Why stop at the window?

Bringing 5G mmWave indoors

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A broadband connection is more than a link to the home or business. It does not stop at the wall or at the window. It extends throughout the home or business venue to connect all the devices – phones and laptops, but also cameras, TVs and other entertainment devices, sensors – mostly wirelessly, mostly through Wi-Fi. Even if the indoor cellular coverage is good (and often it is not), operators encourage subscribers to use Wi-Fi because operators do not have to pay for the Wi-Fi infrastructure and transport, and Wi-Fi reduces the demand on their cellular networks. And users often prefer Wi-Fi to cellular when indoors, even if they have unlimited cellular access, because Wi-Fi often has a higher throughput and better coverage.

Broadband service providers have gradually expanded their role in managing indoor connectivity by adding a Wi-Fi access point (AP) to the equipment installed on customers' premises. This can be a revenue opportunity and a customer retention tool, but it also helps operators identify and solve customer service issues. Without visibility into the Wi-Fi network, service providers may not know whether a performance issue is caused by Wi-Fi or by the broadband connection, and they may find it difficult to help the customer.

Mobile operators and other service providers who bring FWA to the home or workplace using 5G mmWave have a new powerful tool to complement Wi-Fi connectivity inside the premises: indoor mmWave coverage. MmWave indoors does not eliminate the need for Wi-Fi coverage: mmWave and Wi-Fi complement each other and together they enrich the user experience. For service providers, this is an opportunity to make FWA more valuable to subscribers, increase service stickiness, and increase the frequency reuse of mmWave licensed spectrum. For subscribers, indoor mmWave coverage means higher throughput, and less congestion and interference.

In this paper we explore the opportunity for mmWave FWA service providers to add indoor 5G mmWave coverage along multiple dimensions: deployment options, benefits over a Wi-Fi only model for indoor coverage, business models, and use cases for both residential and business users.

The case for indoor coverage with 5G mmWave

The days of connecting your devices through an Ethernet cable are long gone. Within the home or the workplace, we all are tethered wirelessly, most commonly through a Wi-Fi AP. In most countries, Wi-Fi carries 60% to 85% of wireless traffic (63% according to the Wi-Fi Alliance), of the traffic from mobile devices, and 80% or more of mobile traffic originates indoors.

In many places, indoor cellular coverage is not good, and it is not getting better. The use of higher spectrum frequencies and new building codes that mandate the use of energy-efficient insulating materials limit further the propagation of the wireless signal from the outdoor macro network to indoor locations.

While Wi-Fi has been and continues to be a stunning success in indoor connectivity, it is subject to interference and congestion, and this may reduce its speed and reliability, and increase its latency and jitter. This is because Wi-Fi uses unlicensed spectrum and, to ensure coexistence among co-located networks, it has to use listen-before-talk mechanisms that make it difficult to achieve deterministic performance. Wi-Fi 6 manages contention more effectively than legacy Wi-Fi, but the reliability of the performance will remain lower than for licensed cellular bands, where the network operator has total control over the band and can manage interference and traffic loads.

Adding an access alternative to Wi-Fi in indoor environments where cellular coverage is limited or expensive is valuable to the subscriber. In particular, mmWave indoor coverage is a great complement to Wi-Fi because it provides areas of high throughput and low latency, and deterministic, highly reliable performance. Because mmWave has limited reach and a large amount of spectrum available, congestion is unlikely to become an issue.

While limited in reach, mmWave adds a capacity boost that reduces the traffic load on Wi-Fi (and hence improves Wi-Fi's performance). However, Wi-Fi still provide the coverage throughout the home or workplace.

Why should residential or business subscribers want this boost if Wi-Fi does a good enough job? Some subscribers may use mmWave to increase capacity and offload Wi-Fi traffic to mmWave if their Wi-Fi network gets congested or they cannot effectively manage interference. In addition to greater 5G security, mmWave supports use cases that Wi-Fi is not well suited for, such as online gaming or extended reality (XR) applications, which require both low latency and low jitter, and high reliability. Dedicated gamers will be delighted to have areas in their home where they can play flawlessly, without being tethered to an Ethernet cable, even when the rest of the family is streaming videos to multiple devices.

While mmWave indoor connectivity is a nice-to-have, valuable add-on rather than a must-have feature, it can be a powerful service differentiator for the service provider. In homes with mmWave FWA, adding an internal mmWave repeater does not add much to the subscriber acquisition costs, and it increases the value and stickiness of the service.

Two indoor connectivity scenarios

To examine the value proposition of indoor mmWave, we compare two scenarios: Wi-Fi only and Wi-Fi with mmWave. In both cases, Wi-Fi and mmWave equipment is provided and managed by the service provider. The service provider may or may not charge an installation or rental fee for the equipment in either scenario, but both cases allow for easy self-installation.

In both scenarios, the FWA equipment receiving the mmWave signal from the service provider network is installed on the inside of a window. The equipment has to be installed on a window that is in line of sight with the mmWave macro base station. Software enables customers to select the appropriate location for the equipment if they choose to do the installation.

In the Wi-Fi-only scenario, the CPE on the window integrates the mmWave receiver and Wi-Fi AP at the window, so indoor coverage is exclusively through Wi-Fi.

In the Wi-Fi with mmWave scenario, a mmWave repeater on the window receives the signal from the service provider networks, and transmits it inside the premises to an integrated mmWave and Wi-Fi gateway and to any device that supports mmWave.

Wi-Fi only scenario

The FWA equipment is a mmWave CPE with an integrated Wi-Fi AP that provides indoor coverage from the window. This setup makes it easy for the subscriber to install, because the CPE is a single box that attaches to the inside of the window.

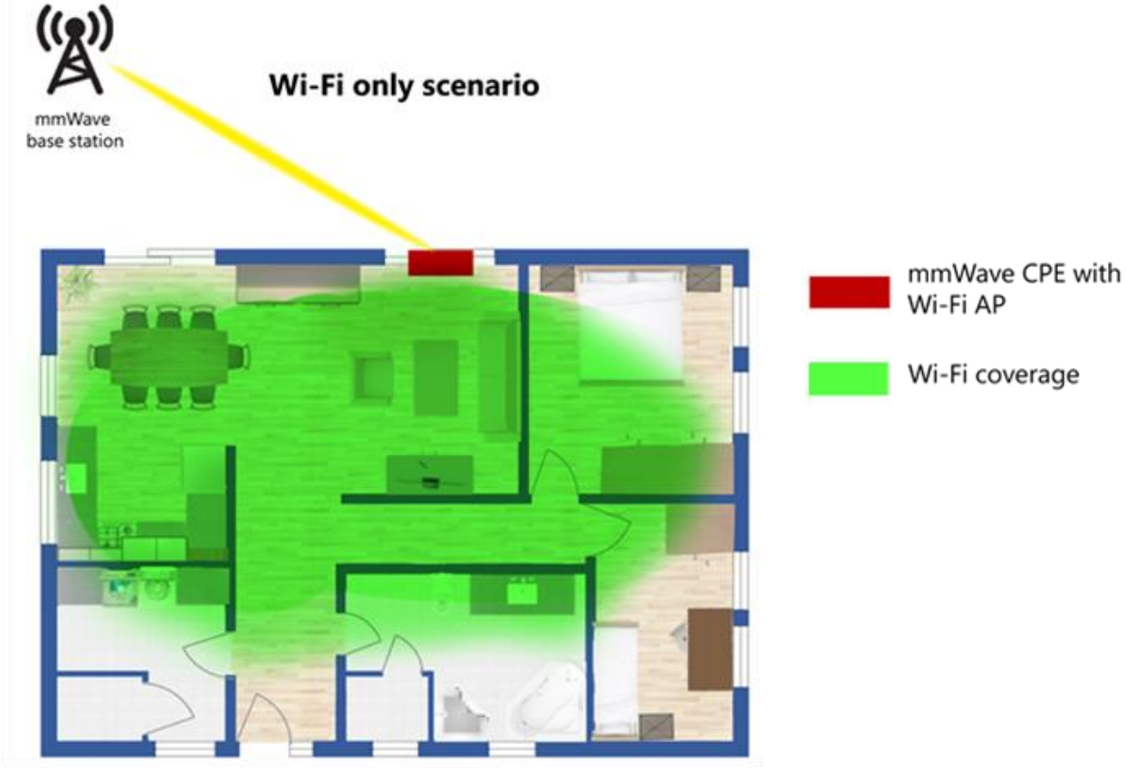
The mmWave CPE provides the broadband connection to the home or business, but the mmWave link stops at the window. The subscriber has access to the FWA broadband connection only through the Wi-Fi AP. The Wi-Fi AP location is dictated by the window location, and, in most environments, this may reduce or constrain the Wi-Fi coverage area.

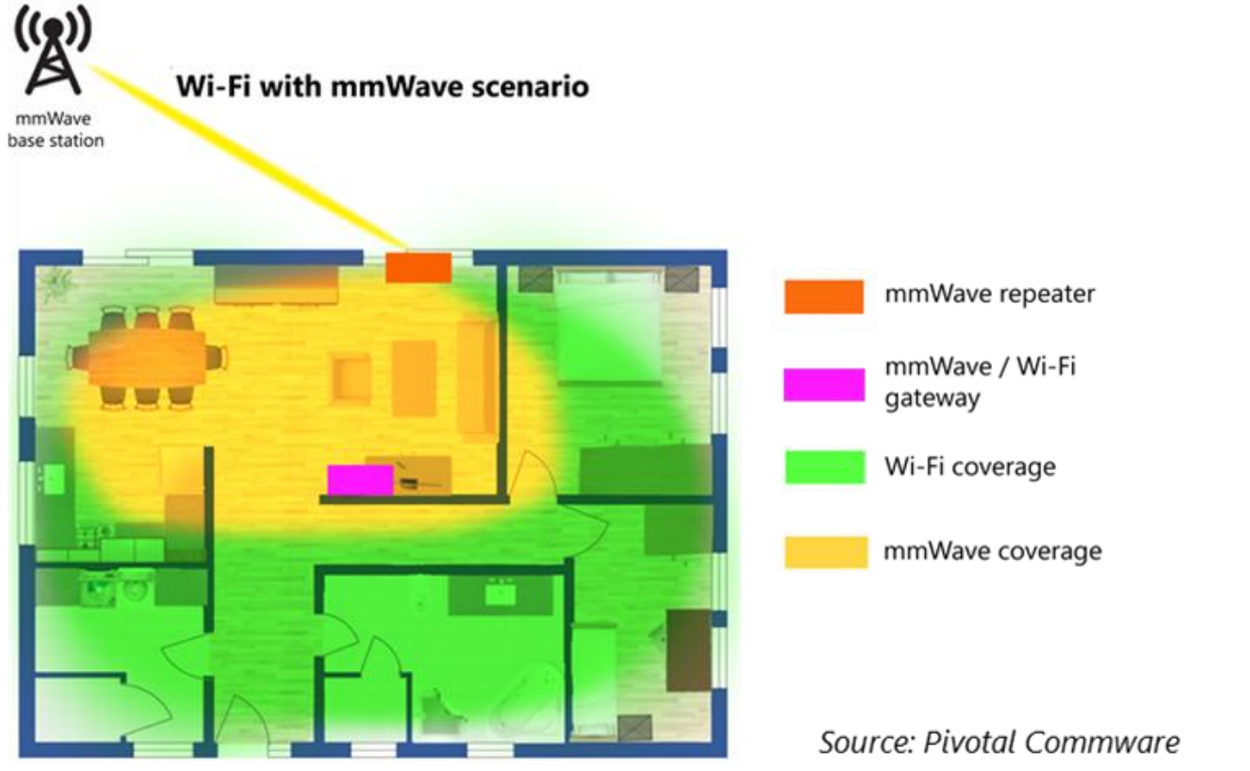
Wi-Fi with mmWave scenario

The FWA equipment is a mmWave repeater mounted on the inside of the window. The mmWave repeater provides both indoor coverage and backhaul to an integrated mmWave and Wi-Fi gateway that the subscriber can place anywhere within the coverage footprint of the mmWave repeater.

The subscriber can connect to the FWA broadband link through Wi-Fi and mmWave. The Wi-Fi and mmWave coverage area are mostly overlapping, with the mmWave footprint being smaller than the Wi-Fi one because of the limited propagation of mmWave frequencies. However, the overall Wi-Fi coverage area will, in most cases, be expanded, because the subscriber can pick the optimal position – e.g., locating the Wi-Fi gateway in a central position is likely to increase its coverage area.

Qualcomm has done multiple trials to explore indoor mmWave performance. In an industrial environment, it demonstrated median download speeds of over 1.5 Gbps in the downlink (400 MHz channel) and 120 Mbps in the uplink (200 MHz channel) in the 28 GHz band.





Source: Pivotal Commware

What is indoor mmWave good for?

The use cases in which mmWave excels are those that require a combination of high throughput, low latency and jitter, and high reliability and deterministic behavior.

Specifically, mmWave is going to be an ideal access technology for applications with rich visual content, with a high resolution and frame rate, such XR (i.e., any combination of AR and VR), and other video-based applications and services. The increase in bandwidth requirements is going to be massive: according to Qualcomm, it will grow from the current 4K 360º video requirement of 10–50 Mbps, to 50–300 Mbps for next-gen 360º video (8K, 90+ FPS, HDR and stereoscopic) and 200–5,000 Mbps for 6DoF video.

mmWave at home

In a residential environment, the two use cases that stand out are online gaming and XR.

Gaming is a widely used application, with gamers playing on average 8.45 hours per week globally, and with mobile phones being the most used gaming device. Online gaming requires an extremely low end-to-end latency – 13–14 ms – which means an even lower access latency, which is difficult to get consistently in a Wi-Fi network. A lower latency not only improves the gaming experience, it also impacts the gamer's ability to score points or achieve targets. Gamers rate fast speeds as the most important factor for user experience, and a third of them mentions limited performance as the reason for not subscribing to a gaming subscription service that does not use a console. Gaming is one of the few applications for which subscribers have shown a willingness to pay, because the optimized, fast and reliable service they pay for can improve the gamer performance. In our Wi-Fi with mmWave scenario, gamers can get a better user experience than they do with Wi-Fi only, as long as they are in the part of the house covered by mmWave and their VR headset or other device supports mmWave natively.

XR applications too require low latency and jitter in addition to high throughput, to be enjoyable and realistic. Without low end-to-end latency – 1–20 msec for immersive experience, and below 5 ms for tactile internet, according to Qualcomm – XR may not work. The user may experience a feeling similar to motion sickness, due to the disruption to the vestibular system, feel confused, or simply not get the intended immersive experience. Indoor mmWave connectivity will improve the quality and reliability of XR, and in turn this will increase the adoption of XR and the value attached to mmWave connectivity.

XR applications have the potential to transform and expand most online activities. Many gaming applications will evolve to effectively become XR applications. Video content and video communications will become an interactive, immersive experience that will create the foundation for the metaverse. With XR, education and health care applications will also become more effective and valuable.

mmWave at work

The enterprise will also benefit from using indoor mmWave for XR applications that can be used for staff collaboration, remote diagnostics and repair, training, or immersive communications.

Robotics, automated operations, automated guided vehicles (AGVs), real-time video applications, and, more generally, IIoT applications also stand to benefit from indoor mmWave's higher reliability, greater security, and lower latency/jitter than Wi-Fi. Healthcare, education, and industrial verticals are among the most eager to adopt XR, according to Perkins Coie.

In enterprises or public venues, mmWave also provides additional capacity and high-throughput connections where the Wi-Fi traffic load is high and insufficient to meet demand. The increase in capacity and throughput will have a double advantage for the user: it will give better connectivity to mmWave devices and will reduce congestion on the Wi-Fi network, thus increasing the overall capacity at the location and improving performance for all devices – Wi-Fi and mmWave ones.

mmWave indoor and outdoor

Indoor mmWave is also a good complement to outdoor coverage for 5G subscribers, because they can keep their cellular connection active as they enter their home or workplace, instead of having to switch to Wi-Fi.

mmWave devices

Currently, 5G phones are the main mmWave devices, and this limits the use cases available to users. With the growing adoption of 5G, an increasing number of subscribers will own 5G devices, and the range of devices will grow to include gaming consoles, XR headsets, tablets and laptops – and these devices can support mmWave. This will increase the attractiveness and value of indoor mmWave coverage to subscribers. At the same time, FWA subscribers with

indoor mmWave will have an incentive to switch to 5G devices.

But, at the same time, the growing use of mmWave in a variety of indoor settings – including enterprises and large venues – will drive an increased demand and availability of IoT and non-phone devices that can connect to mmWave networks. As a result, devices with high throughput or low latency requirements that currently use Wi-Fi in home and workplace environments may soon be able to connect to a mmWave network, either with a built-in module (e.g., for new devices) or with a dongle (e.g., for existing devices). The video streaming quality in a TV may be better when using mmWave instead of Wi-Fi, especially if the Wi-Fi network is heavily used. Similarly, a mmWave connection can provide the right latency for a gaming desktop.

Limited propagation is mmWave's winning feature

For a long time, restricted range has limited the use of mmWave mostly to point-to-point links used for backhaul, and indoor mmWave deployments never took off. This is all changing rapidly. The increased need for indoor infrastructure that supports high capacity density and low latency, and the availability of 5G mmWave equipment and devices that have been initially developed for outdoor networks will drive the deployment of indoor mmWave networks.

In dense indoor environments, mmWave's limited propagation is no longer an obstacle to adoption, but an advantage. A short range means that the spectrum can be more effectively reused, thus increasing the capacity density (i.e., bits per sqft) and avoiding interference. A service provider can use mmWave spectrum for outdoor access and FWA, and for indoor access at the same time, in the same area – and extract more value from its spectrum licenses.

This is much more difficult to do in the sub-6 GHz bands, where an overlapping indoor and outdoor infrastructure can create interference and other transmission issues. Arguably, this is one of the reasons why indoor small cells and other infrastructure has been limited to date: mobile operators find it difficult to manage indoor and outdoor infrastructure in the same locations, and, understandably, prefer to use their expensive licensed spectrum for the more

Wi-Fi and mmWave indoor use cases

	Wi-Fi	mmWave	Residential	Business
Basic data connectivity, including video streaming	●	◔	✓	✓
Voice communications	●	◔	✓	✓
Rich, next-gen video applications	●	●	✓	✓
Gaming, including immersive games	◑	●	✓	
IoT (smart home, smart office)	●	◔	✓	✓
IIoT with tight latency/jitter and reliability requirements	◔	●		✓
XR for healthcare and education applications	◑	●	✓	✓
XR for staff collaboration and training	◑	●		✓
XR for immersive entertainment (sports, fitness, training, concerts and other online events) and metaverse	◑	●	✓	
XR in retail, customer applications	◑	●	✓	✓
XR for remote control and tactile internet, diagnostics and repair	◑	●		✓
Enterprise automation, robotics	◔	●		✓
AVG (e.g., in warehouses)	◔	●		✓
Good ● ◕ ◑ ◔ ○ Bad				

profitable outdoor infrastructure.

All these issues disappear with mmWave. Service providers can use mmWave to extend their coverage to indoor locations – and, in the case of the extension of FWA with an indoor repeater, with a minimal marginal cost, since they already have a macro mmWave network that they can use for backhaul and to provide broadband connectivity to the home or business.

It also turns out that indoor mmWave propagation is not as severely limited as initially expected. While the coverage area of a Wi-Fi AP or a sub-6 GHz small cell is larger and the NLOS connectivity more reliable, mmWave can play an important, complementary role in indoor connectivity to increase capacity and provide offload.

In its headquarters in San Diego, Qualcomm has shown that mmWave can provide good indoor coverage, including some NLOS. While the mmWave signal cannot penetrate thick walls, it can often go through some internal walls, without a big throughput penalty. Other vendors have reported NLOS coverage through reflections in outdoor locations over the last years. Of course, reflection-dependent coverage is highly dependent on topology and cannot be predicted or expected, but it can nevertheless provide a welcome expansion of the footprint.

Is there a sustainable business case for indoor mmWave?

The business case for adding indoor mmWave for a service provider is a simple one. Adding indoor mmWave when signing up a new subscriber does not significantly change the subscriber acquisition costs. The customer acquisition and installation process is the same for both the Wi-Fi-only and the Wi-Fi-with-mmWave scenarios. The only difference is in the equipment selected.

The cost will depend on the equipment features and the vendor, but the largest component is going to be the mmWave equipment on the window, which both scenarios need. The cost difference between a mmWave CPE with an integrated Wi-Fi AP, and a mmWave repeater plus a mmWave/Wi-Fi gateway is going to be low, and represent a minimal percentage of the overall customer acquisition costs.

Pivotal's all-indoor, subscriber-installed Echo 5G provides indoor mmWave coverage at 28 GHz. The repeater measures 4.5" x 5.5" x 1", weighs 1.25 lbs, and plugs into a wall outlet.
Source: Pivotal Commware

If adding mmWave coverage indoors increases the marginal equipment cost, then the service provider may charge a higher rental fee. An equipment cost difference of $24 would translate into $1/month increase in rental fees over a two-year period.

However, because of the benefits that indoor mmWave offers (see table), the service provider may be able to recoup the $24 increase in equipment cost through a reduction of customer support costs. For instance, Nokia estimates that 30%–50% of customer support calls to FWA service providers are related to indoor Wi-Fi, and that such calls cost $20–$30. By improving indoor connectivity a service provider should see a reduction in customer support calls. Eliminating one such call would compensate for the additional $24 that the service provider incurs during installation.

Offering indoor mmWave coverage gives the FWA service provider a differentiator by expanding its indoor coverage capabilities, at a time when subscribers expect the FWA connection to carry on indoors. According to Omdia, 70% of residential Wi-Fi APs are supplied and managed by the service provider. For these service providers – as well as for those that don't offer indoor wireless – adding mmWave to Wi-Fi in their 5G FWA service offering is a low-hanging fruit that benefits them and improves the subscriber experience.

The benefits of indoor mmWave for service providers
Improve the subscriber experience with a minimal marginal addition to the subscriber acquisition cost
Increase the attractiveness and stickiness of FWA service, to attract more subscribers and reduce churn
Expand the role in managing the indoor coverage of subscribers, with improved visibility into network performance and devices, and greater ability to resolve subscriber performance issues
Reduce the incidence of subscriber calls due to slow network speeds (they account for 65% of customer support calls, according to Omdia)
Offer revenue-generating premium-plan options and devices (e.g., for gamers) and smart home/office applications that require cellular connectivity (e.g., security cameras, healthcare devices linked to a provider)
Support XR and other applications that require high bandwidth and low latency more effectively than with Wi-Fi
Offload cellular traffic from macro networks (including sub-6 GHz and 4G traffic) for mobile operators and provide service continuity from outdoor to indoor locations
Increase the use of mmWave spectrum at no additional cost or impact on the macro network
Introduce enterprise plans or services that require edge computing, network slicing or URLLC, stringent SLAs for indoor connectivity, and elevated security to protect enterprise data
Add a mmWave indoor connectivity option as a differentiator for FTTH customers
Motivate subscribers to upgrade to 5G devices (for mobile operators offering bundled cellular and FWA plans)

About Pivotal Commware

Pivotal Commware develops communications platforms, systems and applications based on Holographic Beam Forming®. HBF antenna technology enables network operators to increase network speed, capacity and spectral efficiency using the lowest cost, size, weight and power consumption (C-SWaP) envelope available. The company is privately held and headquartered in Kirkland, Washington.

About Senza Fili

Senza Fili provides advisory support on wireless technologies and services. At Senza Fili we have in-depth expertise in financial modeling, market forecasts and research, strategy, business plan support, and due diligence. Our client base is international and spans the entire value chain: clients include wireline, fixed wireless, and mobile operators, enterprises and other vertical players, vendors, system integrators, investors, regulators, and industry associations. We provide a bridge between technologies and services, helping our clients assess established and emerging technologies, use these technologies to support new or existing services, and build solid, profitable business models. Independent advice, a strong quantitative orientation, and an international perspective are the hallmarks of our work. For additional information, visit www.senzafili.com.

About Monica Paolini

Monica Paolini, PhD, founded Senza Fili in 2003. She is an expert in wireless technologies and has helped clients worldwide to understand technology and customer requirements, 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 she has written many reports and articles on wireless technologies and services. She has a PhD 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).