Closing the digital divide with mmWave extended range for FWA

5G mmWave extended range is a technology breakthrough that redefines millimeter wave as a solution to deliver wide-area 5G coverage. This innovation extends mmWave coverage from a few hundred meters to more than 7km, enabling cost-effective, fixed wireless access services for suburban and rural communities.

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There is a huge demand for more broadband connectivity all around the world, with more than one billion homes still unconnected and even more underserved. Fixed wireless access (FWA) using 5G New Radio (NR) has emerged as one of the most important ways to close this digital divide, and it is rapidly becoming one of the key use cases for 5G [1].

■ FWA over 5G NR is a technique that delivers high-speed internet access by connecting the 5G network to customer premises equipment (CPE) at a fixed location at the consumer's home or enterprise. FWA has been shown to provide a very attractive and cost-efficient alternative to fixed broadband across a wide range of cases and situations, in particular in areas outside city centers where large distances make fiber deployment expensive [2].

FWA traffic volumes can be 10-50 times higher per subscription than for smartphones, and during the COVID-19 pandemic we have seen an increased use of home broadband and greater digitalization of homes and enterprises – effects that are predicted to drive further data volume increases. Since the average revenue per user of communication service providers (CSPs) is not expected to increase to the same degree, it is critical to design FWA solutions cost-efficiently.

Key methods for efficient fixed wireless access solutions

The large unmet demand for broadband connectivity can be met most cost-efficiently with FWA when it is built on the large installed base and global reach of 3rd Generation Partnership Project (3GPP) mobile technologies (4G LTE and 5G NR). CSPs can maximize the established momentum behind 3GPP technologies by deploying FWA together with mobile broadband (MBB) in existing and new spectrum bands, thanks to the options for ensuring efficient spectrum sharing between the two services. Mid bands using time division duplex (TDD) and frequency division duplex (FDD) low bands are sufficient in many FWA cases. In particular, 3GPP TDD mid band such as n41 (2.5-2.7GHz) and n77 (3.3-4.2GHz) unlocks major MBB+FWA combined opportunities.

High-end offerings in dense suburban areas often require additional capacity. In these cases, "high band" millimeter wave (mmWave) spectrum such as 26GHz and 28GHz can be added, either at the macro sites and/or through densification with new street sites. While mmWave spectrum is often associated with these dense deployments, with each site covering only a few hundred meters, the extended range of mmWave provides CSPs with a golden opportunity to expand the use of mmWave spectrum for FWA to sparser suburbs and semi-rural areas as well.

The principle is illustrated in *Figure 1*, where a macro cell site serving a range of several kilometers has been equipped with 5G NR for both mid band and mmWave radios. As all spectrum assets are available for FWA services in the entire sector, the system will automatically serve homes with mmWave coverage primarily using mmWave (shown in red), while other homes without mmWave coverage will be served by mid band (shown in black). The longer mmWave range needed in these deployments is made possible through a new innovation known as mmWave extended range.

> “CSPs CAN MAXIMIZE THE ESTABLISHED MOMENTUM BEHIND 3GPP TECHNOLOGIES BY DEPLOYING FWA TOGETHER WITH MBB”

How to extend the distance covered by millimeter wave signals

Two aspects must be addressed to operate an FWA network in mmWave spectrum over long distances: maximizing the received signal strength and accommodating long propagation delay.

Maximizing the received signal strength

The wavelengths of mmWave signals are short, as are the antenna elements. Consequently, the energy density of the signal reaching the antenna must be high to get a sufficient signal-to-noise level. Using large antenna arrays on the transmitter side together with beamforming enables the energy to be focused in the desired direction. Beamforming on the receiver side further improves the received signal strength.

Beamforming is a core component of the transmission on mmWave frequencies. It can be applied on both the network and device sides,

Terms and abbreviations

3GPP – 3rd Generation Partnership Project | **CAGR** – Compound Annual Growth Rate | **CPE** – Customer Premises Equipment | **CSP** – Communication Service Provider | **DL** – Downlink | **FDD** – Frequency Division Duplex | **FWA** – Fixed Wireless Access | **MBB** – Mobile Broadband | **mmWave** – Millimeter Wave | **NR** – New Radio | **TDD** – Time Division Duplex | **UL** – Uplink | **xDSL** – Arbitrary Digital Subscriber Line

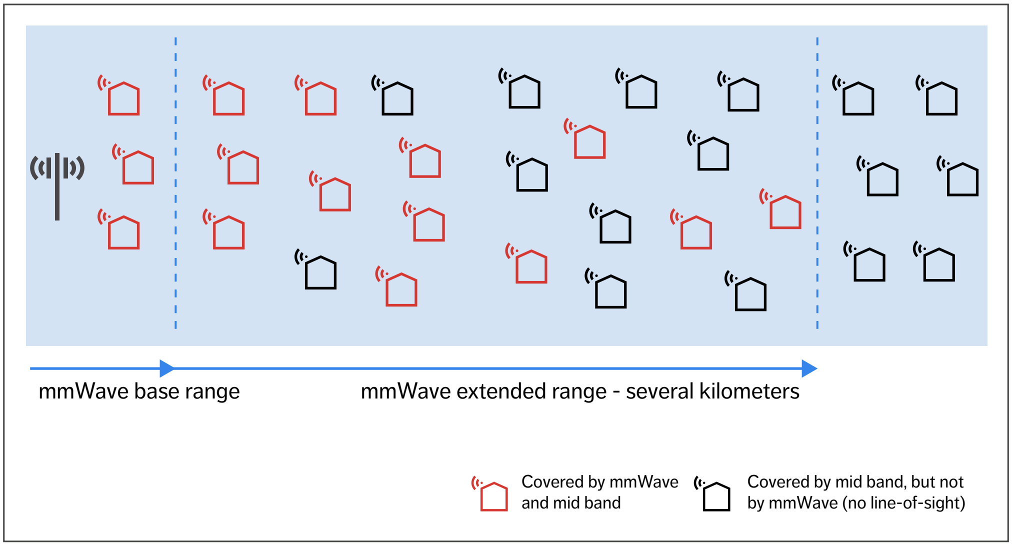

Figure 1 A macro-cell site equipped with 5G NR for both mid band and mmWave, in which well-located homes at a range of several kilometers can be served using mmWave extended range

although the beamforming capability on the network side is more advanced. Beamforming alone is, however, not sufficient to reach distances of many kilometers. Mobile networks operating in the mmWave frequencies today apply beamforming but cannot reach users that are several kilometers away.

With FWA, it is possible to create conditions that are very favorable to long distance coverage. On the network side, existing deployments of high-power radios placed above the main obstacles (by means of macro towers, for example) are already well suited to maximize the downlink (DL) received signal strength.

On the device side, AC-powered CPEs have significantly higher transmit power than battery-powered mobile devices. They can also be placed in the most favorable location for the connection, which is usually outdoors, to avoid wall penetration loss. Both the CPE's transmit power and its location are essential to improve the uplink (UL) received signal strength, which is the factor that typically limits coverage.

Accommodating long propagation delay

The ability to accommodate long propagation delay is a key enabler for long-distance communication. The extended range feature [3] provides this ability. Once sufficiently good signal strength is ensured at a given distance, it is necessary to adapt the communication system to accommodate the propagation delay corresponding to the targeted distance. In mmWave spectrum TDD is applied. With interleaved UL and DL slots, the transceivers need a few microseconds to switch between receiving and transmitting mode. The TDD format therefore includes a short gap period between DL and UL symbols.

The length of this gap period should also accommodate the signal propagation from the transmitter side to the receiver. The longer the distance between these, the larger the gap needs to be. For an MBB-centric deployment where the mmWave cell range does not typically exceed a few hundred meters, mmWave transmissions would only need a very short gap between the DL and UL slots of a TDD pattern.

Figure 2 Testing of the mmWave extended range feature in a semi-rural area at a 6km distance from the macro base station

For longer distances intended for an FWA-capable deployment scenario, the gap needs to be enlarged. This means that a few additional data symbols will be muted to cover for the longer distance. In addition to a larger gap duration, a 3GPP-defined random access preamble format that is favorable to a long-distance scenario is used. Random access preambles are a basic technical component of the 3GPP release 15 specifications and are therefore supported by all devices. On the network side, the detection of random access preambles subject to long propagation delay can be improved by means of an advanced random access receiver algorithm.

The larger gap duration in the TDD pattern required to cover long distances increases the overhead for all devices in larger cells by a few percent and slightly decreases capacity and peak rates. The extended range configuration should therefore be applied only where needed.

Several field testing activities have been carried out to determine how far a radio signal on mmWave frequencies can propagate and what data rates can be expected at this range [4, 5, 6, 7]. *Figure 2* shows the measurement setup for one of the trials that took place in a semi-rural area. The 5G mmWave macro base station 6km away is highlighted with a red circle, and the CPE in the foreground is a Qualcomm 5G Fixed Wireless Access Reference Design. Our field testing showed that in the right conditions, it is possible to achieve DL data rates larger than 1Gbps at a cell range beyond 7km in mmWave frequencies. The feature is now also deployed in commercial networks [8].

Case study: US digital village

The extended range opens up new opportunities to use mmWave spectrum in sparser suburbs and semi-rural areas, which then makes it possible to offload lower frequencies. In such areas, there could be several hundreds of homes per sector. With increasing consumption on both MBB and FWA, the additional capacity that mmWave brings makes such a scenario a sweet spot for combining mmWave and TDD mid band, thereby providing FWA subscribers with high service levels.

In the following simulated scenario, which models

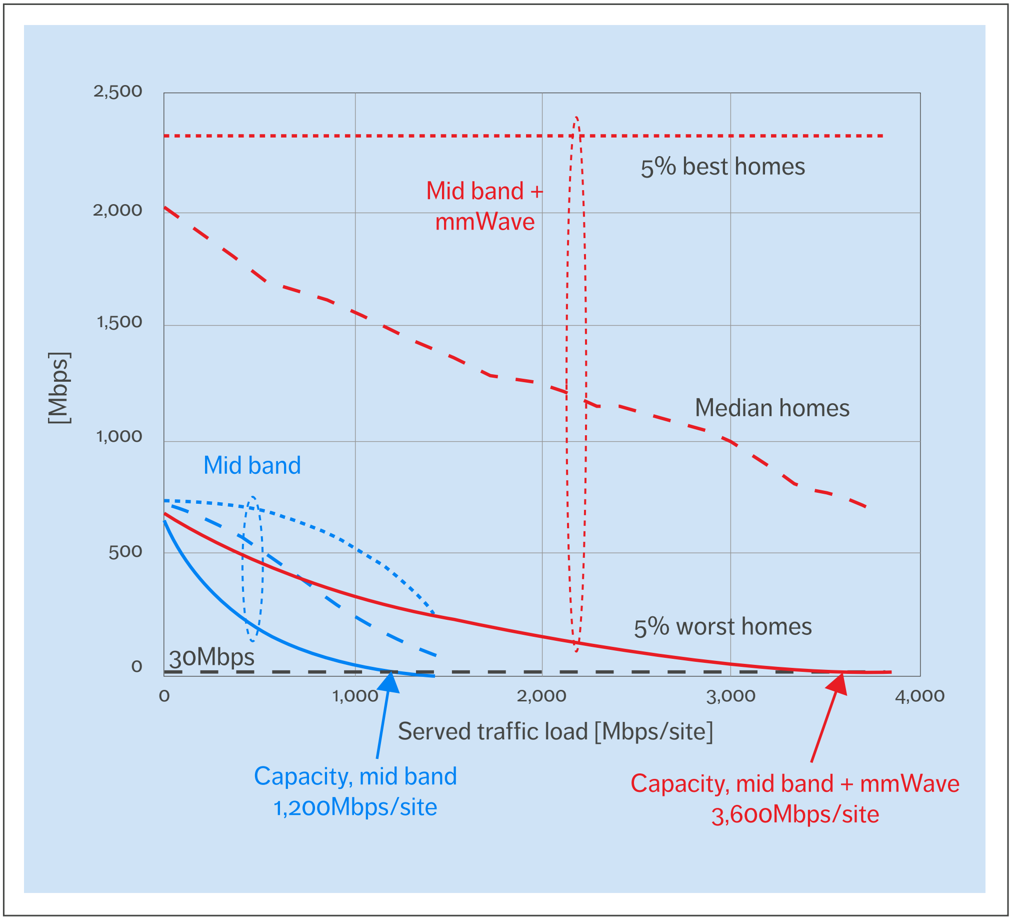

Figure 3 Experienced user data rate – DL user data rate as a function of system load for mid-band-only and mid-band + mmWave deployments

the performance achieved in field trials, we illustrate how mmWave extended range can be used to increase capacity and boost user experience. The case is a version of the digital village case study in the Fixed Wireless Access Handbook [9] that has been adapted to US data consumption patterns.

The original case study includes a stepwise solution and business case analysis showing a return on investment of 22 months. Here, we focus on a comparison of the achievable network capacity, with and without deploying mmWave. The targeted case is a village together with surrounding, more sparsely populated areas where the overall home density is around 150 homes per square kilometer. Current broadband offerings are mainly provided by xDSL or best-effort MBB, but there is no fiber-to-the-home, which makes the area an attractive candidate for FWA.

The existing MBB deployment has as a macro inter-site distance of 3km, and lower FDD bands are used to serve current traffic. Over time, as the MBB traffic grows, it will utilize part of the acquired mid-band spectrum. The excess spectrum can be used for FWA: 100MHz TDD at 3.5GHz and 400MHz in the 28GHz band.

The service targeted by the CSP is FWA with a "fiber-like" experience. This means sold DL data rates of 100-1,000+Mbps without a data cap and with typical DL rates of at least 100Mbps. Combining available spectrum, including lower FDD bands, and mid bands and 28GHz using TDD, the CSP can obtain a combined network deployment catering for both MBB and FWA.

In this analysis, we focus on the mid band and on 28GHz, and we leave out the details on lower bands as well as the performance for the MBB users. However, the suggested approach includes a joint solution for FWA and MBB that also handles the anticipated growth of MBB traffic. Furthermore, as the case is limited by the DL capacity, we leave out the analysis of the UL. To maximize link performance, the case is based on the use of rooftop-placed, high-power CPE that supports mmWave as well as lower bands.

The system is dimensioned to target a minimum DL data rate of 30Mbps for the 5 percent worst located homes, at peak traffic hours, to sustain a fiber-like experience, including multiple HDTV streams per home, also in those worst cases. Regarding data usage, we define a baseline scenario, based on observed current US fixed broadband levels, where the average data consumption per home is expected to be 670GB per month, out of which 90 percent (600GB) is DL traffic [10, 11].

Assuming that 10 percent of the daily traffic occurs during the busiest hour, this corresponds to an average consumption of 2GB per hour at busy hour. We assume an annual growth of 28 percent, partly driven by many homes transitioning from consuming linear TV over satellite or terrestrial broadcast, to using broadband for all media consumption including linear TV and streamed services.

In addition, for comparison we have also defined an all-broadband-media scenario that assumes that all homes have already made this transition. For this case, we assume a consumption rate of 1TB per month per home (900GB per month in the DL) but expect lower annual growth of 10 percent, as the shift to all media consumption over broadband is already completed.

As the capacity needs to grow with an increasing number of customers, as well as with higher average data consumption and speed requirements, it makes sense to gradually increase the capabilities of the network on a needs basis. This means that costs for increased capacity can be taken as late as possible, as opposed to fiber, where a major part of the cost is taken upfront when deploying fiber trunks passing all homes. Furthermore, decisions about capacity enhancements can be made selectively on a sector by sector basis as the numbers of subscribers – and the revenues – increase.

Experienced user data rate

Figure 3 shows the experienced DL user data rate as a function of varying system load for the worst, median and best located homes respectively. The blue curves represent a mid-band-only deployment, while the red ones represent the combined mid-band and mmWave case.

We define the DL capacity as the system load at which the fifth-percentile worst-located homes experience a data rate of 30Mbps (the dashed black line) according to the dimensioning criterion described above. With 100MHz of mid band, the capacity is 1,200Mbps per site, while it is three times higher (3,600Mbps per site) when adding the mmWave spectrum.

Figure 3 demonstrates that, already with a mid-band-only deployment, even the worst-located homes will experience DL rates of 100Mbps or higher at moderate system load, which is most of the time. The peak user rates with mid band alone are in the range of 690-730Mbps depending on the location of the home. After adding 400MHz of mmWave spectrum, the rates of median homes increase drastically, and we also see a significant variation in this range of the peak

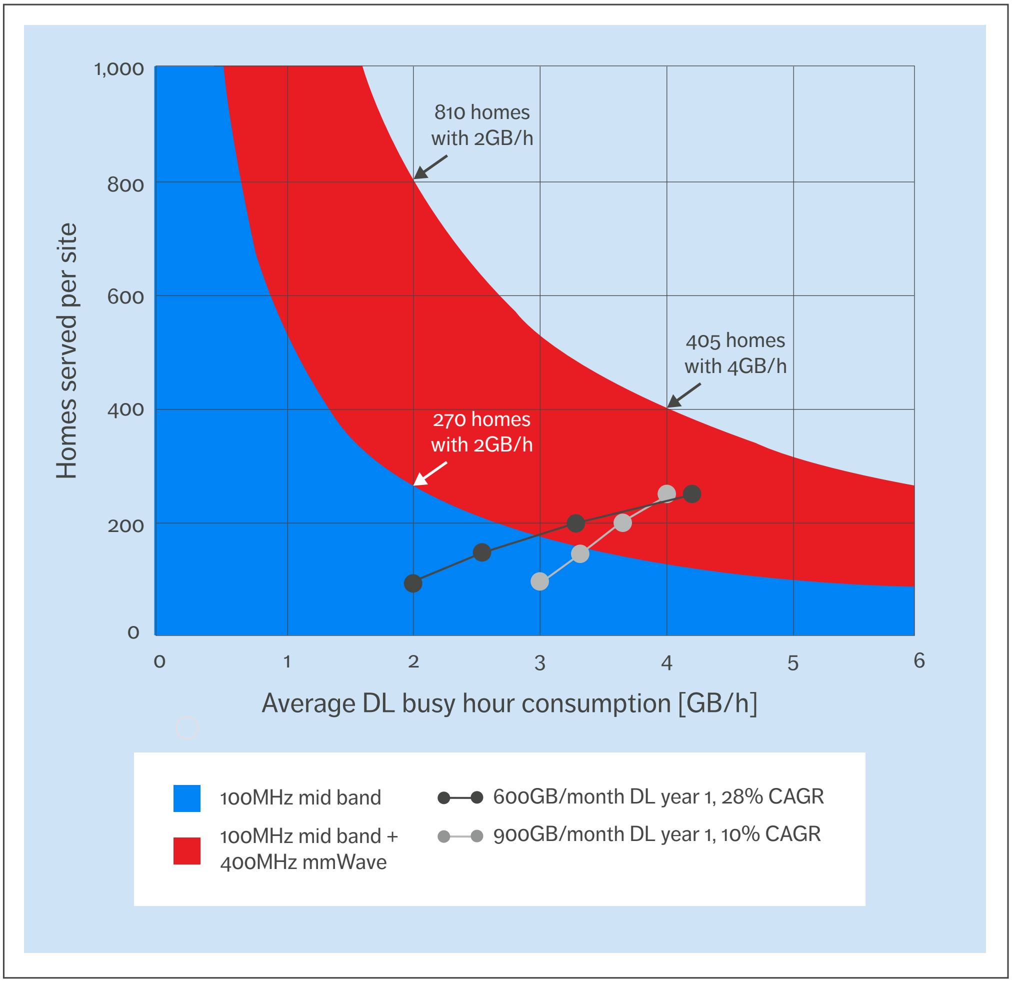

Figure 4 Capacity utilization

rates, which reach up to 2,300Mbps depending on whether or not the home can be served by mmWave.

Capacity utilization

Figure 4 shows how the capacity can be utilized. The colored areas indicate the achievable number of homes served depending on average consumption per home. Blue represents mid band only while red is used for the mid band + mmWave case. As specified in the case study assumptions, the average consumption during peak hours is 2GB in the DL, and then a maximum of 270 homes can be connected per site. With the addition of mmWave spectrum, this number rises to 810, corresponding to 69 percent of all homes if there are 150 homes per square kilometer.

The curves represent two hypothetical growth scenarios, with 100 homes connected in the first year and an additional 50 homes added per year. The dark grey curve represents the baseline scenario starting from 600GB per month and 28 percent annual growth in data consumption, while the light grey curve is the all-broadband-media scenario with higher initial consumption but slower growth. The curves cross at year four, at which point we expect most homes have become all-broadband-media homes, with a corresponding lower annual growth of 10 percent after this point. We clearly see the benefit of adding mmWave spectrum, but also its necessity to handle larger market shares.

The reason for the large capacity improvements that result from adding mmWave extended range is best explained by Figure 1. As mmWave can serve a large number of users close to the base station, it is possible to offload lower bands and use these for homes in less favorable locations instead. The further the reach of mmWave, the larger the offload. Consequently, even though many homes may be unable to use the mmWave spectrum, they will all benefit from the offload from mid band.

The number of homes able to use mmWave will vary by sector size (inter-site distance), foliage and terrain topology, as well as by means to improve the link budget, such as using higher transmitted power and better beamforming capabilities. The propagation conditions of the simulated scenario represent a flat area with a foliage level of around 15 percent, which corresponds to a typical situation in US states such as Illinois and Indiana. In our case, the mmWave coverage was 63 percent at an inter-site distance of 3km.

In addition, homes that can use mmWave can have significantly higher speeds, which opens up for differentiating service offerings with respect to data rates. Homes in favorable locations could be offered higher service levels with subscriptions of 1Gbps or higher to selected homes, using CPE with mmWave capability. Meanwhile, subscribers in less favorable locations, where the mmWave signal is not sufficient, could be offered less expensive mid-band CPE and lower speeds. A dedicated prequalification method would be needed to achieve this.

> “THE DEPLOYMENT OF MMWAVE RADIOS IN ADDITION TO MID-BAND RADIOS RESULTS IN THREE TIMES HIGHER CAPACITY”

Result: Three times higher capacity

To summarize the case study, the deployment of mmWave radios on the macro sites in addition to mid-band radios results in three times higher capacity compared to mid-band-only deployment. It can handle both the baseline scenario and the all-broadband-media scenario with a margin, including realistic growth rates for both MBB and FWA. The network will be able to serve more than 400 homes per site with an average consumption of 4GB per busy hour, corresponding to a monthly DL consumption of 1.2TB. In addition, mmWave spectrum opens up for differentiated speed offerings with 1Gbps+ subscriptions to prequalified homes. Again, it is worth pointing out that the solution is a joint FWA and MBB deployment and that we also utilize the radio resources of legacy FDD bands.

Conclusion

As billions of people continue to wait for reliable fixed broadband connections, fixed wireless access (FWA) is an efficient and scalable alternative with significantly faster time to market. The extended range of millimeter wave (mmWave) spectrum is an innovation that, in combination with mid band, further enhances the comprehensive 5G FWA solution and enables profitable use of mmWave spectrum. With the capacity offload that mmWave enables, mid band can serve a larger number of homes at more distant, challenging locations, making it possible for communication service providers to offer high-end “wireless fiber” services in sparser suburban and semi-rural areas and make substantial progress toward closing the digital divide.

Further reading

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- **Ericsson, Leveraging the potential of 5G millimeter wave, available at:** *https://www.ericsson.com/en/reports-and-papers/further-insights/leveraging-the-potential-of-5g-millimeter-wave*
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