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WHITEPAPER

# Understanding mmWave Planning : A TechM Perspective Whitepaper

# Abstract

By 2028, data traffic is expected to grow ~4x compared to data traffic in 2022 globally. One of the main drivers for this exponential growth is wide adoption of 5G networks and use cases that it will enable e.g., ultra-high definition (UHD) videos, metaverse, real time gaming, fixed wireless access (FWA), and multiple enterprise requirements. The current low and mid band frequencies won't be able to handle this huge data traffic growth due to its limited bandwidth availability. Introduction of mmWave frequency in radio networks enables wider channel bandwidths to be used in 5G networks and will play a key role in providing required 5G network capacity. It will unleash great opportunities and new revenue streams for communications service providers (CSPs/enterprises) to meet the forecasted data demand. However certain considerations need to be in place while we plan networks with mmWave. This white paper presents a comprehensive study to understand mmWave characteristic and associated radio frequency planning using smart, modular, automated, artificial intelligence (AI) based planning tool. It also elaborates the advantages and challenges of mmWave and how they are being addressed using different techniques. Finally, a simulation study is presented to showcase fixed wireless access kind of network using mmWave frequency.


*(n.d.). Retrieved from https://www.3gpp.org/*

# Key Takeaways

# Importance of mmWave in 5G and its Global Status

## Role of mmWave in IMT 2020 5G vision and use cases

The capacity constraints and frequency bandwidth shortage in low and mid band spectrum experienced by wireless communications has especially motivated the use of the unutilized mmWave bands to meet the forecasted data traffic growth. The mmWave spectrum for 5G use is typically from 24 GHz and up till 71 GHz as per 3GPP TR 38.101-2. This spectrum band is also popularly known as FR2 in cellular world. Due to inherent unique characteristics of mmWave, this band is essential for the deployment of high-capacity, low-latency 5G networks.  It complements low band (<2 GHz) and mid-band (2 GHz - 7 GHz) spectrum implementations in dense urban areas and provides fiber-like throughput to suburban and rural areas through 5G fixed wireless access (FWA) technology. It also ensures reliable, secure, and low-latency networks for Industry 4.0.v

The mmWave spectrum comes with huge spectrum range (in GHz) and offers large channel bandwidth ranging from 50 MHz to 400 MHz for the mmWave frequencies till 52 GHz and channel bandwidth up to 2000 MHz for the frequencies ranging from 52 GHz to 71 GHz as per 3GPP release 17. This makes it unique to build high-capacity networks for innovative use cases and digital evolution of global community.

5G use cases using mmWave are described in figure 1:

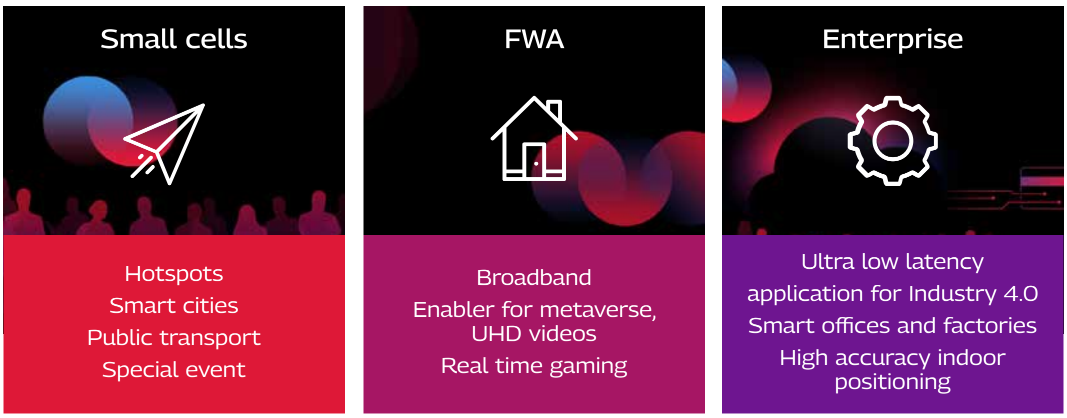



*Figure 1:  mmWave 5G use cases*

## Global mmWave spectrum view

The mmWave frequency range is quite wide in 3GPP ranging from 24 GHz to 71 GHz. However, the most popular mmWave spectrum range as of today is 24 GHz to 28 GHz as these frequencies share a lot of the same performance characteristics. The other preferred mmWave band range is from 37 GHz to 40 GHz and 47 GHz frequencies across the globe. Table 1 below shows FR2 operating bands as per 3GPP Release 17.

| Band | *f* (GHz) | Common Name | Freq. Range (GHz) | Channel Bandwidths (MHz) |
|---|---|---|---|---|
| n257 | 28 | LMDS | 26.50 - 29.50 | 50, 100, 200, 400 |
| n258 | 26 | K-band | 24.25 - 27.50 | 50, 100, 200, 400 |
| n259 | 42 | V-band | 39.50 - 43.50 | 50, 100, 200, 400 |
| n260 | 37/39 | Ka-band | 37.00 - 40.00 | 50, 100, 200, 400 |
| n261 (subset of n257) | 28 | Ka-band | 27.50 - 28.35 | 50, 100, 200, 400 |
| n262 | 47 | Ka-band | 47.2 - 48.2 | 50, 100, 200, 400 |
| n263* | 60 | V-band | 57.00 - 71.00 | 100, 400, 800, 1600, 2000 |
| * This is for unlicensed band operation. | | | | |

*Table 1: 5G mmWave bands nomenclature*

The below figure 2 shows the global view of allocated & reserved mmWave spectrum bands for different regions:

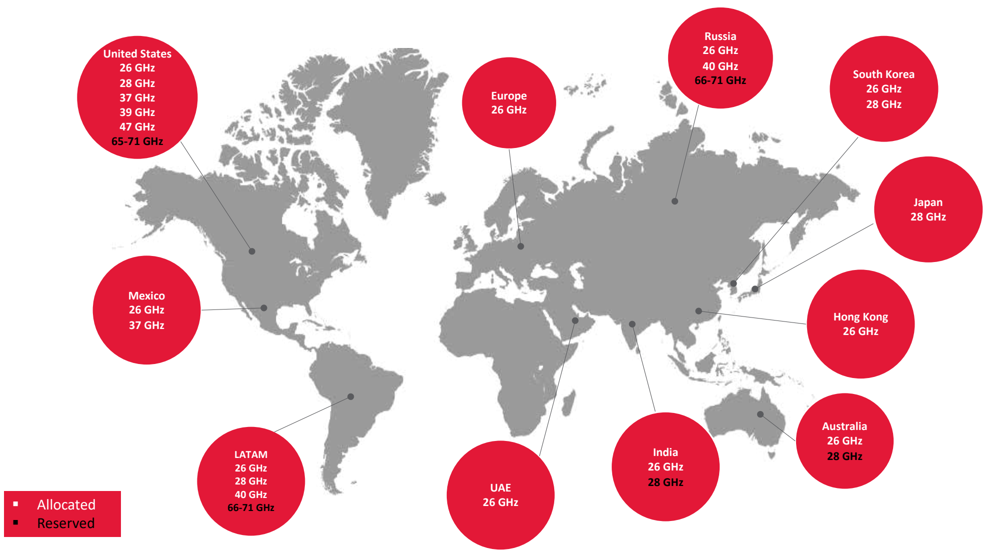



*Figure 2: Global view of 5G mmWave reserved bands (source: TMG & GSMA)*

# mmWave Advantages and Challenges

The inherent characteristics of mmWave brings some advantages and challenges. We have summarized these characteristics and have considered the same while building the planning scenarios.

## Advantages

1. **Bandwidth:** Large amount of spectrum available in mmWave which allows standards body to design/standardize large channel bandwidth. 3GPP has standardized bandwidth of 50 MHz up to 2000 MHz depending on mmWave band under consideration. Due to large channel bandwidth, it is the ideal choice for operators to build high-capacity networks.

2. **Shorter TTI and Low Latency:** 5G NR allows to use flexible subcarrier spacing and mmWave are standardized for higher sub carrier spacing like 60 KHz, 120 KHz and 240 KHz. The ecosystem is aligned to use 120 KHz for the deployments. In comparison to LTE and 5G low bands which works for 15 KHz SCS with slot duration is 1 ms, the mmWave 120 kHz SCS slot duration is 0.125 ms (1/8th of 15 kHz SCS). In 5G, the transmission time interval (TTI) is scheduling entity and equals to 1 slot duration therefore mmWave represents a much shorter TTI duration which leads to low latency.

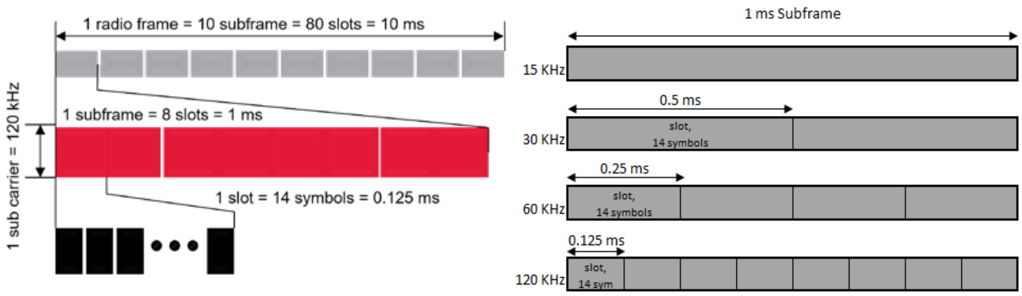



*Figure 3: NR frame configuration for mmWave*

3. **Massive MIMO Antenna:** Massive multiple input, multiple output (MIMO ) is a technique of employing a larger number of antenna arrays typically greater than 8. The antennas at each end of the communications circuit are combined to minimize errors, optimize data speed, and improve the capacity of radio transmissions by enabling data to travel over many signal paths at the same time. mmWave are the waves with wavelength in range of millimeter which enables packing large number of antenna elements in a smaller form factor as compared to traditionally systems. A massive MIMO system employs an antenna array with many antennas typically in the range of 64 - 512 or even further. This technique further enables better performance results in combination with beamforming as explained in below point.

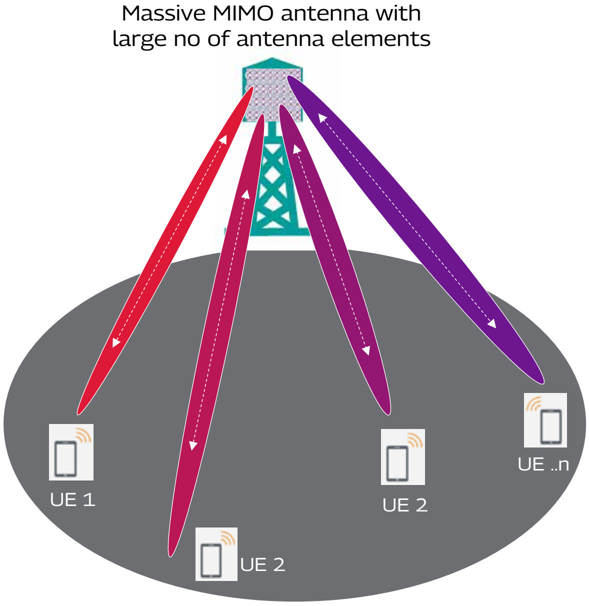



*Figure 4: Massive MIMO*

4. **Beam forming Antenna:** Beamforming is a spatial signal processing technique for directional signal transmission or reception. It is achieved by intentionally controlling the phase and relative amplitude on the same signal at each antenna by a beamformer. A beamformer amplifies the transmitted/received signals in one direction than others. Pointed beams directed towards users improves the received signal quality and reduces inter and intra-cell interference due to directional signal transmission. Transmit and receive beamforming power gain, coupled with reduced interference, boosts signal-to-interference-plus-noise ratio (SINR), bringing higher data rates, more cellular capacity, and improve cell coverage.

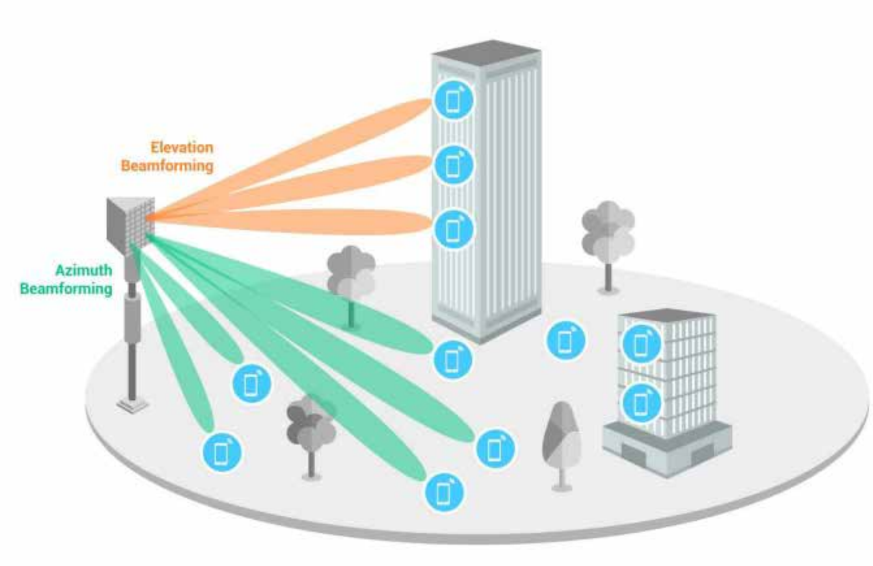



*Figure 5: Beamforming*

## Challenges

mmWave behaves differently in several aspects from the sub-6 GHz frequencies. Let's discuss the key challenges that would be faced while working with mmWave due to its inherent characteristics.

1. **Losses in mmWave:** The propagation link loss in mmWave is significantly higher than in low bands/mid bands. Moreover, the loses in the non-line of sight (NLOS) scenario are further higher as compared to line of sight (LOS) scenario, for the same frequency band in mmWave. Below are the key losses considered while planning a network in mmWave

   - **Free Space Pathloss:** The mmWave suffer higher pathloss relative to lower frequencies, thus limiting the range. For the same distance, compared to 1 GHz, the free space pathloss at 28 GHz is approximately 29 dB higher. While at 38 GHz, the free space pathloss is approximately 32 dB higher

   - **Blockage (Shadowing Effects):** mmWave signals tend to be more sensitive to obstacles in the environment than sub-6 GHz signals because the wavelength is in millimeters, so most objects in the environment appear relatively larger (for e.g., water drop). When in contact with such objects, mmWave signals might experience full or partial signal absorption, reflection, scattering, and/or diffraction. Shadowing effect is generally categorized into three categories: penetration losses, foliage losses, body, and hand losses.

| Environment | Material | Thickness (cm) | Typical Penetration Loss (dB) @28GHz |
|---|---|---|---|
| Outdoor | Tinted Glass | 3.8 | 40.1 |
| | Brick | 185.4 | 28.3 |
| Indoor | Clear Glass | <1.3 | 3.6 - 3.9 |
| | Tinted Glass | <1.3 | 24.5 |
| | Wall | 38.1 | 6.8 |

*Table 2: Typical penetration losses at 28 GHz*

| Frequency Band (Ghz): | 28 GHz |
|---|---|
| Sparse tree (dB) | 8 |
| Dense tree (dB) | 15 |
| 2 tree (dB) | 19 |
| 3 tree (dB) | 24 |
| Typical foliage loss (dB) | 17 |

*Table 3: Typical foliage loss at 28 GHz*

- **Scattering:** Objects with larger size than the propagating wavelength will cause reflection. On the other side, surface irregularity reduces the effective wavelength to create scattering. As a result, surfaces which have comparable wavelengths are common sources of scattering or diffuse reflection in mmWave propagation. The effect of scattering heavily influences mmWave channel modeling based upon ray tracing concepts.
- **Atmospheric Loss:** Radio frequency waves while traveling through the atmosphere are absorbed by gas molecules via electric- and magnetic-dipole absorption processes, this is called atmospheric absorption losses. For the mmWave frequencies the dominant sources of atmospheric loss arise from oxygen (O2) and water vapor (H2O). The mmWave peaks are centered roughly near 23 GHz (H2O), 60 GHz (O2), 115 GHz (O2), 180 GHz (H2O) and 315 GHz (H2O). Thus, rain can create a significant impact on most popular band of mmWave deployment i: e 24-28 GHz. A typical 3 dB rain/ice margin needs to be considered while planning for 24-28 GHz bands.

2. **Shorter Range-** Due to the shorter wavelength of mmWave, they travel less distances in environment compared to low and mid bands. This makes the cell range shorter compared to mid and low bands.

## Addressing the Challenges of mmWave

In addition to the technical challenges seen above, below mentioned are the operational challenges of mmWave due to their inherent propagation characteristics and it is very new in the cellular communications ecosystem:

- Limited coverage
- High losses in non-line of sight
- Limited deployment scenario (FWA only)
- Product ecosystem readiness

However, these can be compensated using latest techniques and advancement in ICT world. Below are the key techniques:

## Beam forming

Beamforming technique as discussed in section 2(a) helps to address the above challenges in mmWave. Beamforming will help to overcome the propagation losses by pointing narrow beams towards the users and called as beamforming gain. There are other techniques in beamforming that helps to improve coverage and mobility in mmWave.

1. **Beam Sweeping:** It is the technique to transmit the beams in predefined directions in a burst at regular intervals to provide the continuous coverage of control channels for all the UE present in a cell. Typically, the primary and secondary synchronization signals and broadcast channels get transmitted at regular intervals in each beam to provide initial access and keep the UE connected to the network.

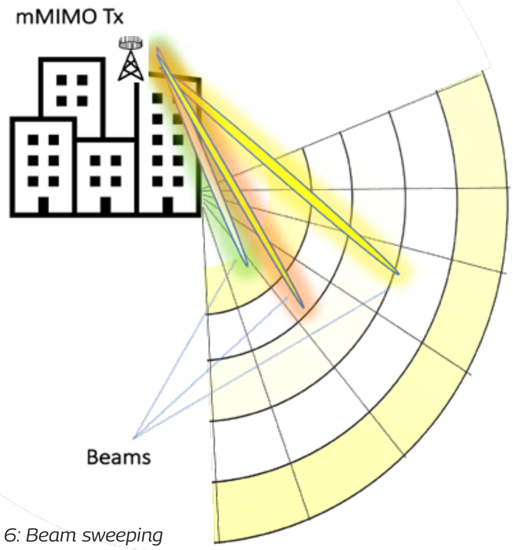



*Figure 6: Beam sweeping*

2. **Beam Switching:** There are multiple beams in beamforming used in mmWave and a UE is latched to the best serving beam for data transmission with the network. If the UE moves out of that beam coverage, Beam switching technique helps to select the best serving beam for that UE at the new location for smother mobility and provide continuous coverage.

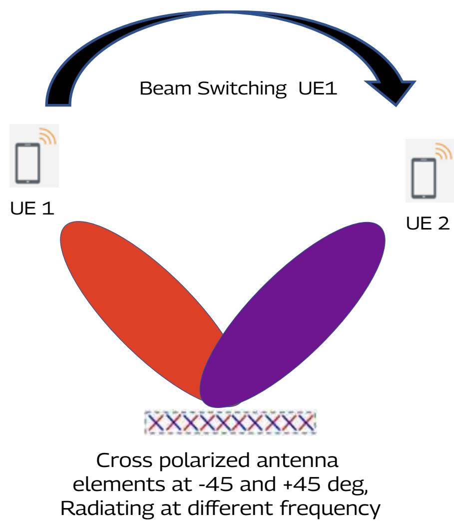



*Figure 7: Beam Switching*

## Dual Connectivity

Dual connectivity is a technique in which a UE is connected to a network with two different nodes (LTE+NR or NR+NR) simultaneously. The architecture where one node is of LTE and other node is of 5G NR, is referred to as EN-DC. Similarly, when both the nodes are of 5G NR, is referred to as NR-DC architecture.

The challenge of uplink limited cell range of mmWave network can be overcome by using it in dual connectivity mode by having the uplink on either LTE eNodeB in case of EN-DC or on 5G NR gNodeB with low/mid band in case of NR-DC. The below figure 9 is a logical representation to understand EN-DC architecture.

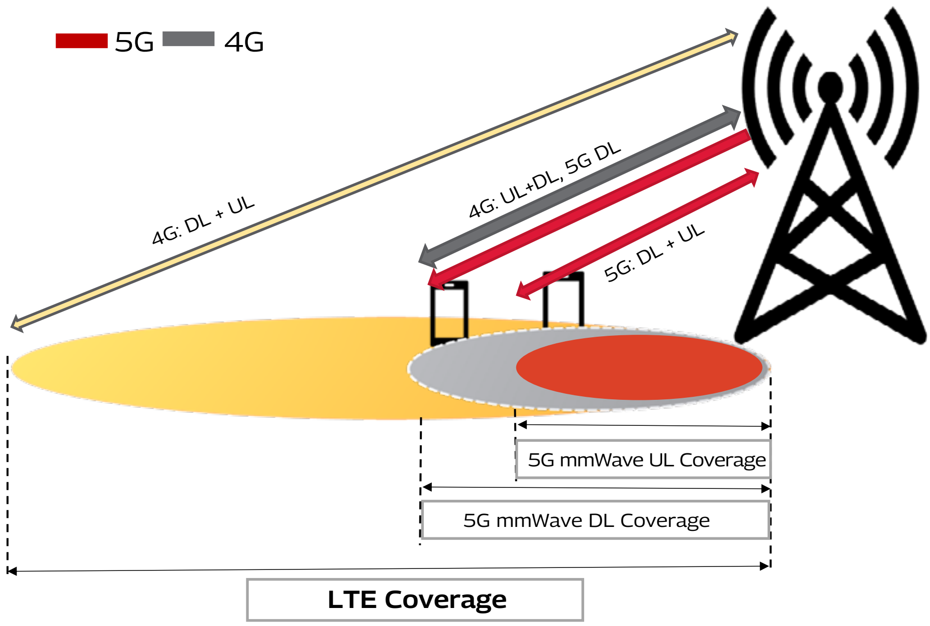



*Figure 8: mmWave coverage EN-DC Scenario*

## Carrier Aggregation

Carrier aggregation (CA) is said to be combining of two or more carriers together to increase the data rates. CA can be used to aggregate up to 800 MHz of spectrum with up to 8 carrier components in DL (as on today) The large spectrum and higher channel bandwidth in mmWave enable to realize up to 800 MHz aggregated bandwidth- leads to higher throughput and capacity.

The carrier aggregation across the FR1 and mmWave bands can be used for extending the coverage by leveraging FR1 band for UL channel. These carrier aggregation band combination strategies will need to consider at network planning stage to make full potential of mmWave in the network.

## Product Ecosystem

mmWave are newly introduced to mobile telecommunication. The product ecosystem i.e., radios, antenna, user devices, CPE are getting developed. Also, the product readiness at this point of time supports 'Non-Stand Alone' type of deployments.

The mmWave products for 'Stand Alone' kind of deployment are still getting developed and getting tested in lab and not mature for commercial deployment at this point of time.

The mmWave coverage can also be extended with the use of high-power CPE. The higher transmit power of the UE (CPE) will extend the UL coverage, thus helping reduce or eliminate the DL-UL imbalance to certain extend.

OEMs are also making use of random-access preamble format which is favorable for long distance scenario as defined in 3GPP R15 and by developing the necessary algorithm in the radio system.

## IAB and Smart Repeater Solutions

There are some techniques and features which are in development phase to ease the mmWave network deployment and extending the coverage. IAB and smart repeaters come as techniques and will be offered as unique proposition for mmWave solutions for variety of deployments. Both solutions currently, are not part of our planning exercise but as we go further, both solutions need to be considered while network planning.

**Integrated Access backhaul (IAB) –** 3GPP has defined new topology for IAB where a RAN node integrates wireless backhaul connection as well as providing connectivity to UEs. This topology will helps extending mmWave deployments in indoor and outdoor locations with reducing capital cost of infrastructure, speeding up the deployment and lower the requirement of fiber at every gNodeB location.

Smart Repeaters – 3GPP is defining network-controlled RF repeater with adaptive beamforming, which could greatly extend the coverage.  This technology can be used to amplify a 5G mmWave signal and then transmit the boosted signal in the required direction. Smart repeaters can be installed easily on streetlights, lampposts, walls, and windows, reducing the high cost of a truck roll, complex zoning and trenching that are typically required for fiber connections.

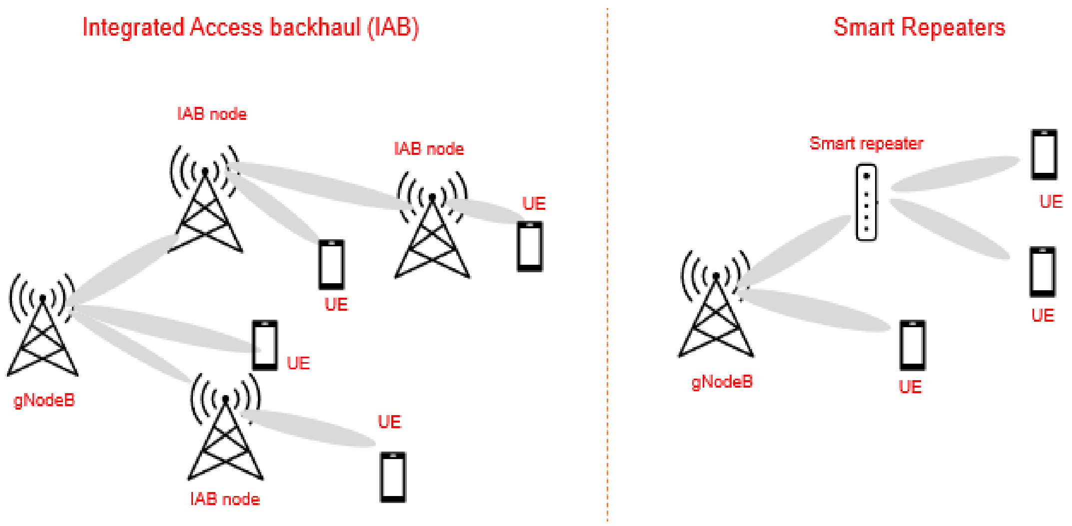



*Figure 9: IAB & Smart repeaters*

# mmWave RF Planning

The small coverage footprint of mmWave sites means they are not suited to providing contiguous coverage. But their high bandwidth means they are very well suited to high-capacity requirements where the location of the traffic is known. So, it becomes very important to choose the right strategy to plan mmWave network depending upon the use case and available resources. Below are the key points that needs to be taken under consideration while planning mmWave networks.

## Strategic planning

### Spectrum Strategy

To realize all the use cases of 5G it is recommended to use mmWave along with mid band and low band with the right spectrum strategy. It is recommended to use low band frequency as an overarching coverage layer. Mid band can be used to cater both capacity and coverage requirements. However, the high user density and high demand areas can be covered with mmWave as a capacity layer.

- **Using mmWave as co-existence with low or mid band:** 5G in low and mid bands will be good for wider coverage and decent capacity but will not meet the huge demand and low latency requirements for use cases like FWA, HD video and gaming, metaverse, holographic applications. So, building a small cell network using mmWave will help to address these high demand and low latency requirements. 5G mmWave small cells as an underlay can be deployed in two scenarios.
    - **User experience enhancement at the cell edge:** in this scenario the mmWave small cell will be deployed at the edge of the macro cell to improve the cell edge user experience. In this case a partial overlap of Macro cell and small cell coverage will be there, and this can be applied to both indoor and outdoor scenarios.
    - **Capacity enhancement:** in this scenario the mmWave small cell will be deployed under complete umbrella layer of mid/low band Macro cell to increase the capacity of a targeted area/hotspot.
- **Using mmWave as standalone:** Due to large amount of spectrum in mmWave band, the spectrum cost is quite less as compared to mid or low bands which makes it an ideal choice of enterprises and wider use like smart cities, public transport areas, hotspots and FWA. 3GPP standards do support stand-alone (SA) deployment on mmWave, however due to lack of product ecosystem this option is not feasible at present. Soon, once the product ecosystem is ready mmWave deployment in SA mode will be supported.

### Subcarrier spacing and frame configuration

1. **Subcarrier spacing:** One of the most distinguishing features of 5G NR from LTE is variable subcarrier spacing (SCS) or also termed as numerology. The multiple numerologies viz. 15 KHz, 30 KHz, 60 KHz, 120 KHz and 240 KHz allows 5G to support diverse deployment scenarios and diverse end-user applications. Low/mid (FR1) bands use 15, 30, 60 KHz SCS and provides

wider coverage and good capacity. mmWave (FR2) uses 60, 120 and 240 KHz subcarrier spacing to provide higher throughputs and ultra-low latency.

- mmWave has high air interface propagation losses and hence the cell range is smaller. Small cell range has shorter propagation channel delay spreads. To match this shorter channel delay spread there is need for shorter cyclic prefix and shorter symbol duration which can be achieved using higher SCS like 120 KHz.

- mmWave frequencies suffer from greater oscillator phase noise which causes a random jitter in the phase of the received signal. The magnitude of this jitter is relatively small when compared to the magnitude of the high SCS thus higher SCS are more robust against this jitter.

2. **Frame Structure:** 5G NR supports flexible frame configuration and provides a unique feature through which each symbol within a slot can either be used to schedule an uplink packet (UL) or downlink packet (DL) or Flexible (F). A symbol marked as flexible means it can be used for either uplink or downlink as per requirement. As per 3GPP TS (38.213 Table 11.1.1-1), there are 256 slot formats. Out of 256 formats, first 56 are already defined by 3GPP with various combinations of D, U, F. The slot/subframe configuration of mmWave shall be aligned with the other existing TDD systems to avoid interference. The preferred slot configurations are 3:1 and 4:1 (DL: UL).
The frame configuration should be defined in the planning tool as per the use case. In our exercise we have chosen below configuration for a DL heavy data use case.

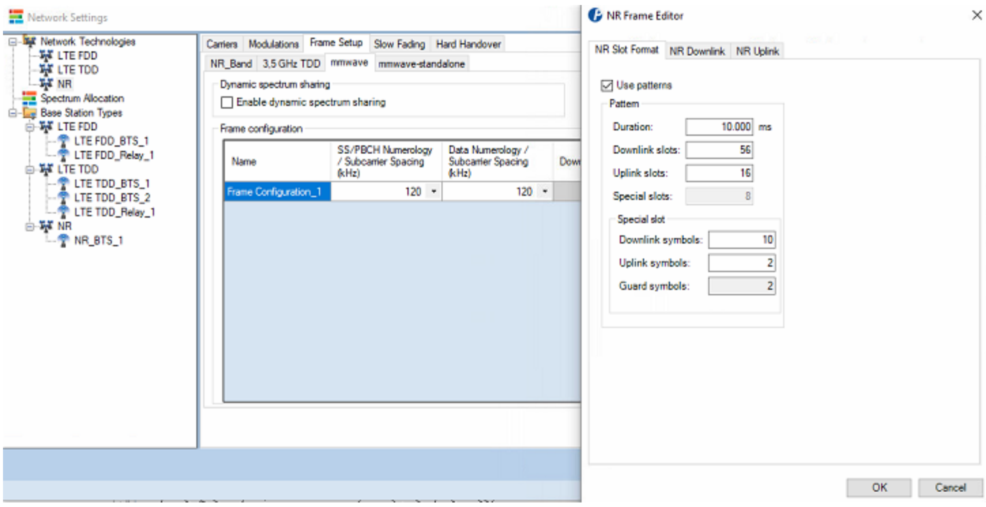



*Figure 10: NR Frame configuration*

## NSA or SA

5G NR supports both NSA and SA deployment mode and let's understand which strategy is the right fit in different scenario. NSA mode has been mostly preferred in early mmWave deployment with one clear reason that 4G core was readily available and current product ecosystem does not support mmWave SA mode deployment. One should keep in mind the below points while planning a mmWave network:

- While using NSA mode the architecture is using EN-DC which means the control plane is managed through LTE and hence lower SCS is used. In this mode we can achieve high throughput network however cannot reach to the maximum potential of mmWave in terms of low latency.
- One can also use mmWave in SA mode in the NR-DC architecture. In this mode we can achieve high throughput network and better latency as compared to EN-DC scenario. In this architecture also we must plan low/mid band frequencies for the control channel networks and the mmWave layer for the user plane.
- Independent SA mode for only mmWave network will be feasible once the product ecosystem is ready. In this mode we can achieve the lowest latency possible using mmWave & higher throughput as well.

## mmWave planning scenarios

Keeping in consideration the advantages and challenges in mmWave, RF planner needs to know exactly which are the high traffic density areas and ensure to plan the mmWave sites very close to these traffic areas. In this section we have explained the mmWave deployment scenarios, realized by Tech Mahindra's planning team and InfoVista's advanced planning tool. The various use cases which can be realized using mmWave spectrum can be broadly categorized into two:

1. **FWA/Enterprise**
2. **Small cells/Hotspot**

To achieve the end results of the planning process RF planner must go through several different activities. We have described the key activities involved in this process here.

## Link Budget

For this link budget calculation, we have chosen an urban area as the area of interest. Further consideration is as below:

- Frequency: FR2/mmWave spectrum, n257 i.e., 28 GHz
- Channel bandwidth: 100 MHz
- Service target: 50 Mbps in downlink and 10 Mbps uplink.
- Radio transmit EIRP: 60 dBm
- CPE transmit power: 33 dBm
- CPE antenna gain: 8 dBi

Some key assumptions for this link Budget are as below:

| Parameter | Assumption | Unit |
|---|---|---|
| **Propogation Model** | UMa (Urban/Sub Urban Marco) | Ref: 3GPP TS 38.901 |
| **SCS** | 120 | KHz |
| **CP Noise Figure** | 7 | dB |
| **gNB Noise Figure** | 6 | dB |
| **MIMO** | 2x2 | Tx/Rx |
| **Channel Model** | CDL (D) | Ref: 3GPP TS 38.900 |

*Table 4: 28 GHz LB assumptions*

Typical link budget at 28 GHz frequency is shown in Table 3:

| DL Link Budget | Value | UL Link Budget | Value |
|---|---|---|---|
| **Typical Total EIRP/100 MHz** | 60 dBm[1] | **Typical Total EIRP/100 MHz** | 41 dBm[1] |
| **Receiver Sensitivity** | -84.4 dBm[2] | **Receiver Sensitivity** | -87.6 dBm[2] |
| **MAPL** | 149.5 dB | **MAPL** | 149.8 dB |
| **MAPL clutter losses considered** | 121.2 dB[3] | **MAPL clutter losses considered** | 121.5 dB[3] |

*Table 5: UL & DL link budget at 28 GHz*

**Based on the labels in the above table:**

1. The total EIRP at gNB is calculated as considering transmit power plus beam forming antenna gain. The EIRP at CPE is calculated as considering 33 dBm (2W) transmit power and 8 dBi antenna gain. [1]
2. Receiver sensitivity is calculated as = Noise figure (dB) + Thermal noise (dBm) + SINR (dB). Noise figure is considered as per values in Table 4. The required SINR values are achieved considering the cell edge throughput target 50 Mbps in DL and 10 Mbps in UL and MCS index table 1 for PDSCH as per 3GPP TS 38.214.[2]
3. Clutter losses are significant in mmWave, clutter losses of ~28 dB (vegetation losses, penetration losses (concrete walls/toughened glass), standard deviation) are considered.[3]

This link budget gives a RNP design target of approximately -103 dBm with coverage probability of 95%.

## Deployment scenarios /use cases (FWA/enterprise, small cells/hotspots)

Based on the market analysis the prominent use case of mmWave seems to be FWA and small cells for hotspots, for which we have simulated coverage and throughput in our planning exercise.

Based on the labels in the above table:

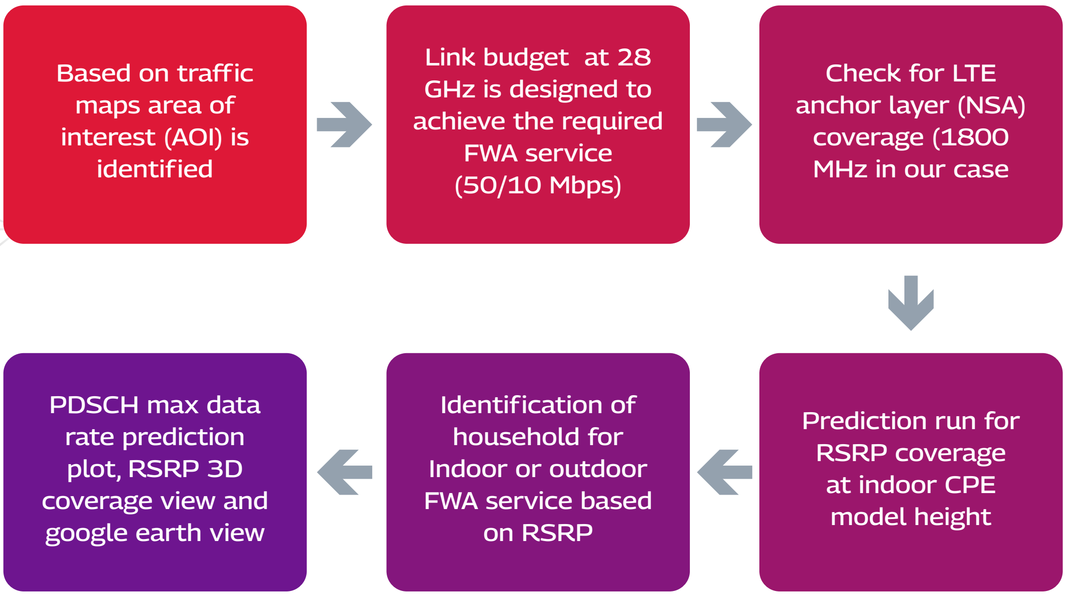
## 1. FWA/Enterprise:

mmWave is well suited for fixed wireless access scenarios such as providing home/enterprise broadband. Few key advantages of FWA with mmWave are as mentioned below:

- It can deliver fiber like throughputs
- Faster deployment compared to FTTH
- Monetize 5G with additional revenue streams
- Can handle high data demand due to large channel bandwidth

We have considered an urban area in this exercise to provide FWA services. The link budget results in above section are used to perform the simulations in planning tool. Considering NSA deployment readiness, the prerequisite to meet our objective was to ensure the area of interest for FWA with 28 GHz (mmWave) is well covered by LTE 1800 band, typical EN-DC scenario. As a next step, our objective was to identify the best possible location for mmWave cell site to cover the maximum number of buildings/house and ensure good quality signal on the rooftop and façade area. Based on prediction results it can be identified that which buildings can be served better with indoor CPE or outdoor CPE. Such analysis helps to expedite the efforts to recommend CPE positioning (indoor or outdoor) for the specific venue and reduce the efforts of field survey.

**The below flow chart represent the mmWave FWA planning methodology and analysis done to simulate the FWA planning service using planning tool.**



The encircled area below has been identified as an Area of Interest (AOI) for FWA, based on traffic map data.

*Figure 11: Google Earth view of Urban clutter selected for mmWave FWA Study*

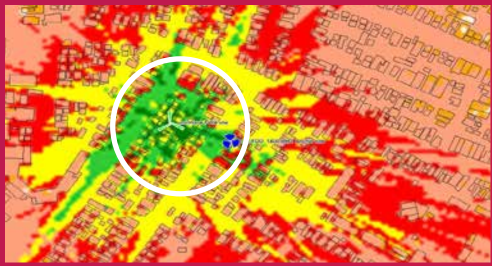


*Figure 12: Predicted coverage of mmWave super imposed on LTE FDD 1800 MHz anchor layer*

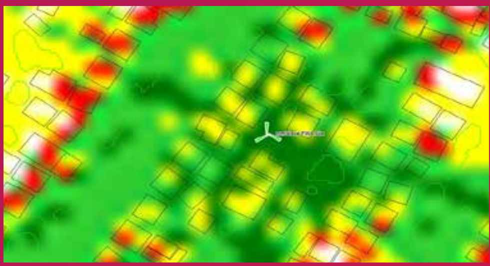


*Figure 13: Predicted outdoor & indoor coverage of mmWave FWA site focused at targeted AOI over 3D building and vegetation polygons*

*Figure 14: Predicted Indoor coverage of mmWave FWA site focused at targeted AOI along with blanket coverage prediction of FDD 1800 MHz anchor Site*

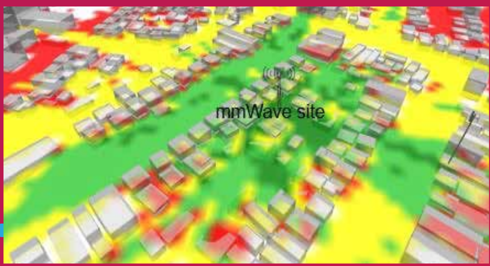



*Figure 15: mmWave site 3D coverage View*

| mmWave RSRP Range (dBm) | Color |
|---|---|
| -140 to -103 | |
| -103 to -90 | |
| -90 to -75 | |
| -75 to -50 | |
| | |
| **LTE RSRP Range (dBm)** | **Color** |
| -140 to -115 | |
| -115 to -50 | |

*Table 6: RSRP coverage legends*

*Figure 16: Focused Google earth view of AOI for FWA*

*Figure 17: Google earth view of Street and Houses to be served with mmWave FWA*

*Figure 18: PDSCH max achievable data rate prediction of mmWave FWA site focused at AOI*

| PDSCH max Acheivable data rate (Mbps) | Color |
|---|---|
| 0 to 50 | |
| 50 to 100 | |
| 100 to 250 | |
| 250 to 500 | |
| 500 to 1000 | |

*Table 7: PDSCH max achievable data rate legends*

### 2. Small cells/Hotspot

Hotspots are perhaps the most obvious use case for mmWave. Small cells are typically deployed by operators at hotspot locations, where there is large amount of traffic demand in a relatively small area. Examples of small cell deployment locations includes, stadiums, concert halls, airports, and shopping malls etc. Small cell can be deployed in both SA and NSA mode.

Standalone mmWave small cell deployment is a challenge due to limited device ecosystem in present scenario. Considering this limitation, we have not covered this specific use case in this planning exercise.

## Key Learnings

- Since the cell range is typically very small in mmWave, un-calibrated model results can lead to predict too few or too many sites. Thus, use of calibrated and advanced propagation model is very important for effective use of CAPEX. As per report by Mobile Experts even 1 dB improvement in RSRP modeling precision, could save a nationwide U.S. mobile network approximately $2 billion over a 10-year period through a reduction in the number of base stations and smalls cells deployed.
- Having an appropriate 3D geo map with all the required clutters is an important to predict FWA CPE positioning accurately.
- Due to the inherent characteristics of shorter cell range of mmWave, it is important to study the availability of Radio products which are developed to overcome these challenges & provide better cell range.
- Understanding the Ecosystem (frequencies & products) and deployment timelines from the CSPs is critical to provide the right planning approach (EN-DC, NR-DC, SA) for mmWave.
- Use of traffic maps is highly recommended in case of planning mmWave cell to identify the high traffic density area for FWA service as well as small cells.
- Selection of suitable massive MIMO and beamforming antenna is the key to success in mmWave planning.

# mmWave planning tool and features

## Tools characteristics and features

To successfully plan a mmWave network, it requires a planning tool with the right capabilities. Most of the capabilities are generic for any technology & for different spectrum bands, however mmWave does have a few unique requirements. In this section we will look at both the requirements i.e., generic as well as specific to mmWave.

*Figure 19: RSRP in a dense urban area*

At the very highest level, planning tools need to fulfil 4 key use cases:

- Network simulation – Coverage, interference, quality
- Capacity Planning – Cell dimensioning, load balancing
- Parameter planning – Neighbor list optimization, code planning (e.g., PCI, PRACH, RSI)
- Design optimization – What-if scenario simulations and network design optimization based on traffic and ROI

To achieve these use cases, requires a planning tool which has the following core capabilities at least:

1. **What-if scenario planning and automatic site selection:** When deploying mmWave, contiguous coverage is not the primary aim. The aim is to deploy sites where they will absorb the most traffic from the other carrier layers and where the extra bandwidth will have maximum impact on subscriber QoE. To achieve this, requires a planning tool with scenario planning and automatic site selection based on multiple data inputs including network traffic (throughput and volume), ARPU maps and more. A data-driven approach is required.
2. **3D planning:** Planning in 2D is no longer sufficient. Subscribers want to be able to use their phones in high-rise buildings, emergency services need to use their phones on helipads on top of hospitals, and command and control of drones is rapidly growing into a lucrative market for mobile network operators. To ensure the network can meet these use cases requires a planning tool that supports 3D planning including 3D site selection and optimization, 3D beamforming analysis and 3D network statistics.

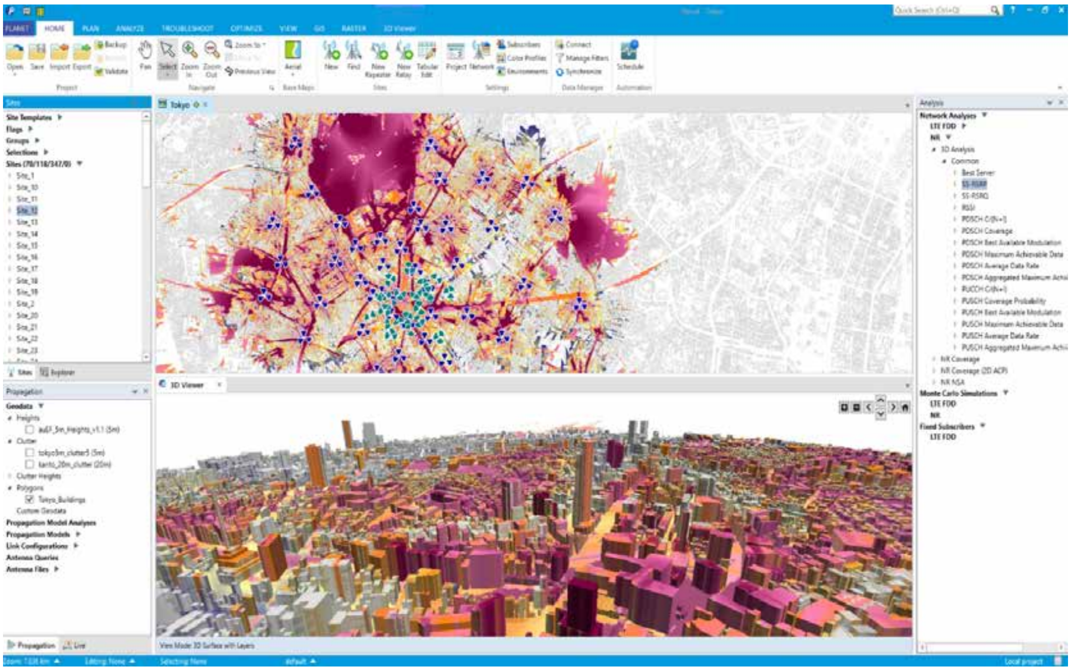


*Figure 20: 2D and 3D view of RSRP*

3. **Advanced propagation modeling:** The relatively small cell sizes and the extent to which clutter affects mmWave propagation means advanced propagation modeling is probably the most important capability of a planning tool when designing mmWave networks. We will look at the specifics of what is required from a propagation model in detail in the next section. In terms of the planning tool though, it is important that it has the capability to automatically tune models using external data sources as well as benchmark models against field measurements.

4. **Virtualized and Open RAN architecture support:** As networks evolve many operators will be looking to transition their traditional network to an Open RAN architecture. A planning tool therefore needs to be able to support virtualized architectures to ensure it is futureproof.

5. **High resolution 3D geodata:** Clutter has a very large effect on propagation of high frequencies in mmWave. At 28 GHz, propagation attenuation can be up to 2-3dB/m due to trees. It is therefore necessary to have very high-resolution clutter data including 3D buildings with roof structure details and vegetation including canopy heights and individual trees. A planning tool needs to support 3D maps at the highest possible resolutions and feature propagation models capable of leveraging this high-resolution data.

6. **Technology feature support:** To successfully plan a technology, it requires a planning tool that supports all the relevant features of the technology. For 5G this includes massive MIMO, 3D beamforming, beam switching antennas, latency modeling, dynamic spectrum sharing, CPE for FWA scenario and more.

7. **Scalability:** With high resolution geodata, 3D predictions and raytracing or ray-launching propagation models, calculating coverage becomes an extremely processor intensive exercise. Planning tools need to be able to harness large amounts of hardware to complete predictions in a reasonable time. A cloud-based micro services approach provides the elastic horizontal scalability to undertake large computations without the need to have large amounts of dedicated hardware which would spend a lot of time underutilized.

## Advanced Propagation Models of mmWave

As mentioned earlier, propagation accuracy is probably the most important aspect of a planning tool. If coverage predictions are optimistic, too few sites will be built resulting in coverage black spots and poor signal quality, leading to churn and uncaptured revenues. While if coverage predictions are pessimistic too many sites will be built increasing CAPEX expenditure by up to 20% and reducing profitability. It is therefore critical that propagation models are as accurate as possible to avoid these scenarios.

*Figure 21: 3D traffic demand map*

To deliver highly accurate propagation requires a model which supports the following:

1. **mmWave:** Perhaps obvious, but when designing a mmWave network, the chosen propagation model must support mmWave frequencies and must include critical features such as building and vegetation through loss support, rain modeling and assessment of line-of-sight and non-line-of-sight coverage.

2. **Calibration:** Calibration is a critical component of a mmWave propagation model. Models should be pre-calibrated using machine learning and massive data sets, so they have a high degree of accuracy out of the box. They can then be further calibrated with drive or walk test data gathered from the specific network. Finally, they should be continuously benchmarked against crowdsources and/or geo-located trace data to validate they are aligned with actual customer experiences.

3. **Ray-tracing or ray-launching:** In dense urban environments, when sites cover a relatively small area and there is lots of opportunity for radio waves to reflect and refract. Ray-tracing and ray-launching deliver significantly more accuracy than standard algorithms in these situations. But these algorithms require extreme computational power, which results in slower calculations or significantly larger hardware requirements. The AIM propagation models in Planet have intelligence built in so ray-tracing or ray-launching are only activated when required.

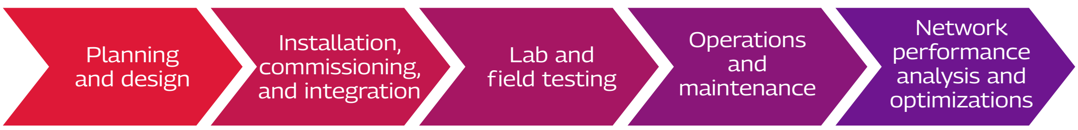
4. **Unmasked predictions:** By taking an unmasked prediction approach to propagation modeling means pathloss recalculations are not required when a cell configuration is changed. This dramatically reduces the propagation predictions required during design optimization exercises and increases the efficiency of arriving at the optimal plan.

# Conclusion

We have studied the advantages, challenges, and mitigation techniques for mmWave in this paper. Certainly, the advantages are far more promising to deliver the desired results of high throughput & low latency for the next generation & high data demand networks by deploying FWA & Small cells kind of network. Such kind of deployment of wireless networks with mmWave are capable to handle the use cases viz. Metaverse, UHD videos, real time gaming, any specific enterprise needs etc. The challenges in mmWave can be overcome by the latest techniques like massive MIMO and beamforming to a great extent. However, to build the next-gen networks using mmWave with more pragmatic view, RF planning using advanced planning tools, smartly using all the features & available inputs with an expert's knowledge plays a significant role. Tech Mahindra being a veteran in Telecom Service provider is ready with all these capabilities to offer the 5G mmWave services to our Global Customers.

Tech Mahindra is a global service provider and SI partner in the telecom world. We have built our portfolio of telecommunication services and solutions with over 30+ years of global experience. We understand the challenges of network transformation by adopting new technologies, operations of massive and multi-technology networks, high end user expectations and cost competitiveness in front of CSPs in today's business environment. To address these challenges by innovative solution and efficient way, Tech Mahindra offers services across network lifecycle management.

Our 4G/5G RAN ORAN services and solutions are span across different phases of network lifecycle management.

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# Terms

| Abbreviations | Abbreviations |
|---|---|
| 3GPP | 3rd Generation Partnership Project |
| CA | Carrier aggregation |
| CAPEX | Capital Expenditure |
| CPE | Customer Premise(s) Equipment |
| CSP | Cellular service provider |
| eMBB | enhanced Mobile Broadband |
| EN-DC | E-UTRAN New Radio – Dual Connectivity |
| FR | Frequency Range |
| FTTH | Fiber to the home |
| FWA | Fixed Wireless Access |
| GSMA | Global System for Mobile communications Association |
| IAB | Integrated Access Backhaul |
| IMT | International Mobile Telecommunications |
| LTE | Long term Evolution |
| MAPL | maximum allowed path loss |
| MCS | Modulation and Coding scheme |
| MIMO | Multiple Input multiple output |
| mMTC | Massive Machine Type Communications |
| NR | New Radio |
| NR-DC | New Radio - Dual Connectivity |
| NSA/SA | Non-Standalone Architecture/Standalone Architecture |
| OFDM | Orthogonal frequency-division multiplexing |
| PDSCH | Physical Downlink Shared Channel |
| RAN | Radio access Network |
| RF | Radio Frequency |
| RSRP | Reference Signal Received Power |
| SCS | Subcarrier spacing |
| SINR | boosts signal-to-interference-plus-noise ratio |
| TTI | Transmission time interval |
| UHD | Ultra-High Definition |
| URLCC | Ultra-Reliable Low Latency Communications |

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