a high-capacity pipe going to the core edge – because, ultimately, fiber is one of the things that's required to get low latency, and to use a high number of bands and massive MIMO.

The second part is that connection to the core network. We believe in virtualization. We've been working on virtualization technology for a few years. This year, we announced and showed our GENESIS RAX solution. It's still being developed, in cooperation with operators who are giving us input. It's also being developed with inputs from the enterprise and the middleprise markets.

We believe technology is going to be part of the future. How, exactly, it rolls out and how we create the splits, that's going to take some time to work out, because the carriers haven't exactly figured out what they think is best for them.

Ultimately, those solutions have to come together into one cohesive, end-to-end solution that the enterprise/middleprise purchases. Until that happens, we're going to be in a trouble point.

Monica: I guess this will happen with 5G – but it's starting already, ahead of 5G. You're going to have multiple air interfaces being integrated. Will you support multiple types of access?

Ken: The RF infrastructure will be completely protocol independent, like it is today, and it will also be completely band agnostic, but it can flex. The middleprise has been telling us – our customers have been telling us – they need a solution that can flex more easily.

When I say flexible, I mean we can switch from 700 MHz to 600 MHz. We can change from LTE to CBRS LTE and bands such as 3.5 GHz. They need an infrastructure that can flex easily without a rip and replace, which has been an epidemic in the DAS industry for a long time.

Every time there's a major protocol or band change, it requires a rip and replace, higher densities, and all these types of things. Building owners don't mind adding a device here and there, or putting an extra device on the ceiling, but they don't want to rip it all down and start over. That's really the key. That's what SOLiD is working on.

On the radio side, it is the same thing. At the Mobile World Congress at the beginning of this year, we showed a solution that can scale to 3,000 users, and it can do so on any band from 600 MHz to 3.5 GHz, and it can do so with LTE or with any future version of LTE. It's completely agnostic to that.

That's exactly what we believe the marketplace needs: scale and flexibility. That's what people are asking for, and the carriers like it as well. They have to have ways of approving and standardizing on that so they have an ecosystem.

Until that shakes out in the next few years, we're all going to move in that direction.

Monica: The enterprise wants to give access to multiple operators over the mobile infrastructure it owns. But mobile operators are sometimes wary about sharing the infrastructure, because they feel that they don't control it.

Ken: On the DAS side or the RF infrastructure side, I don't think sharing is a problem anymore. Globally, we see that the operators understand. If it's designed correctly, it's not going to impact operators that much. It doesn't affect them at all.

On the radio resource side, absolutely, there's no sharing. There shouldn't be sharing, with the exception of solutions like CBRS, which is a shared-frequency band. There're folks out there, like Federated Wireless, working on solutions that will allow CBRS sharing to occur, and we absolutely support that.

Technologies such as CBRS or MulteFire are going to expand the tool kit available to solve those problems. They're going to share where it doesn't have an impact on their potential volume service. Everybody wants to be able to differentiate as a competitor, and so do the operators. We need to support that.

As an equipment provider, we work hard to make sure each party's interests are protected. Ultimately, the carriers have to protect their services. The building owner wants to know that each service is provided to its fullest.

Monica: You mentioned various things moving forward. Virtualization – it has started, but not quite there yet. 5G – how is that going to affect both what you are doing for the enterprise, and how the enterprise's requirements and the solutions change over the next five years?

Ken: In the end, building owners don't really care. They just want the service. If there were a magic pipe fiber that would come from someplace and supply everyone at once, service wise, they really don't care. What virtualization does is lower costs and provide the appropriate control and scalability.

For example, GENESIS RAX is virtualized. It provides the control the carrier needs and the flexibility the building owner needs. You turn on the system and it has several different bands running.

Then one of the operators, let's say T-Mobile, comes and says, "We want to add 600 MHz. We want to add some more capacity. Can you turn that on?" The radio resource needs to be such that the operator can add that band, and the DAS needs to be such that it can add that bandwidth, literally, with a click of a mouse button. That's what operators ask for.

That's the only way for costs to align. I keep going back to cost. It is all about cost. Virtualization provides control and flexibility, and lowers cost. That's what it's all about.

The trick to virtualization, though, is that it has to be built around standards. Right now, we're building towards LTE 3GPP standards. I'm not talking only about the air-interface standards. I'm talking about standards for the core network connection. What are the standards for certifying different types of radios and network devices?

The focus needs to be on working on those standards. That allows OEMs like SOLiD to develop the end-to-end solutions and be compatible with those core networks. Virtualization drives that. It

enables that. It's something that, up until now, was proprietary, and there was really no way to virtualize networks using proprietary technologies.

The more the core network is standardized, the faster the adoption of virtualization will be. Alternatively, each operator can have its own standard, as long as that standard allows for quick adoption and creates a competitive environment. An ideal situation for the carrier and the building owner is that there are multiple products to pick from to solve this problem.

That's what I want as an OEM, and that's what everyone should want, because there won't be one winner. Having one winner is not enough – we have that now. We have two OEM suppliers and there's no competition. There's no way for anyone to move forward.

These OEM suppliers are still going to have a big place at that table, as well, but it's going to open up to all types of companies that are going to be providing technology to support virtualization. That's a big part of what virtualization provides: a standard.

About SOLiD

SOLiD helps people stay connected and safe in a rapidly-changing world through a portfolio of RF Amplifier, RF Radio and Optical Transport solutions. SOLiD enables indoor and outdoor cellular and public-safety communications at some of the world's best-known and most challenging venues including leading hospitals; professional and college sports venues; government, university and Fortune 500 corporate buildings and campuses; international airports and metropolitan subways; and other high-profile sites. For further information on SOLiD DAS, Backhaul and Fronthaul solutions, go to www.solid.com or call 888-409-9997.

About Ken Sandfeld

As Executive Vice President, Ken Sandfeld leads the overall sales and product strategy activities for SOLiD's portfolio of network densification solutions. Ken possesses over 17 years of experience in the wireless infrastructure industry and is passionate about bringing innovative technologies to market. Prior to his current leadership role, Ken held management positions at MobileAccess, Remec, Spectrian and Zyfer. Today Ken is focused on bringing SOLiD's leapfrog technologies out of incubation and into the market to solve some of the industry's biggest problems. Those areas include high-efficiency amplifiers for indoor and outdoor small cell applications as well as low-cost DWDM tunable optical solutions for the Enterprise and Wireless Operator markets.

CCJPA

Wireless connectivity is more than an amenity in public transportation

A conversation with Jim Allison, Manager of Planning, Capitol Corridor Joint Powers Authority (CCPJA)

Riders love wireless connectivity in public transportation and are often disappointed by the limited mobile coverage. It is indeed difficult to provide reliable and robust connectivity inside trains – the signal does not cross metal barriers well, and the high number of simultaneous handoffs as riders move from one cell to the next is difficult to manage. To address this issue, many transit operators have deployed their own networks to complement mobile coverage – to make their riders happy and increase ridership.

CCJPA was one of the first train operators in the US to build a wireless network that riders can use for free. Now it is expanding the use of its wireless infrastructure to applications that support internal operations, which will improve efficiency and contain costs.

Today with me I have Jim Allison, Manager of Planning at CCJPA, the Capitol Corridor Joint Powers Authority in Northern California.

Monica Paolini: Jim, can you tell us what CCJPA is?

Jim Allison: We are a joint powers authority that oversees intercity train service that's on the corridor. We are composed of transit agencies along a corridor in Northern California, basically between Sacramento and the Bay Area, Silicon Valley. The Capitol Corridor Joint Powers Authority is the oversight entity that was formed at the state level to oversee this particular corridor.

Monica: We've been working together for a long time, so I know you've been doing a lot of work on wireless in transportation since way before there was much going on, both on Wi-Fi and on the cellular side, so you have a unique perspective on how everything has been evolving.

Can you give us some background in terms of what you've done over the last decade now?

Jim: Doesn't seem that long. Just yesterday, a decade ago, we were approached by a vendor because of the characteristics of our network that we operate. We are serving Silicon Valley. We just had a really good demographic on the train, so we were approached to do Wi-Fi trials on the train.

At the time, we were barely into 3G. It was 2G, 3G. The issue was, how do you get the bandwidth to the train, because it was right when Wi-Fi was coming out as a standard. The vendor saw the need for people who are trapped on a train and want to be productive, and started with trials.

We didn't know anything about what was going on in wireless connectivity then. We said, "OK, that sounds good." Then gradually these trials led to the technical understanding we needed as we were moving from 2G to 3G and then 4G.

Then we looked at the business model. What is the potential of this? What does it do to ridership? How do people value it? We really have taken that ride all the way through – looking at various different technologies, some of them satellite, some of them cellular-based, and others trackside, where you build your own network.

We got into the dynamics of these networks, and the business models and costs that would drive broadband connectivity on a train – always from the perspective of trying to make the train a more attractive space for people.

Our riders are on the train for about an hour and a half on average – some more, some less. There's a lot of productive time there. They were asking for Wi-Fi in the train.

Gradually it's gotten better and better as new backhaul options have emerged. The industry as a whole, be it bus or rail, in whatever country, has evolved. There's always, as the British like to say, horses for courses based on what you see out there, what your characteristics are versus your rider demographics, or what the dynamics are in your environment.

Monica: You offered internet access to your customers throughout the years. What do you see changing right now?

Jim: What's changing is internal. The use has always been pretty much as high as what the network has offered. It's all best efforts. At any time, you are at your particular location getting as much bandwidth as you can from the cell-card mix that we have for backhaul. We're seeing people moderating their usage or working with the system to moderate their usage.

We had cases where 5% of the people would be using 80% of the bandwidth, via VPN tunnel or something like that. Gradually we've taken steps with the vendor to even that out, and give everybody a more managed experience, by putting caps on the usage, especially for high-demand applications like video streaming.

For the common good, we have to cap the video streaming. You can watch a video for a while, but then your usage level is hit. You get pushed to the back of the line.

We've learned how to even out the experience. Before, it was very "how's it going to be today?" – a lot of variation. That's one of the biggest things we've been seeing.

We've also been seeing the uptake of wireless connectivity as an important amenity for the ridership. That is something we learned early on, with surveys. It did exactly what we were hoping to. It did add ridership. It was a compelling reason to take the train, and people continue to mention it. It's often, "Why do I take the train? It's because I have Wi-Fi in the train."

Monica: I guess that's an important one, because monetization is a major issue. You seem to have been able to monetize the experience without charging people directly for it.

Jim: Correct. As you know, we worked on this before. We looked at different models about what do you do, should you charge people for this experience or not? How do you gain your revenues?

We're in the situation where we sell tickets. That's how we're getting our revenue. We just needed to offset the capital cost and the ongoing operational costs. In a theoretical sense, this isn't how transit agencies actually operate.

On paper, at least, the capital was recovered over time because we got more riders, and certainly the operational cost is recovered each year, presuming we retain those riderships, meaning those tickets that get paid. We're above water with that.

Now any other applications we've built on top of that to reduce costs or provide different experiences on the train, that's gravy, but then those applications themselves have costs. We're at that transition of using the network for other purposes right now.

Monica: That's something I wanted to talk about. You own the network. It's a very powerful asset that allows you to run other applications on top that can help you with operations. What are you doing in this area?

Jim: The one that we're working on right now is called on-board information system, or OBIS. It's a mandate from the federal government to provide equal access for disability-impaired folks, so ADA rules.

The OBIS project will do automated audio announcements and video announcements on screens. That's all using the backhaul for the in-train communications.

It's all real-time, and it's meant to tie in with the back-office systems that are monitoring the GPS location of the train and doing predictive arrival calculations.

It's tied into that back office, but then if there's a delay or something that happens, then the operations center, which is in a central area, can issue commands to the specific trains that are going to be affected by a delay, for instance. Then they can provide customer care, as well as inform the conductors on the train.

It's an automated process to bring all types of riders up to speed as to what's going on in the service, improve the comfort, and give them reason to believe they're going to get there on time, or at least give them the information you have. It meets a mandate, but it also provides a service.

It's also, as you rotate what's on the video screens, you're going to have the opportunity to promote other features of your service, like a partnership through which we serve the Oakland A's, so we can do Oakland A's advertisements and things like that.

Monica: Are you working also on other applications that are internal to your operations that are not necessarily tied to the ridership?

Jim: Yes, we're in the very early stages of that. There's a huge, long list of things that can be done operationally.

A lot of it is with performance monitoring of your systems, such as your air conditioning systems. You can monitor your food stock, and you can monitor other system parts that might be going bad and change your maintenance practices. By getting access to that data, you also have to effect a change in your operations themselves.

Trains are not known as an industry that is right at the leading edge. Those operational changes are a big cultural challenge to deal with. It's a matter of matching the technology change with the cultural change. We're just at the start, at least in our agency, of looking at condition-based maintenance. That's done via sensors that are on the train, and that data is carried by that network.

Monica: In that case, you have different issues. You have a technology issue: make sure you have a solution that works. It's also a cost issue, and it's a cultural issue. What do you think is the one that slows you down more?

Jim: No question, it's the cultural. Getting through the change with the personnel is the most difficult thing. There is a challenge of getting the money to do the work and getting it scoped out correctly, but it's cultural even to get to that point.

You have to introduce the idea, get a business model together, and then approach it in the right way with the right champions who can lead it through. Cultural change is the hardest one in all cases, but if you have a good business model, then you're good to go.

Monica: Is it the employees who feel threatened, or management? I'm now talking about, in general, what you see, because this comes up all the time, that the cultural issues are the ones that are more difficult to address. The specifics are different at each company, but there is commonality as well.

What are the cultural limitations? You have something that works better, so why wouldn't everybody be embracing it?

Jim: If not everybody understands the proposition, there's resistance to it. You have to show something's broken. Or if it works right now, is it worth changing it gradually? Or what does that show us? Or how are we going to change our entire management practices of maintaining the train?

Right now, a lot of times replacements are done according to a schedule. If you're replacing items that are still otherwise good, you're just replacing them according to a schedule.

If you have sensors on certain items that say, "Hey, this is fine, and you don't need to change it," that is a complicated thing, to answer to the technology that says now you go and change it. It changes your work rules, your union rules, your staffing, all those kinds of things. It's just getting the expertise there to use data in a critical analysis way and pick the right actions at the time.

There're train operators around the world that are further along on this. Really, what we have to do, what I'm going to be needing to do here, is reach out to them to learn how they went about it within their culture, and then bring that back and try to apply it in a customized way here.

Monica: You're dealing with a very difficult environment on a train, because everybody's bored and they want to get connected and do video and everything they can possibly do. At the same time, you're very limited because your backhaul is through cellular, and that's clearly a bottleneck for you.

How is that changing? How can you manage that?

Jim: We have had tough times managing that. We have a situation where we don't own our tracks. We're hosted on a freight railroad. We can't look at a technology solution that involves a trackside network, whereas other operators around the world do have that situation.

They are pursuing that – some of them successfully, some of them not. It was just in the news this week that the MBTA [Massachusetts Bay Transportation Authority, in the Boston area], due to neighbor concerns, shot down the idea of putting in a trackside network, because of the extra power and visual impact. People living along the tracks didn't like that.

In other cases, that's not happening. You have to work in the environment you're given. If you can build them, some of the trackside networks actually are extremely impressive.

Probably one of the most impressive ones is in the subway system in Moscow. They've installed a trackside network there. One of the anecdotes from that is that people go down into the subway in Moscow to download movies because it's faster than what they have at home. Then they go back and watch the movies.

That tells you there's a lot of diversity. We don't have the ability to download movies on our service because we're all backhauled by cellular. There're a lot of differences.

In general, what we're trying to do is manage our capacity by evening out the service. Then as 5G comes along, we can swap out cards and consume the bandwidth that's available from each subscription accordingly.

It's a lot of data, believe me. You can have up to 300 people on the train. If two-thirds or even half of those people are connected, that's a lot of demand, even capped. It's a tough, tough thing to manage.

Monica: Especially because it's free. Everybody has their own Wi-Fi devices, and it's a natural thing to do when you're on a train. The first thing you try is whether Wi-Fi is working.

What about the relationship with mobile operators? Even though it's Wi-Fi service, you rely on them for the backhaul to the train.

Jim: Our relationship with mobile operators is very interesting. It's not direct. We work through our service provider, Amtrak. They have a relationship with mobile operators, but it's not a very strong one, because they're generally just buying modems, modems that have a plan. They aggregate those modems together to provide the bandwidth on the various systems they have.

There hasn't been a lot of collaboration in my direct area or with Amtrak about working to put small cells on trains, even though that opportunity is just sitting there.

The voice quality and the data quality all along the route are not great, and the way it's managed right now shows that it is not an area that's getting a lot of attention. I think some of the rail operators understand it's there, and some of the cell operators are starting to look at it. But it hasn't come to fruition yet, at least in the United States.

I think that's a little different elsewhere, where there're more robust relationships between train operators and cell providers in the country. Of course, sometimes in those situations, government policy brings entities together a little more. We don't have that here in the United States quite yet.

Monica: The use of the train as transportation is less common than, say, in England or other European countries or Asia. In Europe, the rail route is crucial for coverage for an operator. In the US, it's probably not the same.

Jim: Yeah, that's definitely the case. The rail in transit in general in Europe and Asia is much more built into the social fabric of how you get around and pursue your daily life. It is more of a lifestyle choice.

That's slowly changing here in the United States. I think the millennials that we all hear about are looking to be a little more urbanized, because the highways aren't getting any wider, and there is a movement towards more long-distance transit travel.

Short-distance transit travel is not doing as well, but that's not really as much the market for Wi-Fi, because you're not on it, hopefully, long enough. You're moving around in your city with the local transit.

There is definitely a difference between here and the different countries and cultures that have adopted rail, in the way it works together with the cell operator, and the government involvement too.

Monica: Do you see the relationship between rail operators and mobile operators changing?

Wi-Fi service on the train could be seen as an offload for a mobile operator. But also as a rail operator, you can put in small cells in train to allow mobile operators to provide better service to their customers.

Jim: I think the relationship with mobile operators needs a start. There isn't much relationship right now to undertake those initiatives. Transit entities that own their right-of-way are going to have the opportunity to utilize that asset to possibly work in partnership with the cell provider to put base stations there. There's usually fiber in right-of-ways.

There's an opportunity to work with the transit agency to not only use the right-of-way to point away from the tracks, but also to point toward the tracks, depending on where you have your equipment mounted and what the purpose of it is. I know that's happening in some of the larger urbanized subway systems.

That physical asset of right-of-way, and then the asset of having the same customer as a cell provider has – they're being transported and they're using data – creates a unique synergy there.

In the larger transit systems, that is being realized. There is a much greater partnership. I'm thinking of New York and Toronto as examples. In the Moscow situation, there's a relationship between a mobile operator and all the larger subway operators. On intercity rail, the relationship is not quite as strong. So that's where the Wi-Fi piece comes in.

Some entities that have the right-of-way are looking at trackside networks when they

essentially build the network, and then the mast is up. The power is there, and the fiber's backhauling it. That asset of putting up the mast can be realized by other kinds of operators pointing to neighborhoods that are close to the rail. There's a great degree of variation there.

Monica: Do you see the mobile operators getting directly involved in building their own infrastructure if they have access to the trackside? Or do you think they prefer to have a neutral-host model, where some other company is building the infrastructure, and then the operators use it?

Jim: It's typically a neutral-host model. There have been little forays where one cellular operator tries to get in and do something, but these days the transit operators are pretty savvy to the asset that they have.

They go through a neutral-host model, so they can mutually touch most of their customers. The owner of the right-of-way can't leave one incumbent as winner there. It has to be an equal share.

I think the mobile operators understand that that's the better way to work, anyway. They can compete in other areas rather than in getting access to transit agency A's property. Now they have exclusive rights. That's been tried with different situations.

Long Island Railroad was working with a cable company. It's a great way to maybe drive people to that cable company, but then as a train operator, you're stuck with that relationship. It's something that transit operators need to look at very seriously and understand their own assets, so they can relate to the market that's out there, or the market potential that they can see, and also that cellular operators can see.

Monica: You're right. Because wireless access is so important to riders, you cannot limit access to one operator, because your ridership is going to complain.

Let's look at the future. 5G is coming. How is that going to change the transport system? Transportation is one of the big use cases.

Jim: Yeah, that is a big change. In our case, we aggregate the cellular cards that we can get a hold of. We operate with eight cellular cards right now, so a mix of cards from the different operators.

With 5G, we'll have more bandwidth. In concept, we would be able to raise our data caps, and you'd actually be able to do more video streaming. That's going to change a lot of how we can relate to the customer.

The other option with 5G, though, is that riders might start using their own 5G card themselves, even though they're inside a metal box traveling along and getting a lot of handoffs along the way. They may be having a better experience than with 4G. It remains to be seen.

We can probably stick to our business model, because then if you're using our network, you're not using some of the data from your own plan. That's why it's more attractive to have that kind of feature on the train. 5G's going to change the balance point. We'll have to find that balance point of usage, data caps, and managing the network for an even user experience.

About CCJPA

The Capitol Corridor is an intercity passenger train system that provides a convenient alternative to traveling along the congested I-80, I-680 and I-880 freeways by operating fast, reliable and affordable intercity rail service to 17 stations in 8 Northern California counties: Placer, Sacramento, Yolo, Solano, Contra Costa, Alameda, San Francisco, and Santa Clara, a 170-mile rail corridor. An extensive, dedicated motorcoach network provides bus connections to serve the second-largest urban service area in the Western United States. The Capitol Corridor Joint Powers Authority (CCJPA) is a partnership among the six local transit agencies in the eight-county service area which shares the administration and management of the Capitol Corridor. The San Francisco Bay Area Rapid Transit District (BART) provides day-to-day management support to the CCJPA. Capitol Corridor services are developed with input from our riders, private and public sector stakeholders, along with the partners who help deliver the Capitol Corridor service – Amtrak, the Union Pacific Railroad, Caltrans and the various agencies and communities that make up the Capitol Corridor.

About Jim Allison

Jim Allison has been with the Capitol Corridor Joint Powers Authority (CCJPA) / Bay Area Rapid Transit District since October 2000. CCJPA is the management entity for the Intercity Passenger Rail service operating in Northern California. Mr. Allison is the Manager of Planning for new capital/service projects and planning studies along the route. In addition to traditional railway project planning, he leads CCJPA's technology projects, including the wireless/wired network. He has been on the forefront of evaluating technologies and business models for wireless networks for passenger train service since 2004, and he works in partnership with Amtrak to take advantage of these and other communications, network, and application improvements. Mr. Allision has spoken at several international conferences about these topics and maintains close contact with rail operators worldwide who are implementing wireless networks. For ten years prior to joining the CCJPA, Mr. Allison worked for the Bi-State Tahoe Regional Planning Agency, first in current planning and, later, in transportation and air quality. Mr. Allison graduated from the University of California, Davis, with a bachelor of science degree in Environmental Planning and Management.

Sprint

A deeper reach into the enterprise

A conversation with Jan Geldmacher, President, Sprint Business

The relationship between the enterprise and service providers changes as wireless connectivity becomes an even more important asset for the enterprise. In this conversation with Jan Geldmacher, President of Sprint Business, we talked about how mobile operators can reach deeper into the enterprise and introduce new models and services to address the needs of both large and small enterprises.

Monica Paolini: Jan, can you tell us what your role is at Sprint Business?

Jan Geldmacher: I am the president for Sprint Business. That is, basically, everything at Sprint that is B2B related. I oversee our SMB – small and medium business – customers. I oversee the enterprise, the federal segment, the public sector, but also the wholesale sector.

Within the B2B space, we have a variety of products and services that we bring to market. For example, a wireline proposition and portfolio, obviously a wireless portfolio, and an IoT portfolio. It is a very exciting journey, to see all these things coming together in the converged world that we are in.

Monica: There are a lot of changes going on. And some are internal to Sprint. How is your relationship with SoftBank helping you to address the needs of enterprise users?

Jan: Sprint is part of the SoftBank Group. SoftBank is our largest shareholder, with close to 85% ownership.

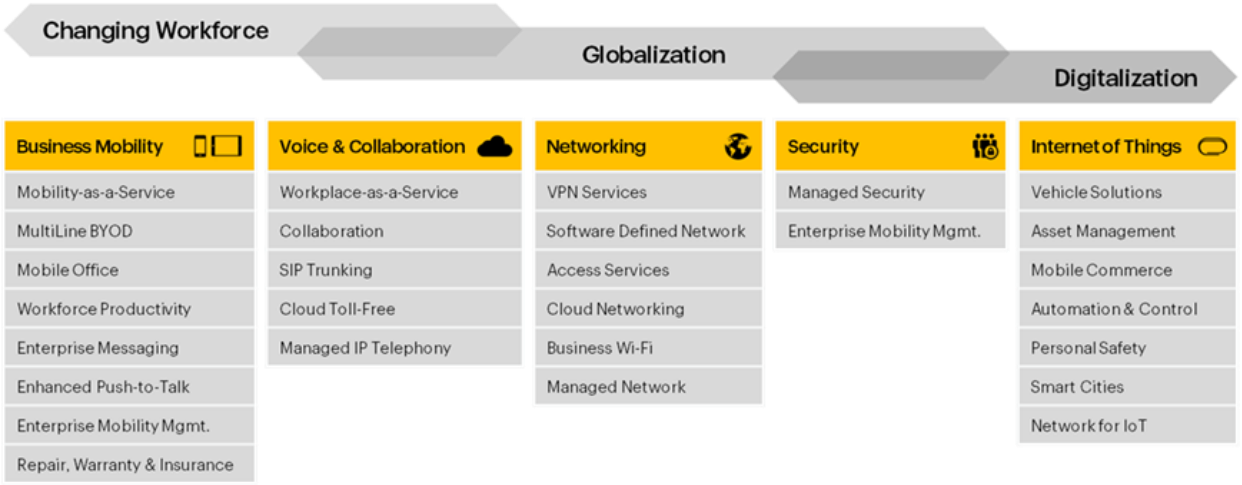
Being part of the SoftBank Group allows us to access its capabilities, know-how, and intellectual property, and to participate very much in the engagement that SoftBank has in the Vision Fund, which is the very large, $100 billion investment fund that our chairman, Masayoshi Son, uses to invest in IoT businesses around the world.

It's a very exciting journey, and being part of that group allows us to think outside of the box and beyond the normal portfolio that a carrier like Sprint would bring to the market.

Monica: There is a lot to learn, because the relationship with the enterprise and IoT works differently in different markets, and we can all learn from each other. How is that working?

Jan: IoT is a very exciting topic. IoT subsumes a variety of different things that companies – small companies, mid-size companies, and large companies – are looking at right now. If you categorize it in a very simple way, you could say IoT is helping companies digitize their processes and get closer to their customers, but it's also helping them to reduce costs and tap into new revenue opportunities.

Having said that, it becomes obvious that IoT touches on all areas of our customers' business – be it production, supply chain or distribution; be it the whole IT environment that helps them to digitize; or be it automation, robotics and artificial intelligence they use to improve their marketing activities. There is so much our portfolio touches



Sprint's vision of wireless connectivity in the enterprise ***Source: Sprint***

when we think about IoT with regard to our business customers.

SoftBank brings to these opportunities so many different companies that the group has invested in. Just think about SoftBank's investment into ARM. ARM is a chip designer that has great intellectual property in providing the industry with a chip design that gets smaller and smaller and, at the same time, more secure – that goes not only into smartphones but into all devices that can be connected.

If you assume that our world is full of sensors – take a car as an example. A car has about 500 sensors already, and all these sensors will be connected. Beyond the pure chip design and the modules that go into the cars, connectivity becomes a very important component.

Then, if you have solved the connectivity issue, all of a sudden you go into collecting the data, using big data, applying artificial intelligence, and helping our customers get closer to their customers. All of these ingredients that you need to accompany your customers on that journey are within the SoftBank Group. It is a very exciting time for us here.

Monica: It's a way to create the ecosystem for businesses from scratch, because it's a whole new area.

Jan: Absolutely.

Monica: By expanding the range of services so that, at some point, IoT will become so pervasive that IoT and connectivity become one. We still distinguish between the two, but is the distinction still relevant?

Jan: You're right. It's probably not appropriate to differentiate anymore. It's the ecosystem that comes together, and connectivity plays a very important part in that, because everything that can be connected in the world will be connected. That's an assumption that the whole industry makes.

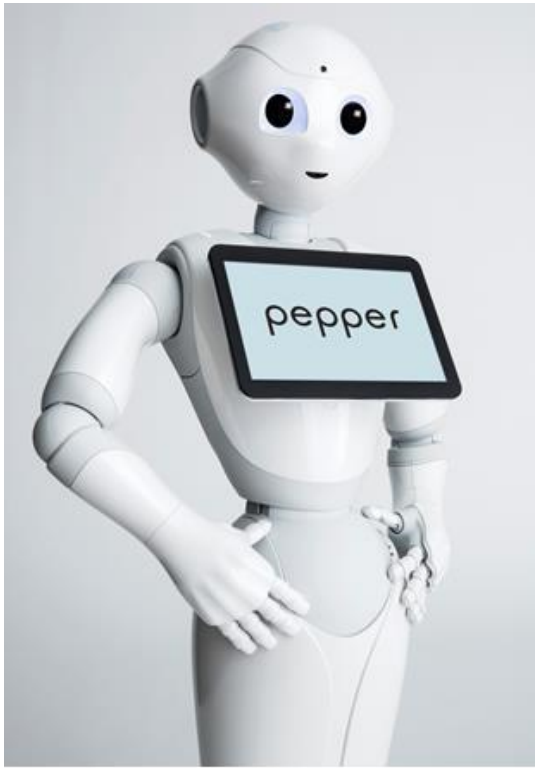
If you think about sensors, we believe there will be a trillion sensors in a couple of years, and all these sensors will somehow be connected, so connectivity becomes an integral part of the sensors in this world. Are we ready to do that today? I think not. Of course, we are on a journey to go through a development to make that happen.

When companies think about connectivity these days, they think about wireline connectivity through IP networks. They think differently, maybe, when they connect their people. They think about wireless networks.

Again, they think differently when they talk about IoT and machine-to-machine communications. Ultimately, all of that will come together. It will converge.

Everything that can be connected will be connected. You won't even know whether you are connected to a machine, or to a human, or whether the machine is connected to another machine, so everything will be connected with anything.

Then, the network that connects gets a completely different purpose, because it must be ultra-reliable, because we relay processes on these networks that are, sometimes, life-critical, or



Sprint plans to pioneer robotics in the enterprise with Pepper, the humanoid robot from SoftBank Robotics America

Source: Sprint

business-critical, at least. That journey has just started.

Monica: This puts a lot of pressure on the network to perform. But it also creates a big opportunity for diversification and extracting more value out of the network, because you have to not just provide connectivity but connectivity for different applications, and each application has its own requirements, so you need to balance them all out.

Your role as an operator is going to become even more important and central in ensuring all these applications not only exist but coexist.

Jan: Absolutely. The networks not only need to provide connectivity, they need to provide connectivity in a reliable way. We need to provide the right speed. We need to provide the right capacity. We have to integrate different protocols in different networks and spectrum areas. Some might be in unlicensed spectrum areas. Some might be in licensed spectrum areas. It will be a complete conversion. That is something that has just started.

When we look into IoT, we don't think that's only 5G- or 4G-related. It will be, of course, Bluetooth, Wi-Fi, and IP fixed-line networks like SD-WAN or IP MPLS networks. It will be mobility, in the sense that we talk about it today, connecting people and applications through the network, through wearables, for example.

The entire ecosystem is something we have to take into account, and the networks will be providing the connectivity in a different way than today.

Latency, for example, will play a role that will be increasingly important over the next couple of years as we make the move into autonomous driving and autonomous steering of enterprise processes, in the way of robots and people operating hand in hand. This requires latencies of 2 or 1 ms for applications with high time sensitivity. These are latencies that we don't see in today's network infrastructure.

Monica: Latency is clearly one of the big changes in requirements – lower and lower latencies. What other changes in the requirements do you see?

Jan: Networks need to be available, so universal coverage is of utmost importance. When you have autonomous environments where things need to be connected everywhere, you can't afford to have places where connectivity is not available.

Therefore, it's so important, when we think about the IoT world, that we include new services like the OneWeb satellite service that SoftBank and the Vision Fund have invested in, where we will launch low-orbit satellites that will provide ubiquitous coverage in areas where we don't even think today about having coverage.

That is true not only for Sprint as a carrier, but for all carriers around the world. We don't have, in the mobile space, ubiquitous coverage everywhere in the world yet. When we move into the autonomous environment, ubiquitous coverage is required.

The same is true when we move into applications like remote diagnostics, remote medicine, where not only latency but also availability of the networks is of utmost importance. Just think about a remote surgery that works on a 99.75% available network. That will not be acceptable.

We need 100% availability. These are new requirements that network providers will have to meet in the next couple of years.

Monica: What about security?

Jan: Again, think about the boom in sensors that we have experienced and, as I said earlier, 500 sensors in the car. If these sensors are not protected, or if access to these sensors is approachable by third parties that are not entitled, that presents a huge risk.

Embedding security in the chip design is of utmost importance – embedding security into our network. Doing very professional and reliable threat management of our networks is on our agenda. Today, in the eyes of many IT decision makers, that's a hurdle that we have yet to overcome, but I think we are very well prepared to tackle that issue.

Monica: There is not only a change in the requirements, it's also a change in the relationship you have with your customers.

Jan: That's a very important point. Telecommunications services have been seen as a commodity for many years, and probably rightly so. We provide a commodity that is scalable, and the faster we grow, the better our price base is, and we let our customers benefit from that. That's the principle. We're selling telecommunications services today.

Looking to the future, when we talk about getting our customers connected to their customers, we are changing the way we communicate with our customers. We move up the value chain. We move more into the areas of the business of our customers. We talk to product management. We talk to sales. We talk to marketing. We very often talk to the R&D folks within our customer companies and go into the business process.

Whereas in the past, and maybe even today still, many times we have been on the purchasing level only, and talking to supply chain organizations,

which is not a bad thing, and we will continue to do that. But we need to prepare to be the trusted advisors of our customers on all levels of their value chain.

Monica: How do you see your role, especially as you move to IoT, in terms of the services you provide? How deep do you go within the enterprise? You provide the connectivity, but do you also provide the services, the applications? Or do you work with third parties, or is it a mix of that?

Jan: IoT is an ecosystem of partners that work together. No company out there is prepared to do it all by itself, end to end, in the value chain. It's bringing together the ecosystem of partners that makes things happen. I believe this is also a differentiator.

Sprint is very prepared to bring to the table the ecosystems of partners that we have already, and we are very open to partnering with new parties that are being created even as we speak. There's a lot going on in the market right now in terms of startups.

When you think about your artificial intelligence discipline, or about big data and data analytics, we have a couple of capabilities and skills on board at Sprint. But we are not nervous in saying that we can't have it all and we can't oversee all the different disciplines that are out there, so we are dependent on partnerships. And we are encouraging our customers, also, to partner with others.

At the end of the day, it's a decision of our customers whether to do a top-down system integration themselves or to ask a provider like Sprint to bring all these different parties to the table and to integrate that. We are prepared to go both ways.

Monica: Different enterprises might want to be more or less directly involved, so there is a need for flexibility on your end.

Jan: Absolutely. It's also dependent on the size of the customer very often. When you talk to mid-size or smaller customers, they don't have the expertise. They don't have the technical know-how. Sometimes they don't have the project or program management resources to run these more complex environments.

We are here to help them to package and bundle solutions as deeply as we can, and have the bespoke part be as little as we can, because that allows us to implement much faster and reduce the innovation risks for our customers.

Then there are large customers – large, multi-national organizations – that have well-established departments that know well how to deconstruct a project into its single parts and system integrate it themselves. We have to deal with all the variety that is out there in the business space. Again, that's very exciting.

Monica: You raised a very important point. When you go to the smaller companies, it's different, because they don't have the know-how. Traditionally, that has been a difficult one to deal with for any operator worldwide.

But likewise, it must be frustrating for a smaller enterprise to not have access to the same services that a bigger company has.

Is there anything different that you do to work more closely with the small and medium enterprises?

Jan: Yes, we do that. We think there are at least two components that we have to bring to the table.

One is that we need to allow small enterprises to offload the innovation risk to their partners. How can you make a decision on implementing a technology that has an innovation cycle that is less than two years? We need to capture that, and we do that by providing our customers with bundled solutions that we sell in a flexible way. In our pure opex model, our customers pay per use or pay per seat or pay per machine, so IoT as a service is the solution to that issue that our customers are facing.

The second component is that we need to come up with a variety of partners in the ecosystem that are prepared to deal with small enterprises. Not every company out there with a three-letter acronym is really prepared to deal with a 50-person enterprise.

We need that ecosystem of partners that understand the language of smaller enterprises and understand the necessity of being speedy in implementing things – because, otherwise, we would disrupt or interrupt their business flow. I think these are the main criteria in the small enterprise space.

Monica: When you get to a larger number of enterprises – as you move out of the largest venues like stadiums, where everybody wants to have a huge presence, and you get to smaller enterprises – do they want to contribute to the

pay-per-service opex model? The enterprise may prefer to pay for the infrastructure it needs and sees as fundamental to its business. It's mission critical for them.

Jan: At the end of the day, of course, the customer pays for the infrastructure. The question is how does the customer pay for the infrastructure?

Is it the capex-based model, where the customer has to do the investment, put the investment onto its balance sheet, write it off over five or seven years and, therefore, needs to make a decision that is very, very savvy and very well-educated? Because in our world – as all of us know in the industry – the innovation cycle is much shorter than the tax depreciation times that we allow.

In an opex model, our customers pay – for the infrastructure and for the devices and even for the people we deploy to integrate it into their systems – in an opex way, a price-per-seat way. I think the move to an opex model is the name of the game. It provides the flexibility to change technology after two years, when the innovation is kicking in, and this is what many smaller customers look at.

Even larger ones do that, so it depends on the financial KPIs that are important. Some customers, even large customers, try to avoid the capex investment and move to opex models. If you think about the whole cloud model that we have been deploying for a couple of years, this is driven by the same economics.

Monica: How is virtualization, the cloud, going to affect the way you provide services? This should add much more flexibility to support smaller companies, right?

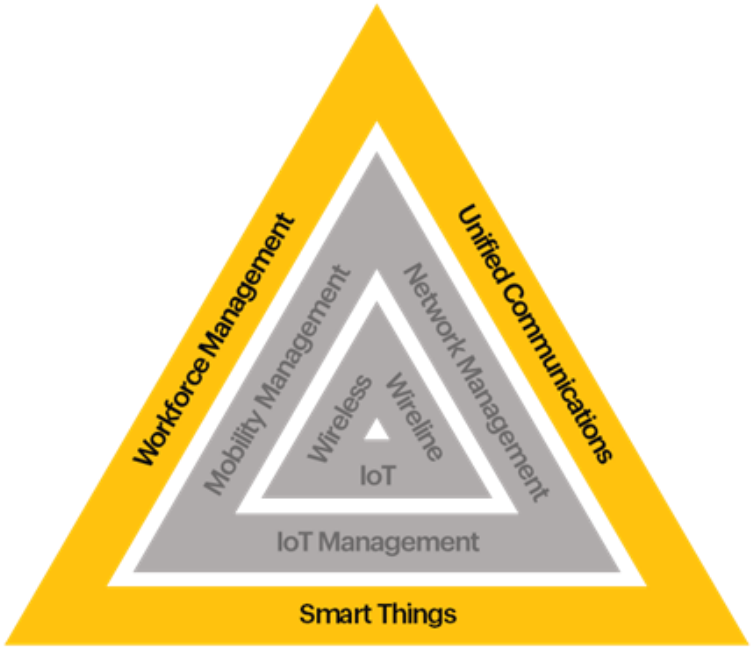
Jan: Cloud is, obviously, nothing new anymore. It's probably the tool of choice for IoT applications. At the end of the day, what we do is connect machines, connect people, and connect locations to the cloud. That's what the three network dimensions that we offer are doing.

Wireless networks, IoT-based networks, or wireline networks connect to applications that are in the cloud and make these applications available to every user – be it machine or be it a person or be it a production site at any place in the world at any time. That's what networks do, and that's what we will continue to do and probably become better and better at doing.

Monica: Let me ask a final question. How do you see the services that you provide changing over the next several years?

Jan: We will continue to move from a pure commodity play into a managed-services play, into a business transformation play through technology and telecommunications products. Connecting people, devices, and locations is the base of the pyramid that we are deploying in terms of services.

The next layer that comes above that, after connecting people, sites and machines, is managing that for our customers. More and more customers go away from self-managed environments and give that management capacity and capability out in an outsourcing or an out-tasking contract to carriers like us.



The enterprise ecosystem *Source: Sprint*

Then, the journey continues into business process reengineering, reusing telecommunications services. Putting connectivity into a car is not a commodity play; putting connectivity into a car is a telco becoming a part of the car. Therefore, it's a product that the customer or the car manufacturer, the OEM, is consuming like they consume the car.

That's a change in the way we develop our products. It's a change in the way we deploy our services. It's a change in the way we sell and bring our services to the market. That will continue as a journey.

Monica: It's a journey towards having more wireless, more ubiquitous coverage and capacity,

but also trying to move out from the commodity and provide more specific value for the different services for that, right?

Jan: Yes, absolutely. However, the commodity play will remain a very important play for us, because, at the end of the day, telecommunication lifts from scale, and scale is achieved by providing great quality in a way that customers love to consume it.

Only then can we increase the distribution of our services through a reduction of the cost that it takes to produce the unit. The scale play will be accompanied by managed services and moving up the value chain, but still, it will remain a commodity play in the pure connectivity that is grounding everything.

About Sprint Business

Sprint (NYSE: S) is a communications services company that creates more and better ways to connect its customers to the things they care about most. Sprint served 53.7 million connections as of June 30, 2017, and is widely recognized for developing, engineering and deploying innovative technologies, including the first wireless 4G service from a national carrier in the United States; leading no-contract brands including Virgin Mobile USA, Boost Mobile, and Assurance Wireless; instant national and international push-to-talk capabilities; and a global Tier 1 Internet backbone. Sprint has been named to the Dow Jones Sustainability Index (DJSI) North America for the past five years. You can learn about Sprint Business services at www.Sprint.com/business, or follow us @Sprintbusiness, LinkedIn, or our thought leadership blog.

About Jan Geldmacher

Jan Geldmacher is President, Sprint Business. He joined the company in August 2016 and reports to CEO Marcelo Claure. Jan leads Sprint's national sales and service teams focused on delivering wireless, wireline and IoT solutions to large, global corporations along with small- and medium-sized businesses. Before joining Sprint, Jan served as chief executive officer of Vodafone Global Enterprise, the London-based business unit responsible for defining the strategy and operational execution of Vodafone's relationships with multinational corporate customers worldwide. Jan also served as director of Vodafone's Enterprise Business Unit, CEO of British Telecom Germany, Member of T-Systems' executive team and head of international networks and joint ventures with Bonn, Germany-based Deutsche Telecom. Prior to that Jan worked in various management and sales positions at European telecom companies. He started his career with AT&T Global Information Solutions (NCR Corp.). Jan graduated with a degree in Business Administration from the University of Cologne.

Glossary

3GPP	Third Generation Partnership Project
5G	Fifth generation
8K	8,000 pixels [video horizontal resolution]
ADA	Americans with Disabilities Act
AR	Augmented reality
ARPU	Average revenue per user
B2B	Business to business
BBU	Baseband unit
BSA	Base station antenna
BTS	Base transceiver station
BYOD	Bring your own device
Cat	Category
CBRS	Citizens Broadband Radio Service
CDMA	Code division multiple access
CO	Central office
CORD	Central Office Re-Architected as a Data Center
CPRI	Common Public Radio Interface
C-RAN	Cloud RAN
CU	Coverage unit
DAS	Distributed antenna system
DRS	Distributed Radio Systems
DSL	Digital subscriber line
DWDM	Dense wavelength-division multiplexing
eBIU	Enhanced base station interface unit
FTTH	Fiber to the home
FTTX	Fiber to the x
GAA	General Authorized Access
GPRS	General packet radio service
GPS	Global positioning system
GSM	Global System for Mobile Communications
HSDPA	High Speed Downlink Packet Access
IBW	In-building wireless
IMS	IP multimedia subsystem
IoT	Internet of things
ISP	Internet service provider
ITU	International Telecommunication Union
KPI	Key performance indicator
LAA	Licensed-assisted access
LTE	Long Term Evolution
LTE-A	LTE Advanced
LWA	LTE Wi-Fi aggregation
MIMO	Multiple input, multiple output
mmW	Millimeter wave
MNO	Mobile network operator
MPLS	Multiprotocol Label Switching
NB	Narrowband
NGMN	Next Generation Mobile Networks [Alliance]
NH	Neutral host
NR	New radio
OBIS	On-board information system
OBSAI	Open Base Station Architecture Initiative
OEM	Original equipment manufacturer
OTT	Over the top
PoE	Power over Ethernet
QoE	Quality of experience
R&D	Research and development
RAN	Radio access network
RAX	Radio Access eXchange
RF	Radio frequency
RFIC	Radio frequency integrated circuit
ROI	Return on investment
ROU	Remote optical unit
RRH	Remote radio head
SAS	Spectrum Access System
SD-WAN	Software-defined wide area network
SIM	Subscriber Identity Module
SIP	Session initiation protocol
SLA	Service level agreement
SMB	Small and medium business
TCO	Total cost of ownership
TDD	Time division duplex
UCG	Universal connectivity grid
UE	User equipment
UI	User interface
vCPE	Virtual customer premises equipment
VPN	Virtual Private Network
VR	Virtual reality
vRAN	Virtual RAN
WAN	Wide-area network
XaaS	Everything as a service

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Monica Paolini, Ph.D., is the founder and president of Senza Fili. She is an expert in wireless technologies and has helped clients worldwide to understand new technologies and customer requirements, create and assess financial TCO and ROI models, evaluate business plan opportunities, market their services and products, and estimate the market size and revenue opportunity of new and established wireless technologies. She frequently gives presentations at conferences, and writes reports, blog entries and articles on wireless technologies and services, covering end-to-end mobile networks, the operator, enterprise and IoT markets. She has a Ph.D. in cognitive science from the University of California, San Diego (US), an MBA from the University of Oxford (UK), and a BA/MA in philosophy from the University of Bologna (Italy). You can reach her at monica.paolini@senzafiliconsulting.com.