5G AFIANCE

GOBIERNO DE ESPAÑA | MINISTERIO DE ECONOMÍA Y EMPRESA | SECRETARÍA DE ESTADO PARA EL AVANCE DIGITAL

5GAFIANCE – Antenas 5G para acceso fijo a Internet con mejora de capacidad

5G antennas for fixed Internet access with capacity enhancement

E4 – REQUISITOS PARA LA ANTENA 5G FWA OPTIMIZADA

Requirements for the Optimized FWA 5G Antenna

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Resumen Ejecutivo

El presente documento incluye la definición de los requisitos de las antenas de las unidades de abonado para el caso de uso de acceso fijo inalámbrico con tecnología 5G.

Los requisitos tienen dependencias sobre el estándar 5G actualmente en consolidación. En este entregable se recogen los requisitos de posibles escenarios de acceso fijo en entornos urbanos, suburbano y rurales, así como las prestaciones físicas y de control de 5G, juntamente con las bandas de trabajo objetivo que se fijan para estos casos en 3.5GHz y 28GHz.

Executive Summary

This document includes the definition of the requirements of the subscriber unit antennas for the case of use of fixed wireless access with 5G technology.

The requirements have dependencies on the 5G standard currently under consolidation. This deliverable includes the requirements of possible fixed access scenarios in urban, suburban and rural environments, as well as the physical and control benefits of 5G, together with the target work bands that are set for these cases in 3.5GHz and 28GHz.

1 Introduction

It is estimated that the demand for residential bandwidth will at least double in the next 5 years. The most common technology solutions that address this type of services are: ITU standard PONs (Passive Optical Networks), IEEE standard PONs, DOCSIS3.1 (Data Over Cable Service Interface Specification) and Wi-Gig 802.11ay; but all these solutions involve the deployment of cable/fiber infrastructure at a significant cost. However, there are scenarios where fiber/cable deployment is not a viable option, mainly due to subscriber dispersion. This is the case for rural environments, although it could also affect urban and suburban areas.

In Spain, 20% of the population does not yet have access to a broadband service with rates above 100Mbps. With current technologies these rates can be achieved with fixed coaxial (HFC) and fiber (FTTx) or even 4G LTE networks that are expected to also provide data transmission services with peak speeds greater than 100 Mbps under certain conditions. The inability to access broadband services is associated with scenarios where fiber/cable deployment is an economically unworkable option. In these cases, a Fixed Wireless Access (FWA)-based solution becomes a lower deployment cost-effective alternative that provides fiber/cable-like service capabilities.

FWA based on 5G (5GFWA) proposes two technological solutions. The first makes use of medium transmission bands (3.5 GHz) and multi-antenna systems (MIMO) (5G-FWA-MB), the second would perform the transmission in the millimeter band (mmWave, 28 GHz) and again make use of multi-antenna deployment (5G-FWA-mmW). In the first case it is proposed as an alternative to FTTx in suburban and rural environments where infrastructure deployment would come at a high cost. The second technological proposal would be deployed in urban areas to compete with the deployment of fiber. The implementation of 5G-FWA technology needs to address a set of challenges that include very poor propagation conditions (at both frequencies) if the CPE is inside the building. The deployment of multiple antennas is also a major technological challenge, especially when such separate frequency bands must coexist, and beamforming networks must feed a large number of antennas.

Most 5G antenna technologies are developed for the base station infrastructure. Antennas for 5G user equipment are primarily designed for handsets (smartphones) and have a very limited number of radiant elements which significantly limits the final capacity of the link and both existing physical antenna concepts and control intelligence are designed to serve mobility. Fixed Wireless Access (FWA) requires longer ranges and greater capacity compared with the mobility services at the expense of lack of mobility. In many cases, the deployment is conditioned to the installation costs on the user side, being the total self-installation indoors a necessity to ensure the success of 5G-FWA.

This project will therefore investigate new antenna structures that host classical frequency bands along with much higher frequencies in the same set, i.e. sharing the same opening. 5G FWA antenna beamforming requires automated dynamic aiming for cases where the subscriber relocates the CPE. In these cases, the new aiming direction should be estimated with great precision using dynamic learning techniques.

The objective of this project is to design, develop and demonstrate the antenna technologies required in the CPE for the provision of 5G-FWA-MB and 5G-FWA-mmW services. We want to achieve a final multiband solution where the costs of installing and reconfiguration the solution are minimal. To do this, it is proposed to design a technological solution with a single antenna that serves in the two frequency bands and allows the re-targeting of the link to be carried out dynamically using learning tools that maximize the capacity of the link.

Section 2 includes the 5G standard considerations that the developments have to take into account to be aligned with it. Section 3 shows an initial coverage study of using the mmWaves for offering fixed wireless access. This section also includes some performance requirements for the project development. Section 4 introduces the different proposals for the end-to-end validation setup, also including some requirements for the antenna subsystem design and the beam control subsystem.

2 5G Standard Considerations

To define the requirements for the antenna subsystem and for the beam control system it is necessary to know how the 5G standard works. This section introduces the main aspects of 5G standard and explains the specific aspects that must be taken into account for the purposes of the project.

2.1 5G Standard Introduction

The 5th generation cellular technology is being developed to deliver significantly increased operational performance. Enhanced mobile broadband (eMBB) is one of the three initial 5G use cases defined by 3GPP. eMBB is an extension to the existing 4G services and will be one of the most common 5G use case. In fact, first 5G standard release is mainly focused on eMBB.

One of the new characteristics of 5G is the introduction of the numerology concept (section 4.2 of [1]). 4G uses a subcarrier spacing (SCS) of 15KHz. In 5G, different SCS are allowed and their values depends on the numerology value defined. Thus, the SCS value can be obtained using the next expression: SCS = $2^{\mu}\cdot 15$[kHz], being μ the numerology value taking values from 0 to 4. Table 1 shows the SCS value associated to each numerology.

Table 1: SCS, Cyclic Prefix, Number of slots per frame, Number of Slots per Subframe & Number of Symbols per Subframe Depending on the Numerology Value (μ) Selected

μ	$\Delta f = SCS = 2^{\mu} \cdot 15[kHz]$	Cyclic prefix	$N_{slot}^{frame,\mu}$	$N_{slot}^{subframe,\mu}$	$N_{symb}^{subframe,\mu}$
0	15	Normal	10	1	14
1	30	Normal	20	2	28
2	60	Normal, Extended	40	4	56
3	120	Normal	80	8	112
4	240	Normal	160	16	224

Note that numerology μ=2 (SCS=60kHz) is only supported for data transmission, and numerology μ=2 (SCS = 240kHz) is only supported for synchronization transmission.

Varying the SCS values also varies the OFDM symbol duration, so the timing of 5G also varies (Figure 1 shows an example of the timing of 5G) (see section 4.3 of [1]):

- In 5G the frame duration is 10ms.
- Each frame is divided in 10 subframes, so each subframe takes 1ms.

- The subframes can contain different number of slots depending on the numerology value selected (see Table 1). Each slot contains 14 OFDM symbols for normal Cyclic Prefix (CP) and 12 OFDM symbols for extended (CP).
- A half-frame entity is also defined. Each frame is divided in 2 half-frames, so each subframe takes 5ms.

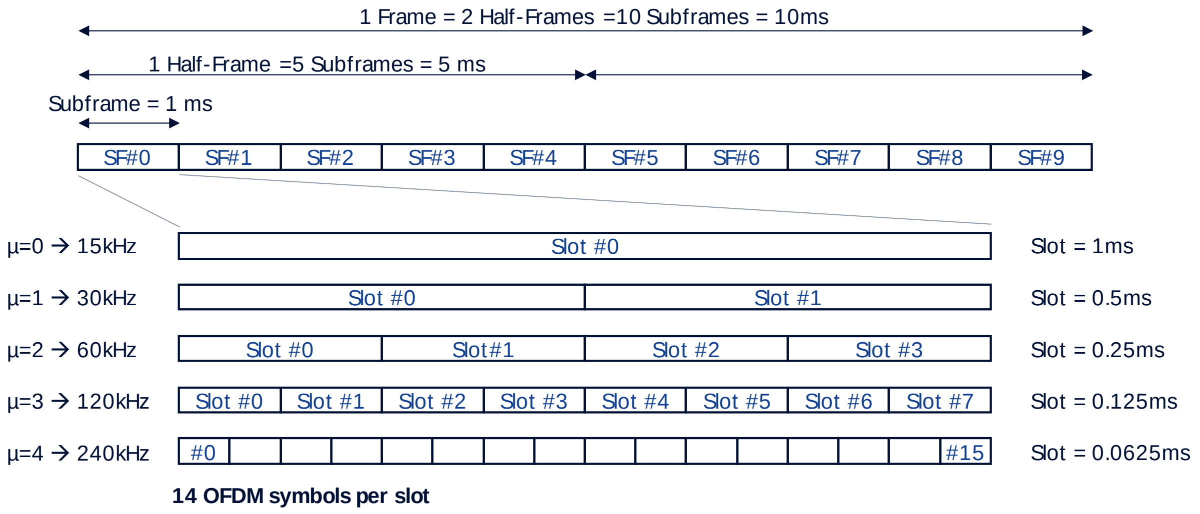

Figure 1: 5G Frame Timing Structure

2.1.1 Resource grid

Once the frequency and the time structure have been described, Figure 2 shows the time-frequency grid. Where *k* is the subcarrier index and *l* is the OFDM symbol index (see Table 1).

$N_{\text{symb}}^{\text{subframe},\mu}$ $\mathrm{N}_{\text{symb}}^{\text{subframe},\mu}$$\mathrm{N}_{\text{symb}}^{\text{subframe},\mu}$is the number of symbols per subframe as defined in Table 1, and $N_{\text{grid}}^{\text{size},\mu}$ is the size of the grid in terms of resource blocks.

Each element in the resource grid is called Resource Element and it is uniquely identified by $(k,l)_{p,\mu}$, for antenna port *p* and numerology *μ*, where *k* is the index in the frequency domain and *l* refers to the symbol position in the time domain relative to some reference point.

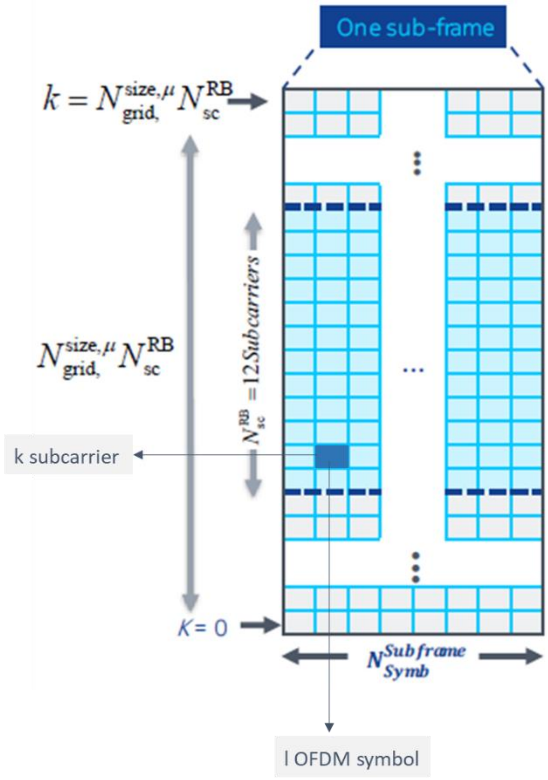

Figure 2: Time-Frequency Grid for 5G

In 5G, Point A is defined as a common reference point for resource block grids. Point A is obtained using two parameters:

- The frequency offset between point A and lower subcarrier of the lower RB. This frequency offset is expressed in units of RB, assuming 15kHz for FR1 and 60kHz for FR2.
- An absolute frequency-location expressed as in ARFCN (Absolute Radio-Frequency Channel Number).

Using the reference ‘Point A’ common resource blocks have been defined as absolute positions of the resource blocks into the grid and are numbered from 0 and upwards in the frequency domain for subcarrier spacing configuration μμ. The center of subcarrier 0 of common resource block 0 for subcarrier spacing configuration μ coincides with ‘Point A’. Different carriers can have different common resource blocks defined.

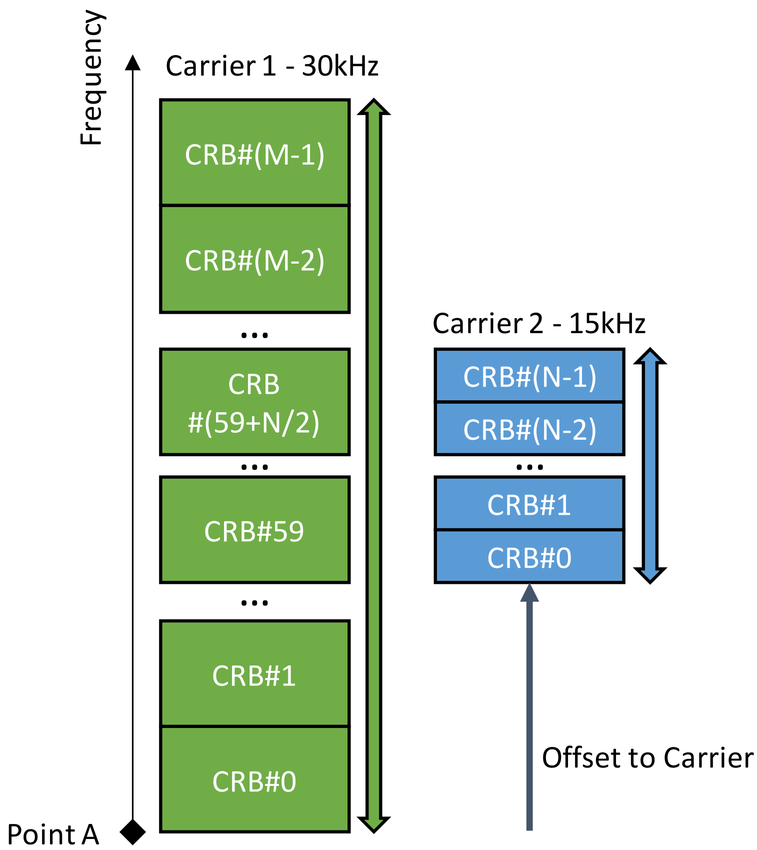

Figure 3: Example of Point A and Common Resource Blocks using Two Different Carriers.

On the other hand, physical resource blocks have been defined as relative positions. For subcarrier configuration μ physical resource blocks are defined within a bandwidth part and numbered from 0 to $N_{\mathrm{BWP},i}^{\mathrm{size},\mu} - 1$ where i is the number of the bandwidth part.

For 5G, a new concept known as bandwidth part (BWP) has been defined. A BWP is a subset of contiguous common resource blocks for a given numerology μ_i in bandwidth part i on a given carrier. The BWPs are defined by:

- BWP starting point, $N_{\mathrm{BWP},i}^{\mathrm{start},\mu}$.
- Number of resource blocks of the BWP, $N_{\mathrm{BWP},i}^{\mathrm{size},\mu}$.

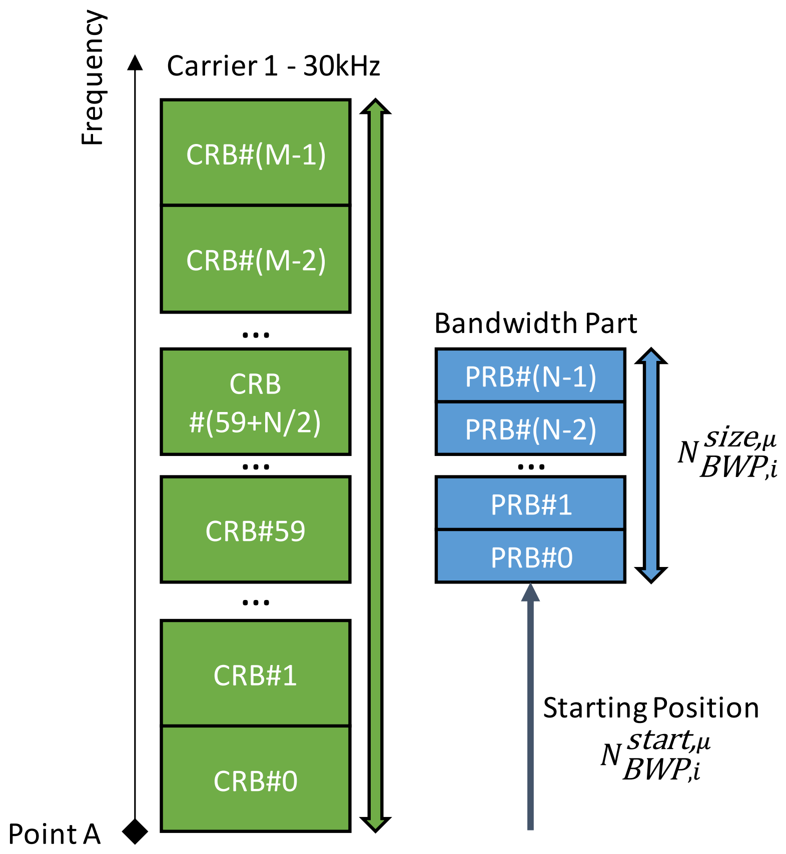

Figure 4: Example of Physical Resource Blocks and Bandwidth Parts

Network carrier comprises of CRBs, and BWP comprises of PRBs.

A UE can be configured with up to four BWPs in the downlink with a single downlink BWP being active at a given time. The UE is not expected to receive PDSCH (Physical Downlink Shared Channel), PDCCH (Physical Downlink Control Channel), or CSI-RS (Channel State Information – Reference Signal) (except for RRM) outside an active BWP, but others physical channels can be conveyed outside the BWP.

A UE can be configured with up to four BWPs in the uplink with a single uplink BWP being active at a given time. The UE shall not transmit PUSCH (Physical Uplink Shared Channel) or PUCCH (Physical Uplink Control Channel) outside an active BWP. For an active cell, the UE shall not transmit SRS (Sounding Reference Signals) outside an active BWP.

The total bandwidth of a carrier can be divided into several bandwidth parts. From network perspective, different bandwidth parts can be associated with different numerologies (subcarrier spacing, cyclic prefix).

Bandwidth parts are analog to Component Carrier used in LTE. In 5G, not all the devices have to support the full carrier bandwidth, for example 400MHz. UEs can take advantage of BWP to reduce the complexity and to optimize the UE operations in frequency domain without wasting effort: the UE has not to monitor the whole bandwidth, and it can reduce its power consumption. From the network perspective, BWP can be used for optimizing the performance of the network in frequency domain.

BWP can be used for four main different use cases:

- To allow those UEs with reduced capacities to use the network. In this case the UEs has not be able to support the whole carrier bandwidth. The UEs can have a single dedicated bandwidth configured.
- To optimize the network by balancing the load on the cell. Different BWP can be defined into the same carrier bandwidth and frequency multiplexing can be applied.
- To support power limited devices. Different BWP can be defined within a carried bandwidth, e.g. one wide for non-power limited devices and one narrow for power limited devices.
- To allow different configurations at the same time. Different BWP of the same size but with different configurations can be defined.

There is an initial active downlink BWP defined to establish signaling connection between the gNB and the UE, and so the initial link connection. This initial BWP includes the signals send by the gNB to carry out the initial access.

2.1.2 Frequency bands

Another novelty included in 5G is the possibility to use millimeter wave (mmWave) spectrum with large bandwidth which improves the capacity and throughput many folds over 4G. Table 2 shows the different frequency ranges in which 5G can operate.

Table 2: 5G Frequency Ranges [2]

Frequency range designation	Corresponding frequency range
FR1	**410 MHz – 7125 MHz**
FR2	**24250 MHz – 52600 MHz**

Not all the numerologies can be used at each frequency range. Numerologies from 0 to 2 can be used for FR1, and numerologies from 2 to 4 can be used for FR2.

5G allows using wider bandwidths for the signal transmissions. There are different standardized bandwidths defined depending on the frequency range and the numerology. Table 3 shows the bandwidths allowed for FR1 depending on the SCS and Table 4 shows the bandwidths allowed for FR2 depending on the SCS.

Table 3: Transmission bandwidth configuration for FR1.

SCS (kHz)	5 MHz	10 MHz	15 MHz	20 MHz	25 MHz	30 MHz	40 MHz	50 MHz	60 MHz	70 MHz	80 MHz	90 MHz	100 MHz
	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}
15	25	52	79	106	133	160	216	270	N/A	N/A	N/A	N/A	N/A
30	11	24	38	51	65	78	106	133	162	189	217	245	273
60	N/A	11	18	24	31	38	51	65	79	93	107	121	135

Table 4: Transmission bandwidth configuration N_{RB} for FR2

SCS (kHz)	50 MHz	100 MHz	200 MHz	400 MHz
	N_{RB}	N_{RB}	N_{RB}	N_{RB}
60	66	132	264	N/A
120	32	66	132	264

In the previous tables, N_{RB} means the number of resource blocks. In 5G the Resource Blocks (RB) are the same than in 4G: 1RB = 12 consecutive subcarriers in the frequency domain. Note that the bandwidth of each PRB depends on the numerology.

Next Tables show the operating bands defined by the 3GPP for both FR1 and FR2 respectively. The yellow filled cells indicate the bands initially considered in this project (without limiting the usage of the other bands). The most probably frequency bands are n77 and n78 for FR1 (note that this frequency bands include the band n48), and n256, n257, n261 for FR2.

Table 5: NR operating bands in FR1 [2]

NR *operating band*	Uplink (UL) *operating band* BS receive / UE transmit $F_{UL,low}$ – $F_{UL,high}$	Downlink (DL) *operating band* BS transmit / UE receive $F_{DL,low}$ – $F_{DL,high}$	Duplex mode
n1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
n2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
n3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	FDD
n5	824 MHz – 849 MHz	869 MHz – 894 MHz	FDD
n7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz	FDD
n8	880 MHz – 915 MHz	925 MHz – 960 MHz	FDD
n12	699 MHz – 716 MHz	729 MHz – 746 MHz	FDD
n14	788 MHz – 798 MHz	758 MHz – 768 MHz	FDD
n18	815 MHz – 830 MHz	860 MHz – 875 MHz	FDD
n20	832 MHz – 862 MHz	791 MHz – 821 MHz	FDD
n25	1850 MHz – 1915 MHz	1930 MHz – 1995 MHz	FDD
n28	703 MHz – 748 MHz	758 MHz – 803 MHz	FDD
n29	N/A	717 MHz – 728 MHz	SDL
n30	2305 MHz – 2315 MHz	2350 MHz – 2360 MHz	FDD

n34	2010 MHz – 2025 MHz	2010 MHz – 2025 MHz	TDD
n38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz	TDD
n39	1880 MHz – 1920 MHz	1880 MHz – 1920 MHz	TDD
n40	2300 MHz – 2400 MHz	2300 MHz – 2400 MHz	TDD
n41	2496 MHz – 2690 MHz	2496 MHz – 2690 MHz	TDD
n48	3550 MHz – 3700 MHz	3550 MHz – 3700 MHz	TDD
n50	1432 MHz – 1517 MHz	1432 MHz – 1517 MHz	TDD
n51	1427 MHz – 1432 MHz	1427 MHz – 1432 MHz	TDD
n65	1920 MHz – 2010 MHz	2110 MHz – 2200 MHz	FDD
n66	1710 MHz – 1780 MHz	2110 MHz – 2200 MHz	FDD
n70	1695 MHz – 1710 MHz	1995 MHz – 2020 MHz	FDD
n71	663 MHz – 698 MHz	617 MHz – 652 MHz	FDD
n74	1427 MHz – 1470 MHz	1475 MHz – 1518 MHz	FDD
n75	N/A	1432 MHz – 1517 MHz	SDL
n76	N/A	1427 MHz – 1432 MHz	SDL
n77	3300 MHz – 4200 MHz	3300 MHz – 4200 MHz	TDD
n78	3300 MHz – 3800 MHz	3300 MHz – 3800 MHz	TDD
n79	4400 MHz – 5000 MHz	4400 MHz – 5000 MHz	TDD
n80	1710 MHz – 1785 MHz	N/A	SUL
n81	880 MHz – 915 MHz	N/A	SUL
n82	832 MHz – 862 MHz	N/A	SUL
n83	703 MHz – 748 MHz	N/A	SUL
n84	1920 MHz – 1980 MHz	N/A	SUL
n86	1710 MHz – 1780 MHz	N/A	SUL
n89	824 MHz – 849 MHz	N/A	SUL
[n90]	2496 MHz – 2690 MHz	2496 MHz – 2690 MHz	TDD

Table 6: NR operating bands in FR2 [2]

NR *operating band*	Uplink (UL) and Downlink (DL) *operating band* BS transmit/receive UE transmit/receive $F_{UL,low}$ – $F_{UL,high}$ $F_{DL,low}$ – $F_{DL,high}$	Duplex mode
n257	26500 MHz – 29500 MHz	TDD
n258	24250 MHz – 27500 MHz	TDD
n260	37000 MHz – 40000 MHz	TDD
n261	27500 MHz – 28350 MHz	TDD

2.1.3 Initial Access

2.1.3.1 SS-PBCH block

The first operation a UE must do to access to a network is the cell search. Cell search is the procedure by which the UE gets synchronization in time and frequency with a cell and obtains the ID of such cell. To do so, the gNB sends to the UE the Synchronization Signals (SSs): Primary Synchronization Signal (PSS) and Secondary Synchronization Signal (SSS). In 5G the SSs are part of a block called SS-PBCH (Synchronization Signal – Physical Broadcast Channel) block (see [1] section 7.4.3). This block is used by the UE to acquire the downlink synchronization of the network: frequency and time synchronization (slot and frame), cell ID detection and system bandwidth determination.

In the time domain, an SS/PBCH block consists of 4 OFDM symbols, numbered in increasing order from 0 to 3 within the SS/PBCH block.

In the frequency domain, an SS/PBCH block consists of 240 contiguous subcarriers (20 contiguous RBs) with the subcarriers numbered in increasing order from 0 to 239 within the SS/PBCH block.

PSS, SSS, and PBCH with associated DM-RS are mapped to symbols according to Table 7 where:

- the quantities k and l represent the frequency and time indices, respectively, within one SS/PBCH block.
- The quantity v is given by $v = N_{\mathrm{ID}}^{\mathrm{cell}} \bmod 4$.

For a better understanding, Figure 5 shows the resource mapping of the SS-PBCH block.

Table 7: Resources within an SS/PBCH block for PSS, SSS, PBCH, and DM-RS for PBCH [1]

Channel or signal	OFDM symbol number l relative to the start of an SS/PBCH block	Subcarrier number k relative to the start of an SS/PBCH block
PSS	0	56, 57, …, 182
SSS	2	56, 57, …, 182
Set to 0	0	0, 1, …, 55, 183, 184, …, 239
	2	48, 49, …, 55, 183, 184, …, 191
PBCH	1, 3	0, 1, …, 239
	2	0, 1, …, 47, 192, 193, …, 239
DM-RS for PBCH	1, 3	$0+v, 4+v, 8+v, \dots, 236+v$
	2	$0+v, 4+v, 8+v, \dots, 44+v$ $192+v, 196+v, \dots, 236+v$

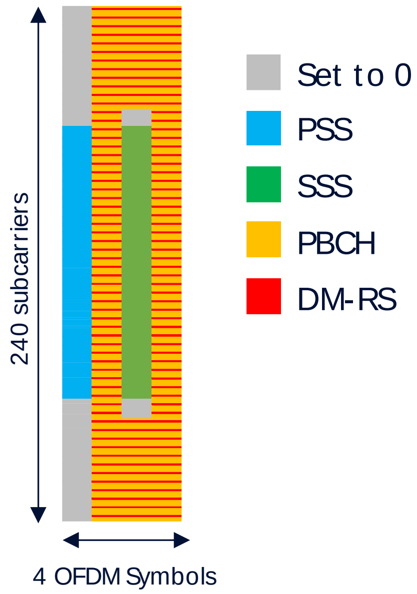

Figure 5: SS-PBCH block Resource Mapping

2.1.3.1.1 Time-Frequency Allocation

The UE shall assume:

- the same cyclic prefix length and subcarrier spacing for the PSS, SSS, PBCH and DM-RS for PBCH.
- for SS/PBCH block type A, $\mu \in \{0, 1\}$ and $k_{\mathrm{SSB}} \in \{0, 1, 2, \ldots, 23\}$ with the quantities k_{SSB}, and $N_{\mathrm{CRB}}^{\mathrm{SSB}}$ expressed in terms of 15 kHz subcarrier spacing where (Figure 6):
    - The quantity k_{SSB} is the subcarrier offset from subcarrier 0 in common resource block $N_{\mathrm{CRB}}^{\mathrm{SSB}}$ to subcarrier 0 of the SS/PBCH block.
    - $N_{\mathrm{CRB}}^{\mathrm{SSB}}$ is the number of the common resource block considered as starting point for SS-PBCH block.
- for SS/PBCH block type B, $\mu \in \{3,4\}$ and $k_{\mathrm{SSB}} \in \{0, 1, 2, \ldots, 11\}$ with the quantity k_{SSB} expressed in terms of the subcarrier spacing provided by the higher-layers and $N_{\mathrm{CRB}}^{\mathrm{SSB}}$ expressed in terms of 60 kHz subcarrier spacing.

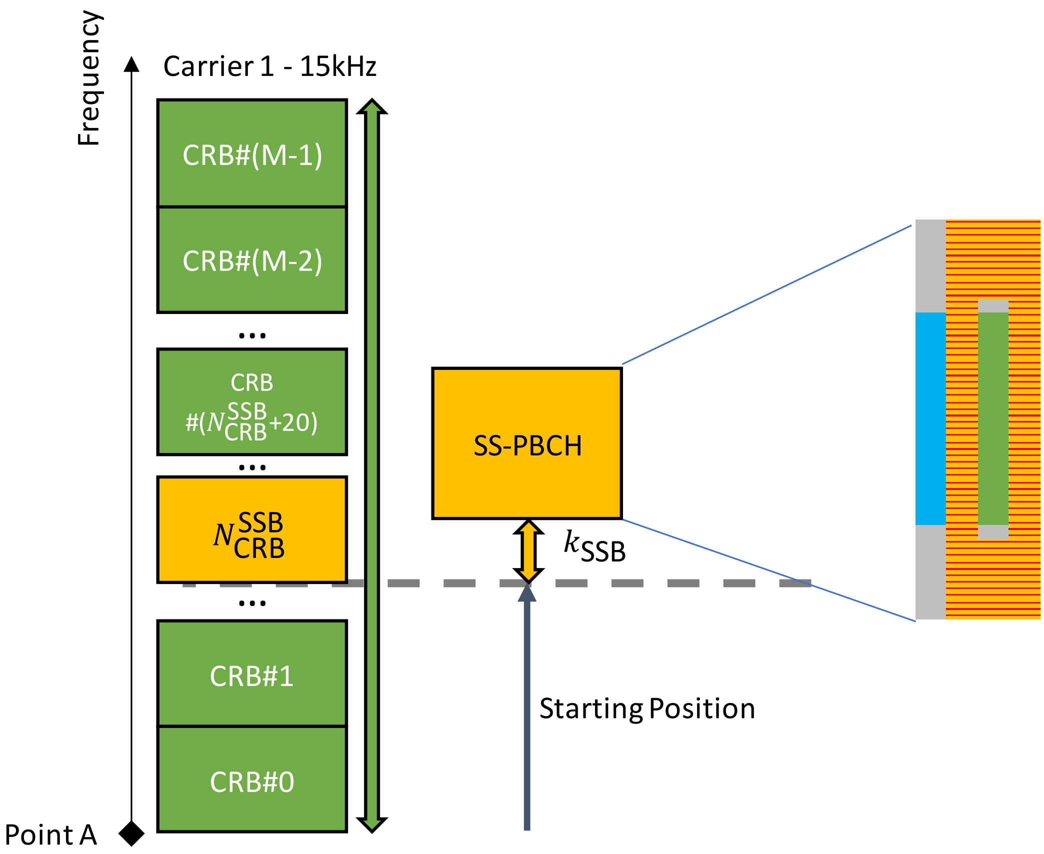

Figure 6: N_{CRB}^{SSB} and k_{SSB} example

In time domain, there are different SS/PBCH Block Allocation depending on the SCS and the carrier frequency. According to [3] section 4.1, for a half frame with SS/PBCH blocks, the first symbol indexes for candidate SS/PBCH blocks are determined according to the SCS of SS/PBCH blocks as follows, where index 0 corresponds to the first symbol of the first slot in a half-frame.

- Case A - 15 kHz SCS (see Figure 7): the first symbols of the candidate SS/PBCH blocks have indexes of $\{2,\ 8\} + 14 \cdot n$.
    - For operations without Shared Spectrum channel access:
        - For carrier frequencies smaller than or equal to 3 GHz, $n = 0,\ 1$.
        - For carrier frequencies within FR1 larger than 3 GHz, $n = 0,\ 1,\ 2,\ 3$.
    - For operation with shared spectrum channel access, $n = 0, 1, 2, 3, 4$.
- Case B - 30 kHz SCS (see Figure 7): the first symbols of the candidate SS/PBCH blocks have indexes $\{4,\ 8,\ 16,\ 20\} + 28 \cdot n$.
    - For carrier frequencies smaller than or equal to 3 GHz, $n = 0$.

    - For carrier frequencies within FR1 larger than 3 GHz, $n = 0,\ 1$.

- Case C - 30 kHz SCS (see Figure 7): the first symbols of the candidate SS/PBCH blocks have indexes $\{2,\ 8\} + 14 \cdot n$.
    - For operations without Shared Spectrum channel access:
        - For paired spectrum operation
            - For carrier frequencies smaller than or equal to 3 GHz, $n = 0,\ 1$. For carrier frequencies within FR1 larger than 3 GHz, $n = 0,\ 1,\ 2,\ 3$.
        - For unpaired spectrum operation
            - For carrier frequencies smaller than or equal to 2.4 GHz, $n = 0,\ 1$. For carrier frequencies within FR1 larger than 2.4 GHz, $n = 0,\ 1,\ 2,\ 3$.
    - For operation with shared spectrum channel access, $n = 0, 1, 2, 3, 4, 5, 6, 7, 8, 9$.

- Case D - 120 kHz SCS (see Figure 7): the first symbols of the candidate SS/PBCH blocks have indexes $\{4,\ 8,\ 16,\ 20\} + 28 \cdot n$. For carrier frequencies within FR2, $n = 0,\ 1,\ 2,\ 3,\ 5,\ 6,\ 7,\ 8,\ 10,\ 11,\ 12,\ 13,\ 15,\ 16,\ 17,\ 18$.

- Case E - 240 kHz SCS (see Figure 7): the first symbols of the candidate SS/PBCH blocks have indexes $\{8,\ 12,\ 16,\ 20,\ 32,\ 36,\ 40,\ 44\} + 56 \cdot n$. For carrier frequencies within FR2, $n = 0,\ 1,\ 2,\ 3,\ 5,\ 6,\ 7,\ 8$.

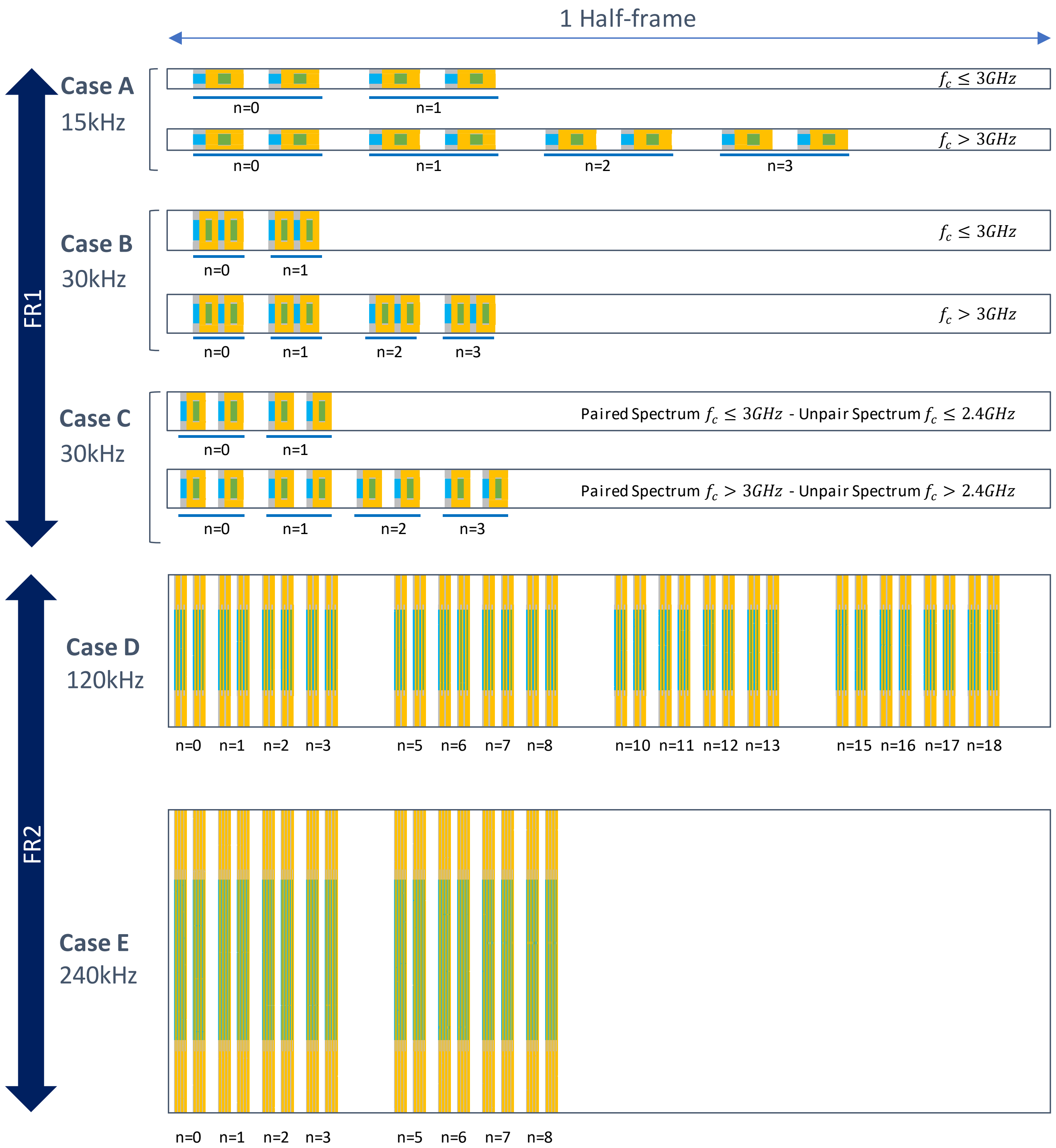

Figure 7: SS/PBCH Block Allocation for a Half Frame Depending on the SCS and the Carrier Frequency

In addition to the synchronization information, broadcast information also must be acquired by the UE after power up. In LTE, both PSS, SSS and the PBCH are placed at the center of the carrier bandwidth and transmitted every 5ms. In 5G, the position of the SS-PBCH block will not be typically placed at the center of the carrier, and the periodicity of the transmission is configurable: 5, 10, 20, 40, 80, or 160ms, being 20ms the typical value, and 5ms the default value (See Figure 8).

Note that each SS-PBCH block can be associated to different beam (See Figure 8). Section 2.1.3.4 includes more information about the beam management.

The candidate SS/PBCH blocks in a half frame are indexed in an ascending order in time from 0 to $\bar{L}_{max}-1$, where:

- for operation without shared spectrum channel access, $\bar{L}_{max}=L_{max}$.
- for operation with shared spectrum channel access, $\bar{L}_{max}=10$ for 15 kHz SCS of SS/PBCH blocks, and $\bar{L}_{max}=20$ for 30 kHz SCS of SS/PBCH blocks.

A UE determines the 2 LSB bits, for $\bar{L}_{max}=4$, or the 3 LSB bits, for $\bar{L}_{max}>4$, of a SS/PBCH block index per half frame from a one-to-one mapping with an index of the DM-RS sequence transmitted in the PBCH (see Section 2.1.3.3).

For $L_{max}>8$, the UE determines the 3 MSB bits of the SS/PBCH block index per half frame from PBCH payload bits $\bar{a}_{\bar{A}+5}, \bar{a}_{\bar{A}+6}, \bar{a}_{\bar{A}+7}$:

- if $\bar{L}_{max}=10$:
  - $\bar{a}_{\bar{A}+5}$ is the MSB of k_{SSB}.
  - $\bar{a}_{\bar{A}+6}$ is reserved.
  - $\bar{a}_{\bar{A}+7}$ is the MSB of candidate SS/PBCH block index.
- if $\bar{L}_{max}=20$:
  - $\bar{a}_{\bar{A}+5}$ is the MSB of k_{SSB}.
  - $\bar{a}_{\bar{A}+6}$, $\bar{a}_{\bar{A}+7}$ are the 5th and 4th bits of the candidate SS/PBCH block index, respectively.
- if $\bar{L}_{max}=64$, $\bar{a}_{\bar{A}+5}, \bar{a}_{\bar{A}+6}, \bar{a}_{\bar{A}+7}$ are the 6th, 5th, and 4th bits of SS/PBCH block index, respectively.

In mmWaves (FR2), the SS-PBCH can be conveyed using a subcarrier spacing (SCS) of 120 kHz or 240 kHz, in both cases, the maximum number of allowed beams for transmit the SS-PBCH is 64 (section 4.1 of [3]). The UE can detect the best beam received and identify it because of:

- the DM-RS includes the index of the beam if the maximum number of beams is lower or equal than 8.
- The DM-RS and the PBCH includes jointly the index of the beam if the maximum number of beams is higher than 8.

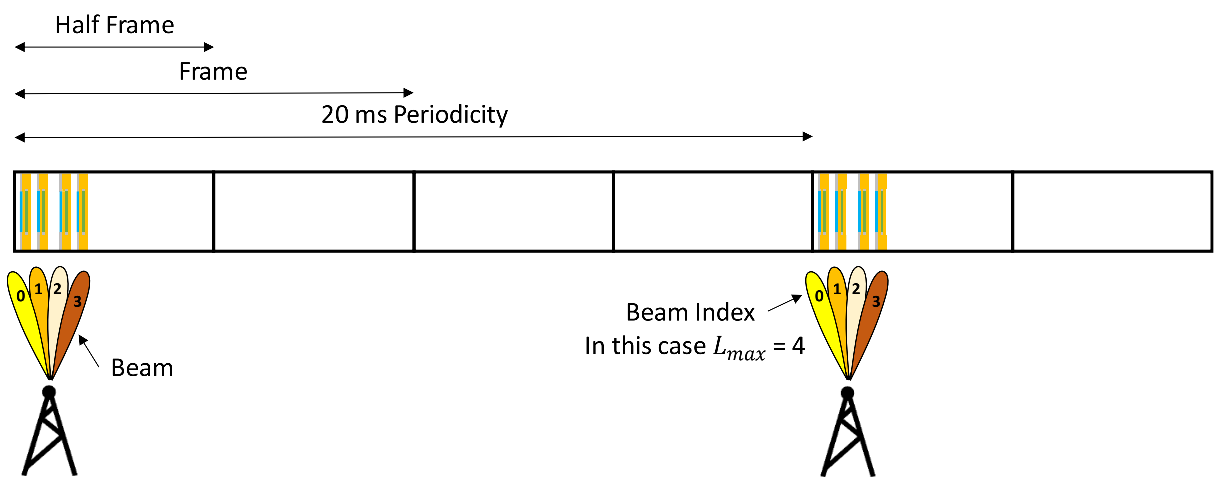

Figure 8: Example of Beam Sweeping and SS-PBCH periodicity

2.1.3.2 Synchronization Signals

According to [1], there are 1008 unique Physical Cell Identities (PCI) given by

$$N_{\mathrm{ID}}^{\mathrm{cell}} = 3N_{\mathrm{ID}}^{(1)} + N_{\mathrm{ID}}^{(2)}$$

where $N_{\mathrm{ID}}^{(1)} \in \{0,1,\ldots,335\}$ and $N_{\mathrm{ID}}^{(2)} \in \{0,1,2\}$. $N_{\mathrm{ID}}^{(2)}$ is obtained using the PSS and $N_{\mathrm{ID}}^{(1)}$ is obtained using the SSS.

2.1.3.2.1 Primary Synchronization Signal

The sequence $d_{\mathrm{PSS}}(n)$ for the primary synchronization signal is defined by

$$\begin{aligned} d_{\mathrm{PSS}}(n) &= 1 - 2x(m) \\ m &= \left(n + 43N_{\mathrm{ID}}^{(2)}\right) \bmod 127 \\ 0 &\le n < 127 \end{aligned}$$

where

$$x(i+7) = \left(x(i+4) + x(i)\right) \, mod \; 2$$

and

$$[x(6) \quad x(5) \quad x(4) \quad x(3) \quad x(2) \quad x(1) \quad x(0)] = [1 \quad 1 \quad 1 \quad 0 \quad 1 \quad 1 \quad 0]$$

The UE shall assume the sequence of symbols $d_{\mathrm{PSS}}(0),\ldots,d_{\mathrm{PSS}}(126)$ constituting the primary synchronization signal to be scaled by a factor β_{PSS} to conform to the PSS power allocation and mapped to resource elements $(k,l)_{p,\mu}$ in increasing order of k where k and l are given by Table 7 and represent the frequency and time indices, respectively, within one SS/PBCH block.

2.1.3.2.2 Secondary Synchronization Signal

The sequence $d_{\mathrm{SSS}}(n)$ for the secondary synchronization signal is quite more complex than the PSS one and is defined by

$$\begin{aligned} d_{\mathrm{SSS}}(n) &= [1-2x_0((n+m_0)\bmod 127)][1-2x_1((n+m_1)\bmod 127)] \\ m_0 &= 15\left\lfloor \frac{N_{\mathrm{ID}}^{(1)}}{112} \right\rfloor + 5N_{\mathrm{ID}}^{(2)} \\ m_1 &= N_{\mathrm{ID}}^{(1)} \bmod 112 \\ 0 &\le n < 127 \end{aligned}$$

where

$$\begin{aligned} x_0(i+7) &= (x_0(i+4)+x_0(i))\bmod 2 \\ x_1(i+7) &= (x_1(i+1)+x_1(i))\bmod 2 \end{aligned}$$

and

$$\begin{aligned} [x_0(6)\ \ x_0(5)\ \ x_0(4)\ \ x_0(3)\ \ x_0(2)\ \ x_0(1)\ \ x_0(0)] &= [0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 1] \\ [x_1(6)\ \ x_1(5)\ \ x_1(4)\ \ x_1(3)\ \ x_1(2)\ \ x_1(1)\ \ x_1(0)] &= [0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 1] \end{aligned}$$

The UE shall assume the sequence of symbols $d_{\mathrm{SSS}}(0),\dots,d_{\mathrm{SSS}}(126)$ constituting the secondary synchronization signal to be scaled by a factor β_{SSS} and mapped to resource elements $(k,l)_{p,\mu}$ in increasing order of k where k and l are given by Table 7 and represent the frequency and time indices, respectively, within one SS/PBCH block.

2.1.3.3 Demodulation Reference Signals for PBCH

The UE shall assume the reference-signal sequence $r(m)$ for an SS/PBCH block is defined by

$$r(m) = \frac{1}{\sqrt{2}}(1-2\cdot c(2m)) + j\frac{1}{\sqrt{2}}(1-2\cdot c(2m+1))$$

Where:

- $c(n)$ is:

$$\begin{aligned} c(n) &= (x_1(n+N_C)+x_2(n+N_C))\bmod 2 \\ x_1(n+31) &= (x_1(n+3)+x_1(n))\bmod 2 \\ x_2(n+31) &= (x_2(n+3)+x_2(n+2)+x_2(n+1)+x_2(n))\bmod 2 \end{aligned}$$

where $N_{\mathrm{C}} = 1600$ and the first m-sequence $x_1(n)$ shall be initialized with $x_1(0) = 1, x_1(n) = 0, n = 1,2,\dots,30$. The initialization of the second m-sequence, $x_2(n)$, the scrambling sequence generator, shall be initialized at the start of each SS/PBCH block occasion with

$$c_{\mathrm{init}} = 2^{11}\left(\bar{i}_{\mathrm{SSB}}+1\right)\left(\left\lfloor N_{\mathrm{ID}}^{\mathrm{cell}}/4\right\rfloor+1\right)+2^{6}\left(\bar{i}_{\mathrm{SSB}}+1\right)+\left(N_{\mathrm{ID}}^{\mathrm{cell}} \bmod 4\right)$$

where

- for $\bar{L}_{\max}$, $\bar{i}_{\mathrm{SSB}} = i_{\mathrm{SSB}} + 4n_{\mathrm{hf}}$ where n_{hf} is the number of the half-frame in which the PBCH is transmitted in a frame with $n_{\mathrm{hf}} = 0$ for the first half-frame in the frame and $n_{\mathrm{hf}} = 1$ for the second half-frame in the frame, and i_{SSB} is the two least significant bits of the candidate SS/PBCH block index.
- for $\bar{L}_{\max} > 4$, $\bar{i}_{\mathrm{SSB}} = i_{\mathrm{SSB}}$ where i_{SSB} is the three least significant bits of the candidate SS/PBCH block index.
- with $\bar{L}_{\max}$ being the maximum number of candidate SS/PBCH candidate SS/PBCH blocks in a half frame.
- Note that DM-RS includes the beam index (SS-PBCH block index) but it must be completed when $\bar{L}_{\max} > 8$.

The UE shall assume the sequence of complex-valued symbols $r(0),\ldots,r(143)$ constituting the demodulation reference signals for the SS/PBCH block to be scaled by a factor of $\beta_{\mathrm{PBCH}}^{\mathrm{DM\text{-}RS}}$ to conform to the PBCH power allocation and to be mapped to resource elements $(k,l)_{p,\mu}$ in increasing order of first k and then l where k and l are given by Table 7 and represent the frequency and time indices, respectively, within one SS/PBCH block.

2.1.3.4 Beam Management for Initial Access

In 5G and more specifically in mmWaves, transmission in the cell is based on beams. To handle the beams, beam management and controlling mechanism is needed. In the literature, there are different beam management techniques, according to [4] there are four different operations for beam management:

- *Beam sweeping*. The gNB (g Node B) covers a specific spatial area with a set of beams with pre-specified intervals and directions.
- *Beam measurement*. Evaluation of the quality of the received signal at the gNB or at the UE.
- *Beam determination*. Selection of the beast suitable beam or beams either at the gNB or at the UE, based on the beam measurement procedure.
- *Beam reporting*. Procedure used by the UE to send beam quality and beam decision information to the Radio Access Network (RAN), via the gNB in Stand-Alone 5G deployments.

One of the most important phases where the Beam Management is fundamental is at the Initial Access (IA). At IA the initial beam pair link establishment is done.

In 4G, the base stations, or eNB, constantly are sending Cell Specific Reference Signals (CRS) in an omnidirectional way. The UEs can estimate the quality of the signal received coming from the surrounding base stations, or eNB, using the CRS.

In 5G, the gNBs are not constantly sending pilots or reference signals and when they do it, they send them into the SS-PBCH blocks and usually use directional beams. The UE uses the PSS and SSS together for cell ID detection, and the DM-RS to estimate the quality of the channel and to identify the different beams (together the PBCH if the number of beams is higher than 8).

As it has been introduced in section 2.1.3.1:

- In 5G each gNB transmits the so-called SS-PBCH blocks. The SS-PBCH block transmitted by the gNB always has the same content but it is transmitted in specific times.
- The gNB does not transmit the SS-PBCH continuously over the time, it is transmitted in different times.
- Furthermore, the SS-PBCH block is repeated within an SS-PBCH burst set for providing beam sweeping, specifically in mmWave. Each SS-PBCH block into a burst corresponds to a different beam.

The standard defines the number of beams that a gNB can transmit for the initial beam sweeping responsible of convey the SS-PBCH block and the periodicity of the SS-PBCH bursts. The number of allowable beams depends on the numerology of the transmission and is defined in the 5G standard (section 4.1 of [3]).

Figure 9 shows the initial beam acquisition procedure identifying the four different operations introduced:

- gNB transmit different beams at different times (Beam Sweeping).
- UE measures the different beams (Beam Measurement). The UE estimates the beam quality.
- UE determines the best beam based on all the measurements (Beam Determination).
- The UE informs to the gNB about its best beam (beam reporting). In this case, for IA procedure, the UE initializes the Random-Access procedure. Note that random access procedure is not covered into this document, but it may be taken into account for the project.

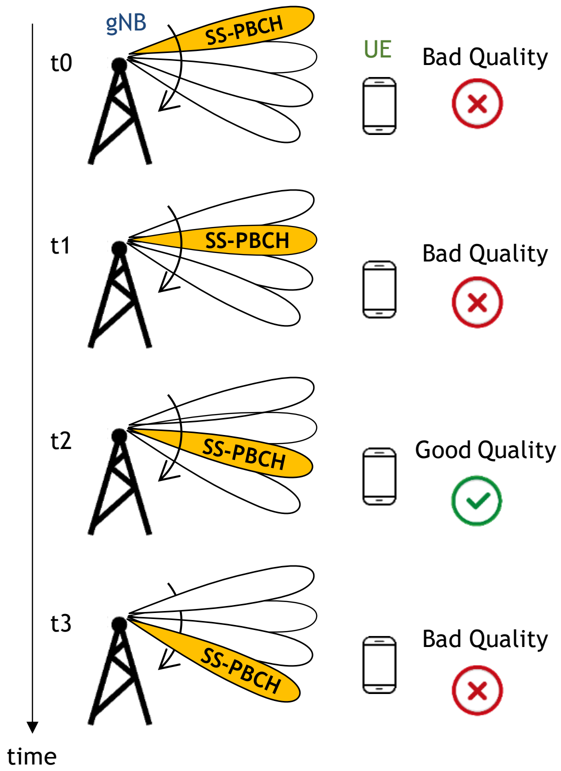

Figure 9: Beam Management Process for Initial Access Procedure

2.1.3.4.1 Radio Link Monitoring

3GPP defines the Radio Link Monitoring (RLM) in section 5 of [3]. This procedure can be included into the beam measurement operation defined in the previous section.

The UE monitors the downlink radio link quality of the primary cell for the purpose of indicating out-of-sync/in-sync status to higher layers. The UE is not required to monitor the downlink radio link quality in DL BWPs other than the active DL BWP, that means that The UE is not required to monitor the downlink radio link quality in DL BWPs other than the active DL BWP on the PSCell.

For RLM:

- The UE is provided:
  - either a CSI-RS (Channel State Information – Reference Signal) resource configuration index, by *csi-RS-Index*,
  - or a SS/PBCH block index, by *ssb-Index*.
- The UE can be configured with up to $N_{\mathrm{LR-RLM}}$ *RadioLinkMonitoringRS* for link recovery procedures, and for radio link monitoring.
  - From the $N_{\mathrm{LR-RLM}}$ *RadioLinkMonitoringRS*, up to N_{RLM} *RadioLinkMonitoringRS* can be used for radio link monitoring depending on a maximum number L_{max} of candidate SS/PBCH blocks per half frame,

- and up to two *RadioLinkMonitoringRS* can be used for link recovery procedures.

Next table shows the values of $N_{\text{LR−RLM}}$ and N_{RLM} for different values of L_{max}.

Table 8: $N_{\text{LR−RLM}}$ and N_{RLM} depending on the maximum number L_{max} of SS/PBCH blocks per half frame

L_{max}	$N_{\text{LR−RLM}}$	N_{RLM}
4	2	2
8	6	4
64	8	8

3 Performance Requirements

Fixed Wireless Access (FWA) is emerging as an initial important commercial use case in 5G. Despite FWA is an existing use case in LTE, 5G opens the possibility to use mmWave spectrum with large bandwidth which improves the capacity and throughput many folds over an LTE based FWA, and it can take advantage of the advanced radio features like massive MIMO, beamforming or MU-MIMO included in 5G standard. In this way, FWA over 5G is an alternative to fiber to the home (FTTH) for last-mile connectivity, especially where fiber deployments are not feasible or cost-effective. 5G FWA can potentially deliver a level of service that is similar to that of a fiber-based broadband network and expected to provide data speeds that are comparable to current broadband standards.

The FWA over 5G is essentially a 5G solution but there are subtle differences from a common 5G eMBB solution. The key objective of the FWA is to provide high speed broadband connections to homes, offices and similar premises. The key differences of FWA with eMBB are the following:

- FWA coverage areas are based on the viability for broadband services in that area.
- Mobility (handovers) is not required in FWA since the User Equipment (UEs) or the Customer Premise Equipment (CPEs) are stationary devices that will be mainly connected to a specific 5G cell.
- In terms of site solutions, high power & high capacity macro base stations are more suitable to provide outdoor to indoor coverage to the CPEs. Thus, Rural Macro cell (RMa) and, in some cases, Urban Macro cell (UMa) deployments are mainly considered.

This section analyzes the cell coverage of 5G communications using mmWaves for the FWA use case including a maximum data rate estimation. Two deployment scenarios have been considered, rural macrocell and urban macrocell. For the coverage study both Line of Sight and Non-Light of Sight conditions have been evaluated, and indoor deployments have been also considered. The results show that outdoors deployments are completely valid for urban macrocells both in LOS and NLOS. For rural macrocell, outdoor deployments guarantee complete cell coverage. Finally, indoor deployments are only feasible for rural microcells and only under certain conditions.

3.1 Channel Model for mmWave Signal Propagation in 5G

As it has been introduced at the beginning, two different type of deployments are considered for FWA use case: Rural Macro cell (RMa) and Urban Macro cell (UMa) deployments.

The Third Generation Partnership Project (3GPP) defines in [5] the channel models for both RMa and UMa deployments. This study uses the models included in [5] but for RMa deployments it additionally uses a propagation model proposed by the New York University in [6] because of according to [7] the model defined in [5] has not been validated in the literature for mmWave frequencies.

FWA could be deployed using outdoor User Terminals (UT) or indoor UT (UT is the same as UE). In [5], the propagation loss models are defined taking into account both outdoor UT and indoor UT. Figure 10.a and Figure 10.b show the distance considerations for both outdoor UT and indoor UT respectively.

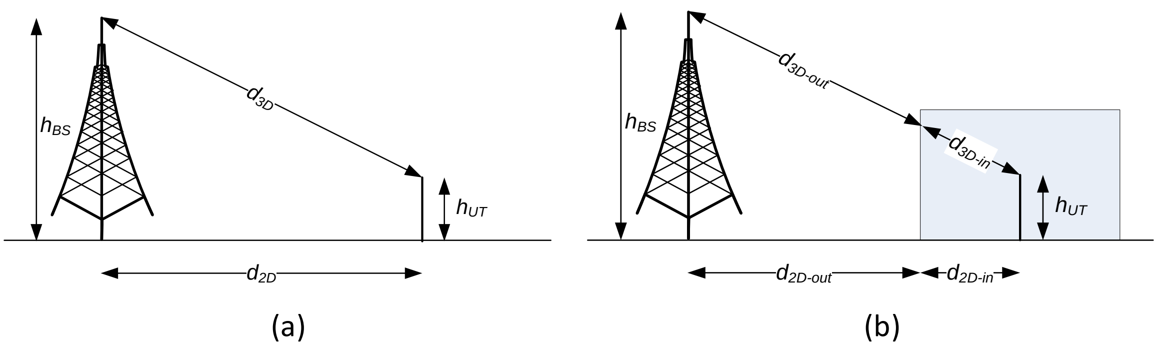

Figure 10: Distances Definition for Outdoor UTs (a) and for Indoor UTs (b) [5]

Next subsections describe each propagation model including the propagation losses due to outdoor to indoor (O2I) penetration of the signal for the indoor UT case. The last subsection includes the transmitted power considerations used for the simulations. It is important to remark that the shadow fading effect is not considered because this study is only focused on the mean coverage.

3.1.1 Rural Macrocell defined by 3GPP in [5]

In [5], the propagation loss model is defined for both those UEs that are in Line of Sight (LOS), and for those UEs that are in Non-Line of Sight (NLOS). In addition, the probability of being in LOS or NLOS is also defined.

For RMa, the LOS probability (Eq. 1) depends only on the distance between the gNB placement and the placement of the UE for outdoor UT, or the placement of the external wall that is closest to the gNB for indoor UT.

$$Pr_{\text{LOS}} = \begin{cases} 1 & , d_{\text{2D-out}} \leq 10m \\ exp\left(-\frac{d_{\text{2D-out}}-10}{1000}\right) & , 10m < d_{\text{2D-out}} \end{cases} \tag{1}$$

Despite the propagation loss model for RMa defined in [5] has not been validated for mmWave frequencies it is used in this paper and it is compared to the propagation model for RMa of [6]. The propagation loss for LOS condition in RMa deployments defined in [5] is:

$$PL_{\text{RMa-LOS}} = \begin{cases} PL_1 & 10m \leq d_{\text{2D}} \leq d_{\text{BP}} \\ PL_2 & d_{\text{BP}} \leq d_{\text{2D}} \leq 10\text{km} \end{cases} \tag{2}$$

Where, d_{BP} is the distance of the break point where the propagation loss changes:

$$d_{BP} = \frac{2\pi h_{BS} h_{UT} f_c}{c} \tag{3}$$

Being, h_{BS} the height of the gNB (in m), h_{UT} the height of the UE (in m), f_c the center frequency (in Hz), and c the propagation velocity in free space (in m/s). On the other side PL1 and PL2 are:

$$PL_1 = 20\,log_{10}(40\pi d_{\text{3D}} f_c/3) + min(0.03h^{1.72}, 10)\,log_{10}(d_{\text{3D}}) - min(0.044h^{1.72}, 14.77) + 0.002\,log_{10}(h) d_{\text{3D}} \tag{4}$$

$$PL_2 = PL_1(d_{\text{BP}}) + 40\,log_{10}(d_{\text{3D}}/d_{\text{BP}}) \tag{5}$$

Where, d_{3D} is the linear distance between the gNB antenna and the UE antenna (in m), and h is the average building height of the streets (in m). Note that for the propagation loss models f_c is in GHz.

The propagation loss for NLOS conditions in RMa deployments defined in [5] is:

$$PL_{\text{RMa-NLOS}} = max(PL_{\text{RMa-LOS}}, PL'_{\text{RMa-NLOS}}) \tag{6}$$

$$\begin{aligned} PL'_{\text{RMa-NLOS}} = {} & 161.04 - 7.1\,log_{10}(W) + 7.5\,log_{10}(h) - (24.37 - 3.7(h/h_{\text{BS}})^2)\,log_{10}(h_{\text{BS}}) + (43.42 - \\ & 3.1\,log_{10}(h_{\text{BS}}))(log_{10}(d_{\text{3D}}) - 3) + 20\,log_{10}(f_c) - (3.2(log_{10}(11.75h_{\text{UT}}))^2 - 4.97) \end{aligned} \tag{7}$$

Where, W is the average street width. In [5], the applicable ranges for W, h, h_{BS} and h_{UT} are defined.

3.1.2 Rural Macrocell defined by NYU in [6]

In this case, the differentiation between LOS and NLOS is maintained, but the propagation loss model does not have any break point, being a simpler propagation model than the one defined for the 3GPP.

The propagation loss for LOS conditions in RMa deployments defined in [6] is:

$$PL_{RMA-LOS-NYU} = 32.4 + 20\log_{10}(f_c) + 23.1\left(1 - 0.03\left(\frac{h_{BS}-35}{35}\right)\right)\log_{10}(d_{3D}) \tag{8}$$

And the propagation loss for NLOS conditions in RMa deployments defined in [6] is:

$$PL_{RMA\_LOS\_NYU} = 32.4 + 20\log_{10}(f_c) + 30.7\left(1 - 0.049\left(\frac{h_{BS}-35}{35}\right)\right)\log_{10}(d_{3D}) \tag{9}$$

3.1.3 Urban Macrocell defined by 3GPP in [5]

For UMa, the LOS probability depends on the distance between the gNB placement and the placement of the UE for outdoor UT, or the placement of the external wall for indoor UT; and on the height of the UE. The expression of the probability used can be found in section 7.4.2 of [5].

The propagation loss for LOS conditions in UMa deployments defined in [5] is:

$$PL_{\text{UMa-LOS}} = \begin{cases} PL_1 & 10m \le d_{\text{2D}} \le d'_{\text{BP}} \\ PL_2 & d'_{\text{BP}} \le d_{\text{2D}} \le 5\text{km} \end{cases} \tag{10}$$

Where, d'_{BP} is the distance of the break point where the propagation loss changes. This break point is different from the one defined for RMa because it uses the effective heights for the gNB (h'_{BS}) and for the UE (h'_{UT})

$$d_{BP} = \frac{2\pi h'_{BS} h'_{UT} f_c}{c} \tag{11}$$

The way to obtain h'_{BS} and h'_{BS} can be found in 7.4.1 of [5]. In this case, PL1 and PL2 are:

$$PL_1 = 28.0 + 22\,log_{10}(d_{\text{3D}}) + 20\,log_{10}(f_c) \tag{12}$$

$$PL_2 = 28.0 + 40\,log_{10}(d_{\text{3D}}) + 20\,log_{10}(f_c) - 9\,log_{10}((d'_{\text{BP}})^2 + (h_{\text{BS}} - h_{\text{UT}})^2) \tag{13}$$

The propagation loss for NLOS conditions in UMa deployments defined in [5] is:

$$PL_{\text{UMa-NLOS}} = max(PL_{\text{UMa-LOS}}, PL'_{\text{UMa-NLOS}}) \tag{14}$$

$$\begin{aligned} PL'_{\text{UMa-NLOS}} = {} & 13.54 + 39.08\log_{10}(d_{\text{3D}}) + \\ & 20\log_{10}(f_c) - 0.6(h_{\text{UT}} - 1.5) \end{aligned} \tag{15}$$

3.1.4 Outdoor to Indoor Penetration Losses

The Outdoor to Indoor (O2I) penetration loss models used for the simulations have been obtained from section 7.4.3 of [5]. O2I penetration loss is added to the propagation losses obtained from the previous sections. Two O2I penetration losses are considered: low-loss model and high loss model. According to [5], only low loss model can be applied to RMa; and for UMa, both models can be applied. In this paper we use only the high-losses model for UMa simulations.

The O2I penetration loss for the low-loss and high-loss model are defined in eq. 16 and eq. 17 respectively:

$$P_{O2I}^{low} = 5 - 10\log_{10}\left(0.3 \cdot 10^{\frac{-L_{Glass}}{10}} + 0.7 \cdot 10^{\frac{-L_{Concrete}}{10}}\right) + 0.5d_{2D-in} \quad (16)$$

$$P_{O2I}^{high} = 5 - 10\log_{10}\left(0.7 \cdot 10^{\frac{-L_{IIRGlass}}{10}} + 0.3 \cdot 10^{\frac{-L_{Concrete}}{10}}\right) + 0.5d_{2D-in} \quad (17)$$

Where L_{Glass}, $L_{Concrete}$, and $L_{IIRGlass}$depends on the center frequency (in GHz):

$$L_{Glass} = 2 + 0.2f_c$$

$$L_{Concrete} = 5 + 4f_c$$

$$L_{Glass} = 23 + 0.3f_c$$

3.1.5 Transmitted Power Considerations

According to the 5G standard [2], the gNB has not any power restriction for Wide Area transmissions such as is the case for FWA. But the standard specifically defines a type of UE for FWA in [8] (power class 1 – FWA UE), and this UE type has a limit in its Effective Isotropic Radiated Power (EIRP) of 55 dBm. Such as power restrictions are mainly associated to the uplink (UL), the EIRP considered for the coverage study is 55dBm.

Note that the simulations have been done using the gNB transmitted EIRP from the FWA UE type EIRP, and it is not considered any gain at the receiver site, that is, the receptor antenna acts as an omnidirectional antenna. This fact offers the possibility of having improvements in the level of received signal if we use directional antennas in the receiver.

On the other side, in [8] the sensitivity of the FWA UE is also defined. The sensitivity depends on the channel bandwidth used by the UE and goes from -97.5 dBm for 50MHz to -88.5dBm for 400MHz. These sensitivity values have been considered as coverage limits in the coverage study.

3.2 Simulations

3.2.1 Scenarios Under Consideration

Four different scenarios have been used for the simulations depending on if the deployment scenario is RMa or UMa and depending on if the UE is deployed outdoors or indoors.

For each scenario different gNB and UE heights have been configured. In the same way, different indoor distances have been selected. In this case, [5] gives a range of indoor allowed distances: from 0 to 10m for RMa and from 0 to 25m for UMa. For the simulations the mean point has been selected.

- Scenario 1 – RMa outdoor. The simulation parameters are: $h_{BS} = 40m$, $h_{UT} = 5m$, $h = 5m$, $W = 20m$. It is considered that the UE antennas are at the top of the buildings and the height of the buildings is 5m.
- Scenario 2 – UMa outdoor. The simulation parameters are: $h_{BS} = 25m$, $h_{UT} = 20m$. In this case an apartment building is considered. It is also considered that the UE antennas are at the top of the building.
- Scenario 3 – RMa indoor. The simulation parameters are: $h_{BS} = 40m$, $h_{UT} = 1.5m$, $h = 5m$, $W = 20m$, $d_{2D-in} = 5m$. It is considered that the UE is placed in the basement plant of a household.
- Scenario 4 – UMa outdoor. The simulation parameters are: $h_{BS} = 25m$, $h_{UT} = 4.5m$, $d_{2D-in} = 12m$. It is considered that the UE is placed in the first plan of an apartment.

For each scenario the simulation results obtained are the path loss (PL), the signal to noise ratio (SNR), and the maximum achievable data rate for both UL and DL.

To obtain the SNR only the thermal noise has been considered.

On the other side, to obtain the maximum achievable transmission rate the next formula obtained from [9] has been used:

$$Data\ Rate(Mbps) = 10^{-6} \sum_{j=1}^{J} \left(v_{layers}^{(j)} Q_m^{(j)} f_m^{(j)} R_{max} \frac{12 N_{PRB}^{BW(j),\mu}}{T_S^{\mu}} \left(1 - OH^{(j)}\right) \right) \quad (18)$$

Where:

- J is the number of aggregated component carriers in a band or band combination. In our case J = 1.
- $v_{layers}^{(j)}$ is the maximum number of supported layers. In our case $v_{layers}^{(j)} = 1$.
- $Q_m^{(j)}$ is the maximum supported modulation order.

- $f_m^{(j)}$ is the scaling factor and can take the values 1, 0.8, 0.75, and 0.4. In our case $f_m^{(j)} = 1$. The maximum one.
- R_{max} is the coding rate.
- μ is the numerology. In our case $\mu = 3$ that corresponds to a SCS of 120kHz.
- T_S^{μ} is the average OFDM symbol duration in a subframe for numerology μ. In this case $T_S^{\mu} = \frac{10^{-3}}{14 \cdot 2^{\mu}}$.
- $N_{PRB}^{BW(j),\mu}$ is the maximum RB allocation in bandwidth with numerology μ. Such as 400MHz of bandwidth are considered, $N_{PRB}^{BW(j),\mu} = 264$.
- $OH^{(j)}$is the overhead and for mmWave can be 0.18 or 0.10. In our case $OH^{(j)} = 0.18$.

In our case we obtain $Q_m^{(j)}$ and R_{max} from the SNR obtained and the MCS Table 5.1.3.1-2 of [10]. To split the MCS indexes among the SNR values, a linear approximation that goes from -5dB, for the lowest MCS index, to 28 dB, for the highest MCS index, has been used. This range of SNR has been divided in 28 different stretches.

3.2.2 Simulation Results

All the figures shown in this section have the same color legend: black for RMa deployments using 3GPP model, magenta for RMa deployments using NYU model, and blue for UMa deployments using 3GPP model.

In the same way, the lines of all the graphs also have the same meaning: solid line for LOS conditions, discontinuous line for NLOS conditions, and dotted line for the combination of LOS conditions and NLOS conditions attending to the LOS probabilities defined in (eq. 2) for RMa and in section 7.4.2 of [5] for UMa.

Figure 11 shows that for outdoor FWA deployments:

- The coverage strongly depends on the LOS or NLOS capability. Considering an Inter Side Distance (ISD) of 5km for RMa, and a ISD of 500m for UMa (see [5]), and based on the receiver sensitivity, FWA over 5G deployments are valid for LOS deployments both for UMa and for RMa independently of the propagation model used.
- On the other side for NLOS, the coverage range is drastically reduced. In this case, for RMa deployments using 3GPP models the coverage range goes from about 100m to 200m and for RMA deployments using NYU model the coverage range goes from 500 m to 1km, depending on the bandwidth configuration. This coverage ranges have been obtained using the received sensitivity explained before.
- If we use the LOS probability, the results for the UMa deployments are similar to the NLOS ones because the LOS probability is high from the

beginning. For RMa, the LOS probability is smoother than for UMa, and thus the average path loss is between the LOS and the NLOS cases.

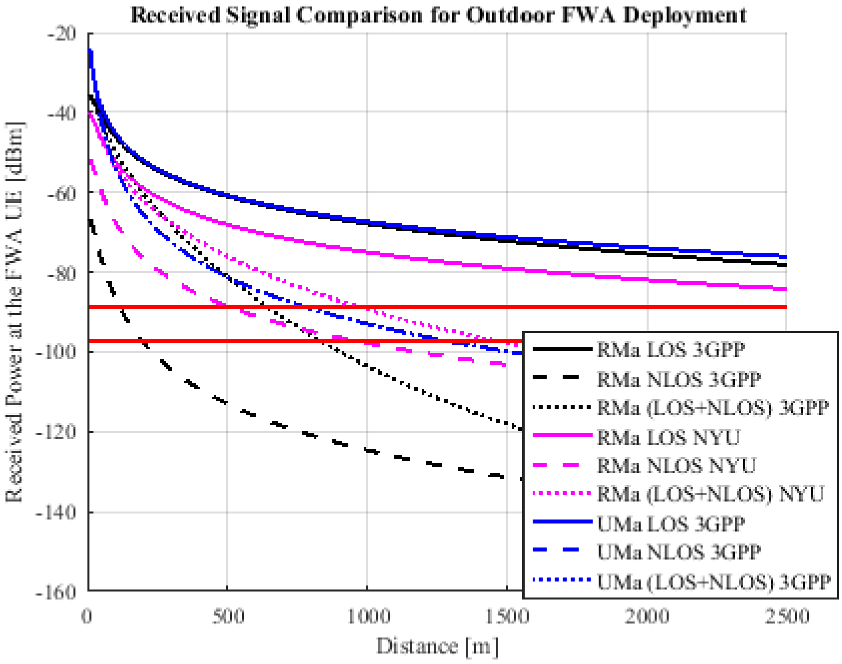

Figure 11: Received Signal Comparison for Only Outdoor Deployments

Focusing on indoor deployments, Figure 12 shows that:

- when the O2I model is applied to NLOS deployments the coverage range is too low to be acceptable independently of the type of deployment.
- If the households where indoor FWA over 5G have LOS (that means that there is only one wall between the gNB antennas and the UE antennas), RMa deployments can reach up from 500m to 1250m for the NYU model and from 1100 m to 2400m for 3GPP model.
- In this case, UMa deployments are not feasible due to the high propagation losses.

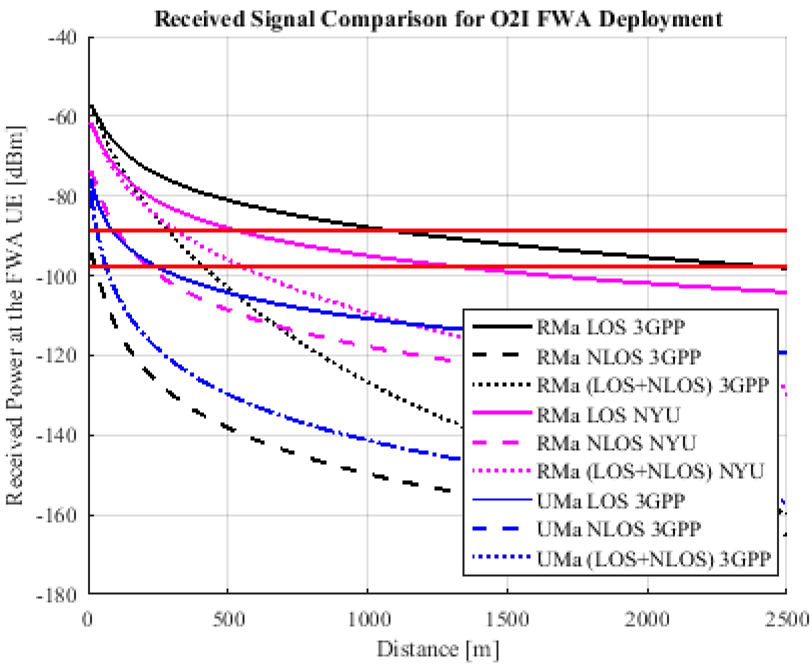

Figure 12: Received Signal Comparison for Indoor Deployments

Figure 13 and Figure 14 show a SNR comparison for both outdoor and indoor FWA deployments over 5G. These figures show that the SNR limitation is not critical, being the sensitivity limitation more restrictive.

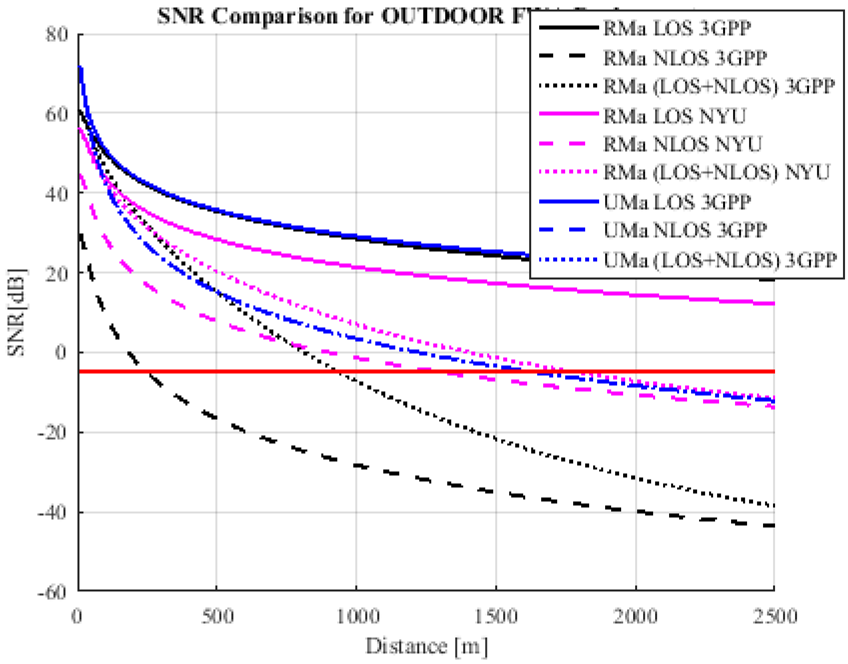

Figure 13: SNR Comparison for Outdoor Deployments

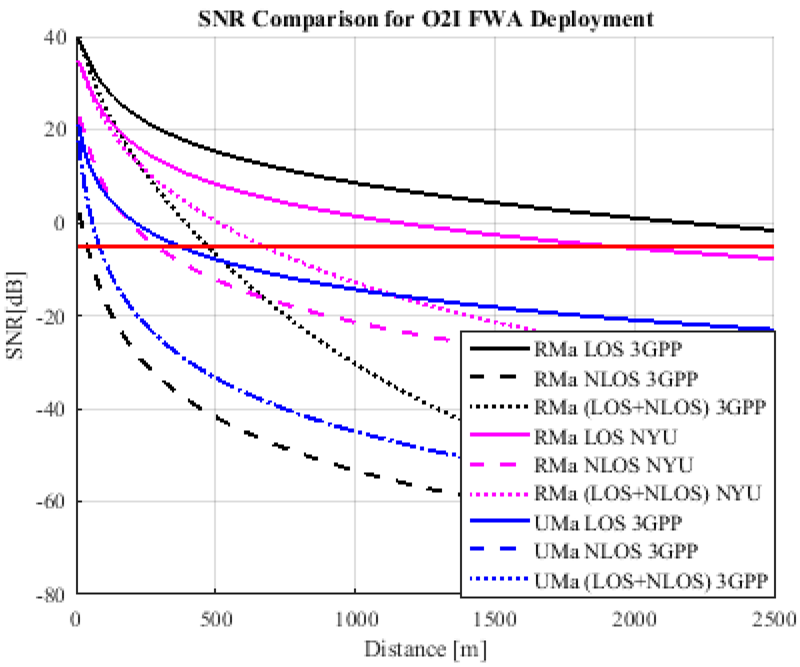

Figure 14: SNR Comparison for Indoor Deployments

Finally, Fig.7 and Fig. 8 show a data rate comparison for both outdoor and indoor FWA deployments over 5G:

- For outdoor FWA deployments with LOS the maximum achievable data rate is higher than 1.5Gbps for the UEs closer more than 500m to the gNB independently of the propagation model; and a data rate of 500Mbps is guaranteed at the whole cell range.
- For outdoor FWA deployments with NLOS:
  - For UMa and RMa models, the coverage limitation comes from the sensitivity.
  - For UMa UEs can achieve more than 1Gbps at the whole cell range taking into account an ISD of 500m.
  - For RMa UEs closer more than 500m to the gNB a data rate higher of 250Mbps is achieved taking the NYU model. The 3GPP model indicates that the maximum allowed distance is about 100 meters.
- For indoor FWA deployments, it only makes sense talk about the RMa deployments with LOS. In this case:
  - if NYU model is considered, UEs closer more than 500m to the gNB can achieve a data rate higher of 500Mbps.
  - And if 3GPP model is considered, the coverage range is higher and UEs closer more than 1000m to the gNB can achieve a data rate higher of 500Mbps.

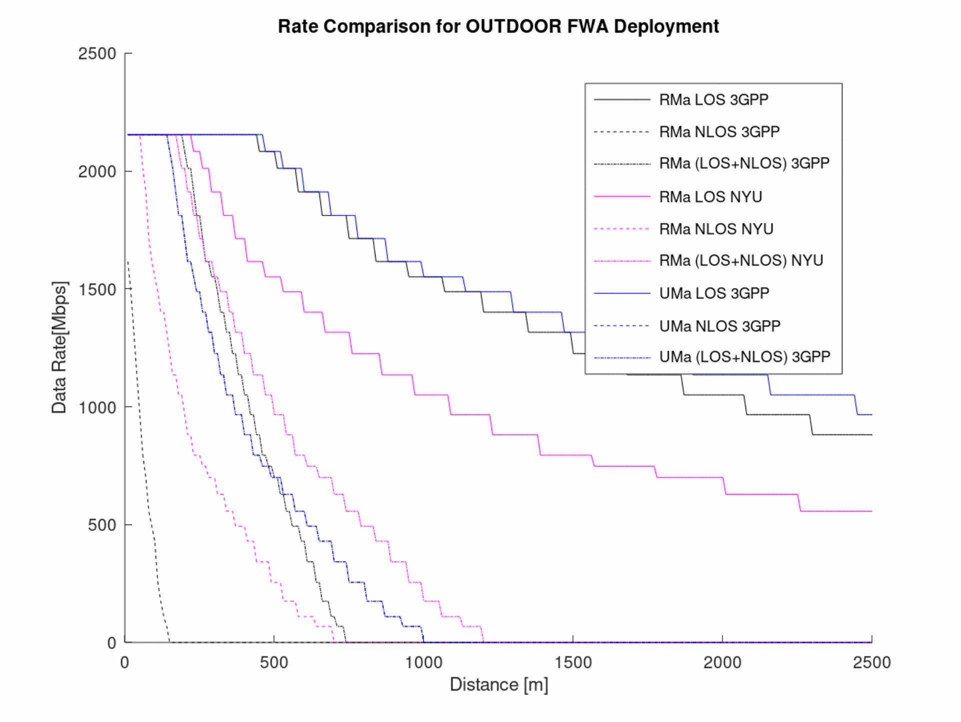

Figure 15: Rate Comparison for Outdoor Deployments

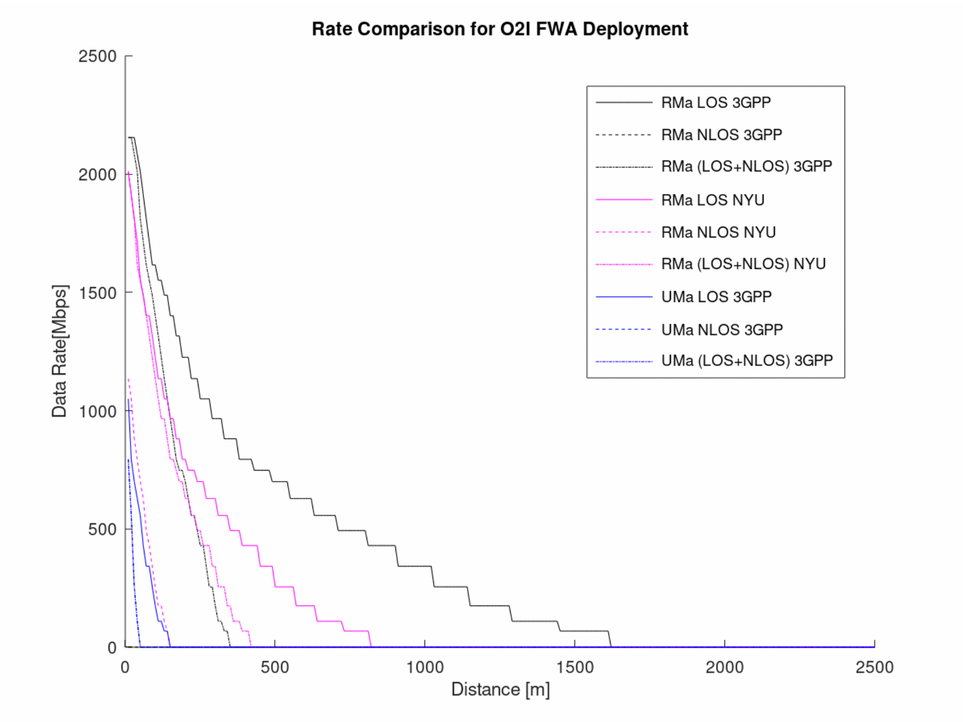

Figure 16: Rate Comparison for Indoor Deployments

3.3 Conclusions

This section includes a coverage study for FWA deployments over 5G using mmWaves, and It has been obtained that the main coverage requirement is imposed by the sensitivity at the UE side.

At the sight of the results, if at the UE side there is not any directional antenna, these kinds of deployments are mainly feasible if outdoor units are used at the UE side, mainly for Rural deployments where the ISD is about 5km. For Urban deployments, NLOS configurations are also valid if the ISD distance is about 500m. In these case, the achievable data rates are high enough to be compared with current fixed broadband access standards, being higher than 500Mbps in the worst case (edge of the cell of the rural deployments).

For indoor FWA deployments over 5G using mmWaves, only rural environments with LOS make sense. It must be noticed that depending on the propagation model these kinds of deployments do not cover the whole cell area. Despite this the achievable rates are high enough to be compared with fixed broadband access standards.

FWA indoor deployments over 5G could improve its coverage range by using more directive antennas and by placing the UE close to the outside wall. In this study only a small set of cases have been analyzed, there could be different scenarios better than the ones shown here.

3.4 Requirements

The requirements specified in this document have different priorities:

- Essential: This tag indicates the requirement is mandatory and it has the maximum priority. The system does not work if this requirement is not fulfilled.
- Important: This tag indicates that the requirement is mandatory. The performance of the system is degraded if this requirement is not fulfilled.
- Good to have: This tag indicates the requirement is not mandatory, but it could improve the solution substantially.
- Cosmetic: The requirement is not mandatory, and the performance of the solution is not affected by it, but the perceived quality of the system can be improved by fulfilling the requirement.

The requirements related to the performance of the network are shown in the next table:

Table 9: Performance Requirements

ID	Description	Severity
P.01	The gain of the designed antennas in mmWave frequencies must maximize the performance of Indoor scenarios both for LOS and NLOS conditions. The gain of the designed antennas in mmWave frequencies for indoor scenarios must be higher than 18dBi.	Essential
P.02	The gain of the designed antennas in mmWave frequencies must maximize the performance of Indoor scenarios both for LOS and NLOS conditions. The gain of the designed antennas in mmWave frequencies for indoor scenarios must be higher than 18dBi.	Essential
P.03	The gain of the designed antennas in sub-6GHz frequencies must be good enough to cover the whole cell in NLOS and indoor scenarios. The gain of the designed antennas in sub-6GHz frequencies must be higher than 10dBi.	Essential
P.04	For indoor scenarios, the beam aiming system / algorithm must check all the directions and select the best one to maximize the quality of the connection. In these scenarios the signal can come from any direction due to the signal reflexions.	Essential
P.05	For outdoor and indoor scenarios, the beam aiming system / algorithm must check all the possible directions within a 120º space in an azimuthal plane and 30º space in a vertical plane and select the best one to maximize the quality of the connection.	Essential
P.06	The data rate of the indoor connections should be higher than 100Mbps at on the whole cell, according to the Agenda 2025 of the European Union.	Important
P.07	The data rate of the outdoor connections both in LOS and NLOS scenarios should be higher than 1Gbps at on the whole cell, according to the Agenda 2025 of the European Union.	Important

P.08	To increase the gain of the antennas in mmWave frequencies, the project team must explore the possibility of using a reflector in combination with commercial low directivity antennas. This approach will allow demonstrating the benefits of the project.	Essential

4 Design Requirements

Before starting with the design requirements, this section includes the considerations taken into account for the end-to-end validation setup. The end-to-end validation setup is very important because of it will be used to verify and validate all the developments of the project. In this project, the design of the validation setup is even more important than in other cases because of at mmWave frequencies, the RF equipment and the signal processing is more complex. Next subsections include the different proposals considered and its implications.

4.1 End-to-End Validation Setup Proposals

4.1.1 Proposal I

This proposal is based on made the whole 5G signal processing using Software Define Radio (SDR) equipment combined with RF devices. Figure 17 shows a high-level view of this proposal.

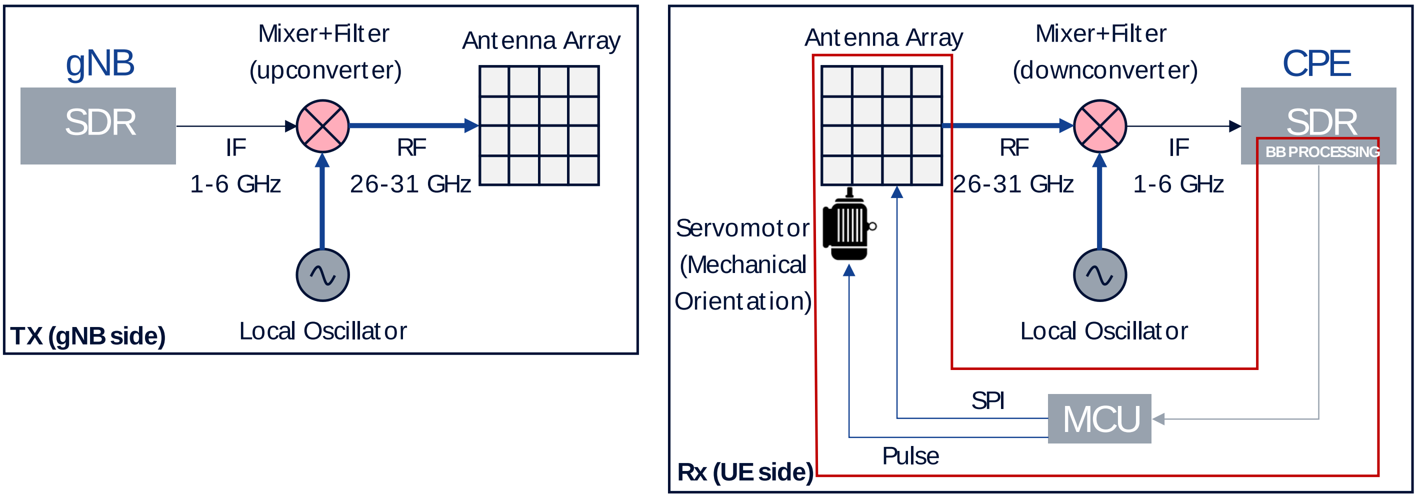

Figure 17: End-to-End Validation Setup – Proposal I

For this proposal:

- We may need two step mixing chain to upconvert the signal to RF depending on the available mixers.
- RF components and SDRs are expensive.

- The solution selected must be cost optimized.
- We need generate the local oscillator precisely.

4.1.2 Proposal II

The second proposal has been designed for split the validation in two different parts, sub-6GHz and mmWave frequency bands. This proposal tries to avoid the RF chain, avoiding the RF mixers. Figure 18 shows a high-level view of this second proposal.

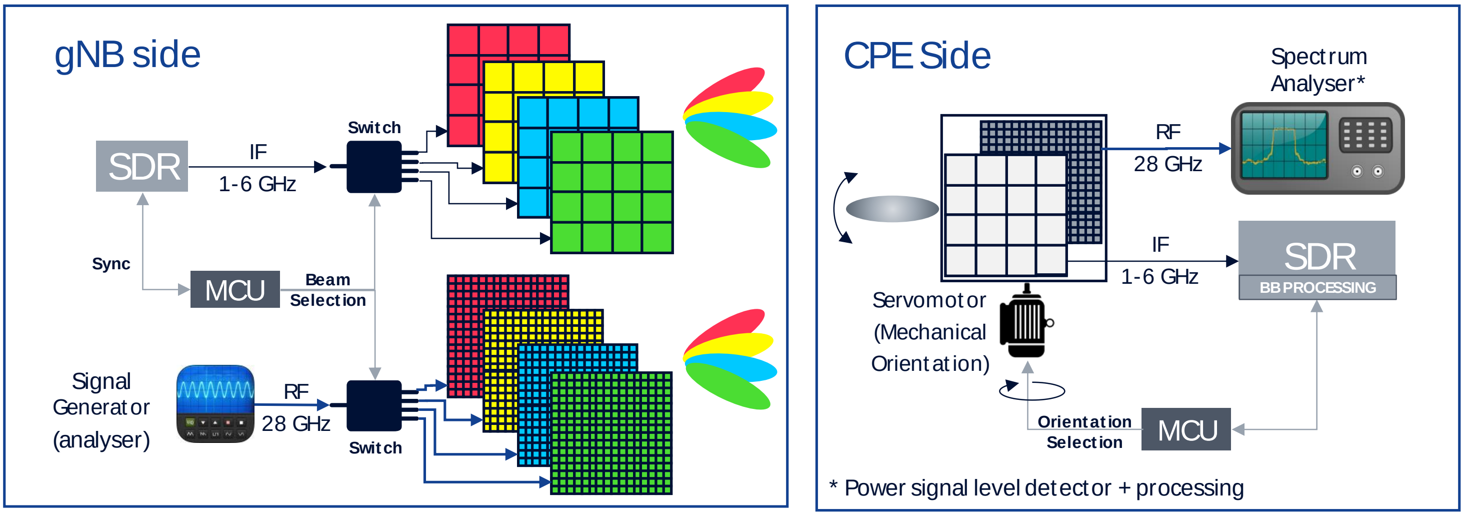

Figure 18: End-to-End Validation Setup – Proposal II

In this proposal and based on Figure 18:

- Each antenna colour corresponds to a different antenna orientation (different azimuth). Antennas of the same colour should be placed together into the same physical support.
- MCU manages the beam selection and must be sync with the SDR.
- At the UE /CPE side, the IF frequency is proposed to be used for baseband processing and beam selection.
- To verify the selected beam, the spectrum analyser is proposed.
- This solution avoids the RF chain to up/downconvert the signal.

Figure 19 and Figure 20 show the gNB side and the CPE side, respectively, in a more detailed way. At the gNB side:

- Two antennas (3.5 GHz and 28 GHz) on the same physical support.
- The main lobe of both antennas must have the same direction of maximum radiation, and they should have the same half-power bandwidth.
- Note that it is only needed one antenna design that will be replicated to generate the different beams.
- There are still some open issues:

  - A power amplifier may be required.
  - The Microcontroller Unit (MCU) has to be defined.
  - The synchronization between the MCU and the SDR has to be defined.
- The RF switches candidates are included in the figure.

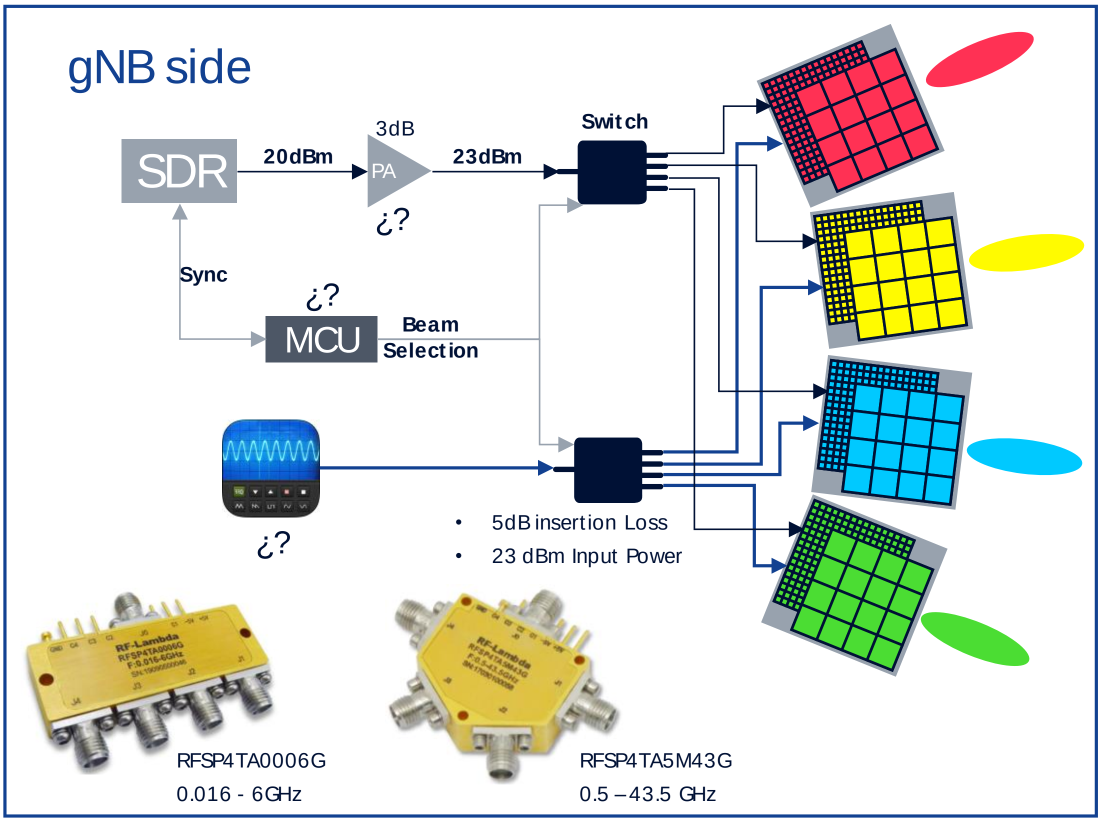

Figure 19: Detail of the gNB side for Proposal II

At the CPE side:

- Same antenna design can be reused for both the gNB side and the CPE side.
- The SDR must know the orientation angle at every time and must be able to manage the orientation angle.
- The SDR must keep sniffing the spectrum for at least 20ms per orientation angle. According to section 2.1.3.1, the SS-PBCH block periodicity can be 5, 10, 20, 40, 80, 160 ms. Ideally, the SDR must sniff the environment each 5ms.
- The SDR must be able to decode the transmitted signal, identify each beam, obtain the beam identity and measure the beam quality.
- It could be possible to measure the signal power of a specific frequency band using a Schottky detector.
- By measuring the signal power, the pointing algorithm can be validated.

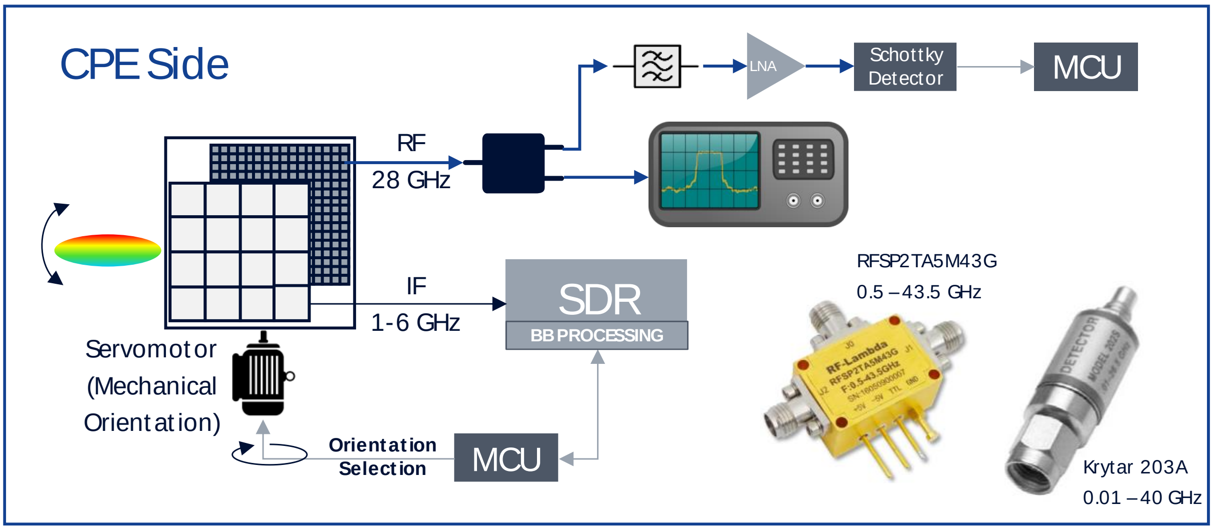

Figure 20: Detail of the CPE side for Proposal II

4.1.2.1 Proposal II Variation

A variation of proposal II is considered to verify the pointing algorithm for mmWaves. In this case, the modification only affects to the CPE. After the Schottky detector, the Rx power can be obtained and then the pointing is completely based on mmWave frequencies. Figure 21 shows this new approach for the CPE side.

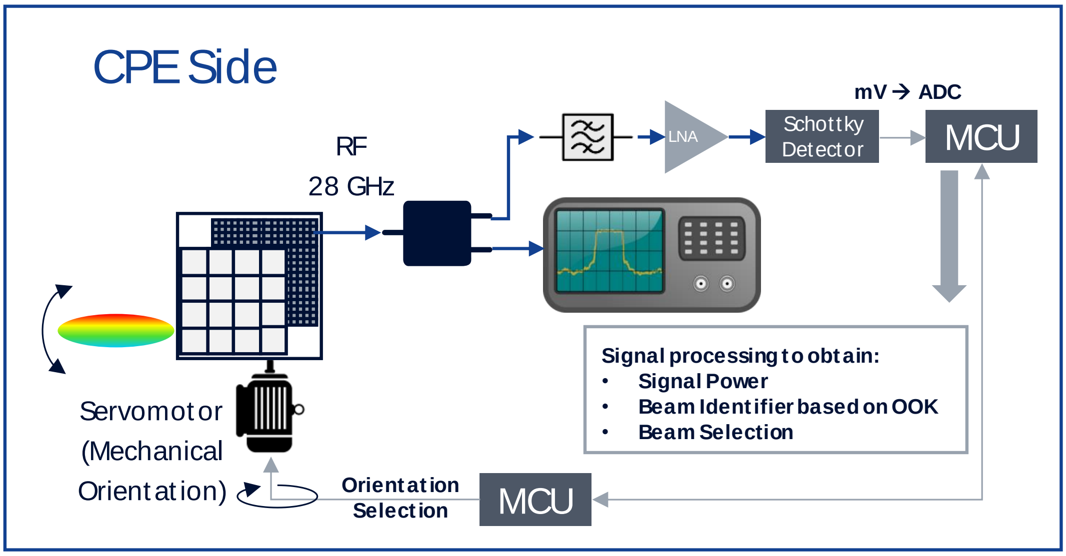

Figure 21: Detail of the CPE side for Proposal II Variation

This approach is based on:

- Use an OOK (On-Off Keying) modulation to differentiate the beams, this allows us to work directly at mmWave frequencies.

- Next figure shows the first approach of the OOK. This coding scheme allows is to generate the codes using serial communications.

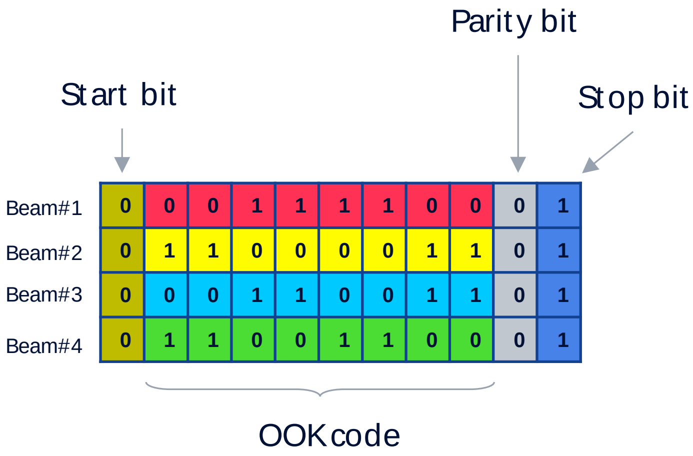

Figure 22: Example of Beam Identification Using OOK coding

- To keep the same averaged transmitted power independently on the OOK code selected, not all the OOK codes are valid. The OOK codes must have the same number of ones as number of zeros. Considering that the OOK codes can have 8 bits, the codes must contain four ones and four zeros. Attending to that constraint, 70 different codes can be generated (see section 8, Annex I: OOK Codes). Note that the maximum number of allowed beams for transmitting the SS-PBCH at a single cell is 64 (see section 2.1.3.1.1), so using the OOK codes proposed it is possible to differentiate all the different beams of a cell. Nevertheless, as the proposal is based on using four different beams, we can split the 8 bits of the serial port transmission word into four groups of two bits, obtaining 6 different valid OOK codes, see Table 10.

Table 10: Valid OOK Codes Using Groups of Two Bits

Beam ID	OOK Code	Decimal Value
1	00001111	15
10	00110011	51
15	00111100	60
56	11000011	195
61	11001100	204
70	11110000	240

- At the transmitter side, each beam is associated to a different OOK code, and it is transmitted using a different antenna. The antenna selection is made using a RF switch (see Figure 19).
- The measurements obtained at each orientation will be stored in a matrix for its later processing to obtain the best aiming direction. Figure 23 shows an example of measurement storage in a matrix, each row corresponds to a different beam index and each column corresponds to a different orientation angle of the CPE.

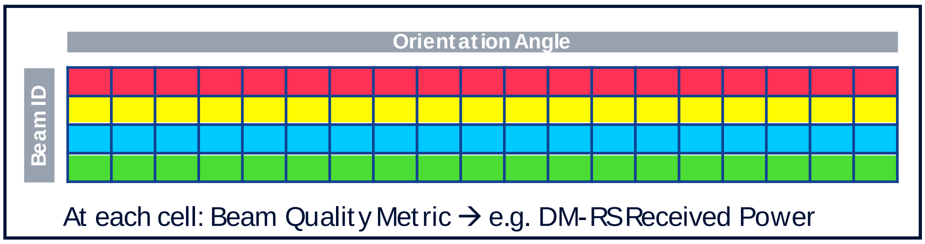

Figure 23: Measurement Storage Example.

- We have to decide the MCU architecture and connections taking into account both proposals (3.5GHz assisted and mmWave pure tone OOK): number of MCUs, capabilities, connections, etc.
- Taking about the time, the worst case happens when the SCS used is 240kHz because of the symbol duration is the lower one: $Tsymb = 4.1667\mu s$. Next table includes the time related considerations for the duration of each bit of the OOK codes. As it can be seen, for mmW frequencies, μ=3,4, the serial port baud rate is limited to its maximum value 256000. That means that the OOK code transmission will take more time than the duration of the SS-PBCH block. To validate the developments carried out in the project this difference can be assumed.

Table 11: Time Considerations for OOK code Transmissions

Numerology (μ)	**0**	**1**	**2**	**3**	4
SCS [kHz]	15	30	60	120	240
Symbol Duration [μs]	66,6667	33,3333	16,6667	8,3333	4,1667
CP Duration [μs]	4,68750	2,34375	1,17188	0,58594	0,29297
Symbol + CP Duration [μs]	71,35420	35,67705	17,83858	8,91924	4,45967
SS-PBCH Block Duration [μs]	285,4168	142,7082	71,35432	35,67696	17,83868
Bit Duration - OOK 10 bits [μs]	28,54168	14,27082	7,135432	3,567696	1,783868
Minimum Sampling frequency [MHz]	0,14014592	0,280292	0,560583	1,121172	2,242318
Serial Port Baudrate (bps)	56000	76800	230400	256000	256000
Serial Port 10 bits Duration [μs]	178,5714286	130,2083	43,40278	39,0625	39,0625

- According to section 2.1.3.1, the SS-PBCH block periodicity can be 5, 10, 20, 40, 80, 160 ms, with 20 ms by default. This requirement is not so restrictive as the SS-PBCH block duration.

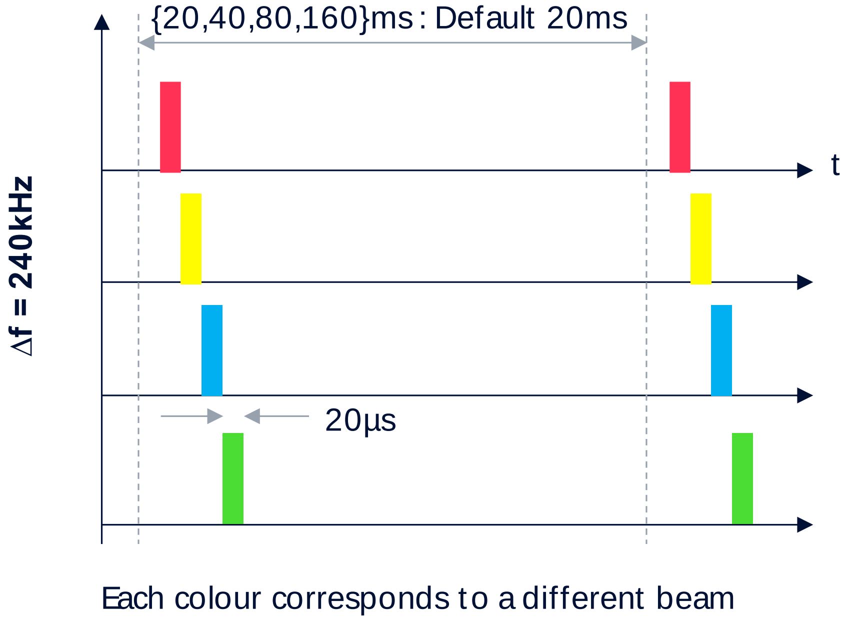

Figure 24: Example of Timing Considerations to generate the OOK Signal and to Decode It

4.1.3 Proposal III

This proposal is based on using a vector network analyser (VNA) both to generate the transmitted signals and to receive them. This proposal avoids including ad-hoc implementations to validate the project developments. In this case, both the transmitter antenna and the receiver antenna are connected to the VNA.

In a first step, the VNA will allow us to characterize the radio channel at different scenarios and different use cases. The radio characterization process is explained in [11], where the architecture of this proposal will be included. The same setup as the implemented to characterize the radio channel could be reused for validating the beam searching process. The receiver will make use of a mechanical pointing system to measure the signals coming from all the different directions of the upper hemisphere, and it will select the direction where the received signal has the best quality / power. More details about the setup implemented for the radio channel characterization and beam searching are included in [11].

4.2 Antenna requirements

Table 12: Antenna Requirements

ID	Description	Severity
A.01	The design for the mmWave Antenna must cover the n257 frequency band. This requirement fixes the frequency band for mmWave frequencies and the bandwidth.	Essential
A.02	The design for the sub 6GHz Antenna must cover the n77 frequency band. This requirement fixes the frequency band for sub 6GHz frequencies and the bandwidth.	Essential
A.03	The type of antennas to be used should be arrays of patch-type or slot-type printed antennas.	Good to Have
A.04	The antenna system for indoor scenarios must include a mechanical pointing system to pointing.	Essential
A.05	The mechanical pointing system may be different and independent depending on the frequency band.	Good to have
A.06	For mmWave, the half power beam width of the antenna should be into a range of 10 to 20 degrees.	Important
A.07	The gain of the mmWave antenna should be higher than 18dBi.	Important
A.08	The pointing sensitivity of the CPE should be at least one quarter of the minimum half power beam width considered for the transmitter.	Important
A.10	Design a reflector solution to improve the directivity of commercial low directivity antennas.	Essential

4.2.1 Antenna Elevation Considerations

The elevation of the antenna at the UE side depends on the distance between the UE and the gNB, the height of the antennas at the gNB, and the height of the UE. The closer the UE is to the gNB the higher elevation angle. Figure 25 shows the elevation angle for different scenarios:

a) Outdoor scenario considering a household with UE height of 5 meters.
b) Indoor scenario considering a household and UE height of 1.5 meters.

c) Outdoor scenario considering a building and UE height of 20 meters.
d) Indoor scenario considering a building and UE height of 4.5 meters (UE placed on the first floor of the building).

It can be noted that the elevation angle increases considerably as the UE gets close to the gNB.

In this case, the maximum elevation angle considered is 30°. This maximum elevation angle fixes the minimum distance from the UE to the gNB to reach perfect pointing match between the UE and the gNB. These minimum distances are included at each graph of Figure 25.

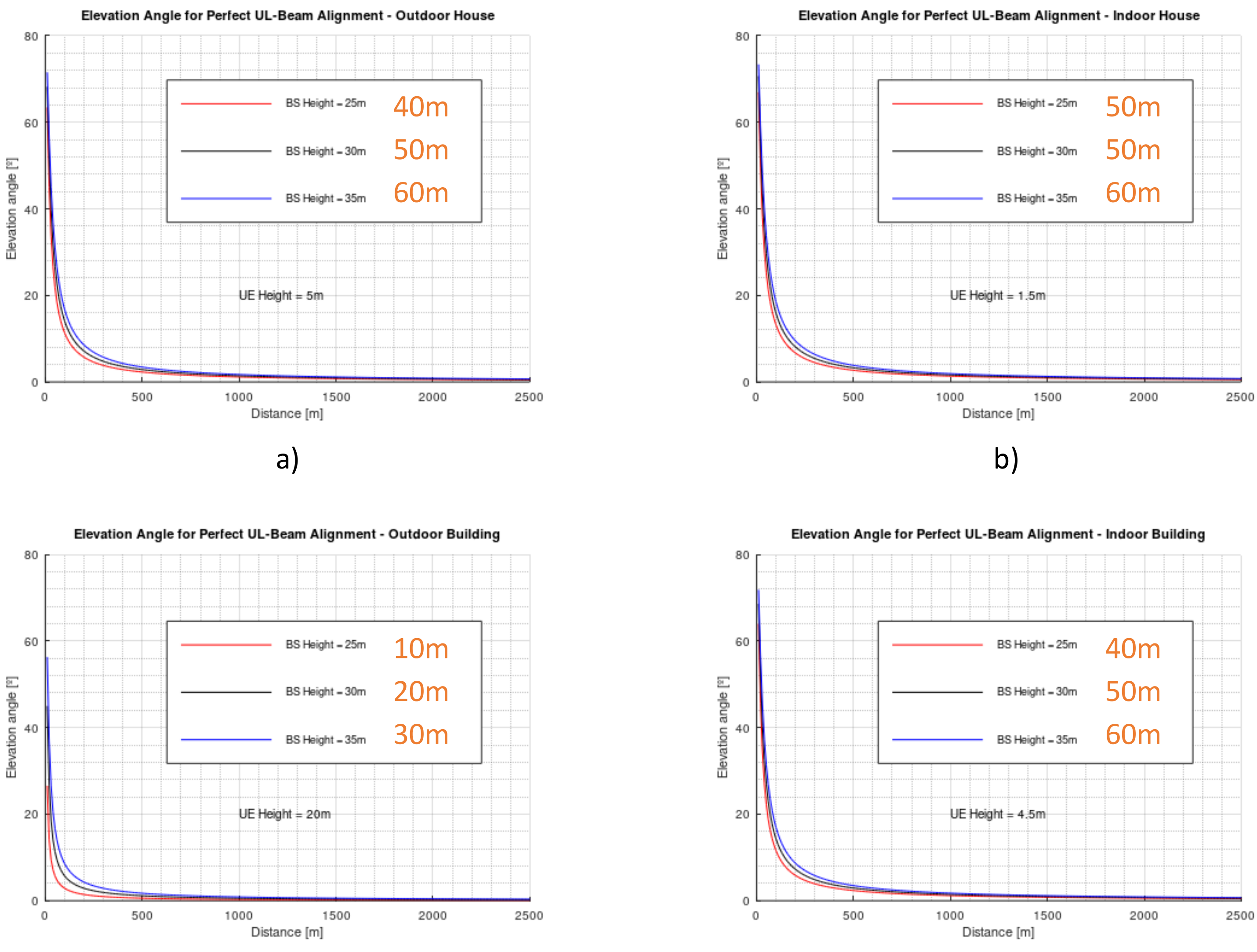

Figure 25: Elevation Angle Consideration - Different Elevation Angles for Different Scenarios

4.3 Beam Control

Table 13: Beam Control Requirements

ID	Description	Severity
B.01	The beam control system must identify the different beams.	Essential
B.02	The beam control system must measure the quality of each beam.	Essential
B.03	The beam control system must be able to store the quality of each beam at each orientation angle.	Essential
B.04	The beam control system must identify the best beam and its orientation.	Essential
B.05	The beam control system should include a beam recovery system.	Important
B.06	The beam control system should minimize the beam searching time	Important
B.07	The beam control system should be able to measure up to 64 beams each 5ms, according to the 3GPP specifications.	Essential

5 Conclusions

This document includes some important aspects about 5G specification that must be taken into account in the development of the project. An initial study about the mmWave coverage has been included to take it a starting point.

Based on the 5G standard requirements and based on the coverage results obtained in the coverage study, the main requirements for the antenna subsystem and the beam control subsystem have been included.

6 References

[1] 3GPP TS 38.211 V15.7.0 (2019-09), “*3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NR; Physical channels and modulation (Release 15)*”, 3GPP, September 2019.

[2] 3GPP TS 38.104 V16.2.0 (2019-12), “*3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NR; Base Station (BS) radio transmission and reception (Release 16)*”, 3GPP, September 2019.

[3] 3GPP TS 38.213 V15.7.0 (2019-09), “*3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NR; Physical layer procedures for control (Release 15)”*, 3GPP, September 2019.

[4] M. Giordani, M. Polese, A. Roy, D. Castor and M. Zorzi, "A Tutorial on Beam Management for 3GPP NR at mmWave Frequencies," in *IEEE Communications Surveys & Tutorials*, vol. 21, no. 1, pp. 173-196, Firstquarter 2019.

doi: 10.1109/COMST.2018.2869411.

[5] 3GPP TR 38.901 V16.0.0 (2019-10), “*3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on channel model for frequencies from 0.5 to 100 GHz (Release 16)*”, 3GPP, October 2019.

[6] G. R. MacCartney and T. S. Rappaport, "*Study on 3GPP rural macrocell path loss models for millimeter wave wireless communications*," 2017 IEEE International Conference on Communications (ICC), Paris, 2017, pp. 1-7

doi: 10.1109/ICC.2017.7996793

[7] T. S. Rappaport, Y. Xing, G. R. MacCartney, A. F. Molisch, E. Mellios and J. Zhang, "Overview of Millimeter Wave Communications for Fifth-Generation (5G) Wireless Networks—With a Focus on Propagation Models," in IEEE Transactions on Antennas and Propagation, vol. 65, no. 12, pp. 6213-6230, Dec. 2017

doi: 10.1109/TAP.2017.2734243

[8] 3GPP TS 38.101-2 V16.1.0 (2019-09), “*3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NR; User Equipment (UE) radio transmission and reception; Part 1: Range 2 Standalone (Release 16)*”, 3GPP, September 2019

[9] 3GPP TS 38.306 V15.7.0 (2019-09), “*3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NR; User Equipment (UE) radio access capabilities (Release 15)*”, 3GPP, September 2019.

[10] 3GPP TS 38.214 V15.7.0 (2019-09), “*3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NR; Physical layer procedures for data (Release 15)*”, 3GPP, September 2019

[11] Deliverable D6, “Beam Control Design”, 5GAFIANCE project, January 2021.

7 Acronyms

3GPP	Third Generation Partnership Project
4G	4^{th} Generation
5G	5^{th} Generation
ARFCN	Absolute Radio-Frequency Channel Number
BWP	Bandwidth Part
CP	Cyclic Prefix
CPE	Customer Premises Equipment
CRB	Common Resource Grid
CRS	Cell Specific Reference Signal
CSI-RS	Channel State Information – Reference Signal
DL	Downlink
DM-RS	Demodulation Reference Signal
DOCSIS	Data Over Cable Service Interface Specification
EIRP	Equivalent Isotropic Radiated Power
eMBB	Enhanced Mobile Broadband
eNB	Evolved node B
FDD	Frequency Duplexing Division
FR	Frequency Range
FTTH	Fiber To The Home
FTTx	Fiber to the something
FWA	Fixed Wireless Access
gNB	g Node B
HFC	Hybrid Fiber and Copper
IA	Initial Access
IEEE	Institute of Electrical and Electronic Engineers
IF	Intermediate Frequency
ISD	Inter-Site Distance
ITU	International Telecommunications Union
LNA	Low Noise Amplifier
LOS	Line of Sight
LTE	Long Term Evolution
MB	Millimeter Band
MCS	Modulation and Coding Scheme

MCU	Micro Controller unit
MIMO	Multiple Input Multiple Output
NLOS	Non-Line of Sight
NYU	New York University
O2I	Outdoor to Indoor
OFDM	Orthogonal Frequency Division Multiplexing
OOK	On-Off Keying
PBCH	Physical Broadcast Channel
PDCCH	Physical Downlink Control Channel
PDSCH	Physical Downlink Shared Channel
PL	Path Loss
PON	Passive Optical Network
PRB	Physical Resource Grid
PSS	Primary Synchronization Signal
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
RAN	Radio Access Network
RB	Resource Block
RF	Radio-Frequency
RLM	Radio Link Monitoring
RMa	Rural Macrocell
RRM	Radio Resource Management
SCS	Subcarrier Spacing
SDR	Software Defined Radio
SNR	Signal to Noise Ratio
SRS	Sounding Reference Signal
SS	Synchronization Signal
SS-PBCH	Synchronization Signal – Physical Broadcast Channel
SSS	Secondary Synchronization Signal
TDD	Time Duplexing Division
UE	User Equipment
UL	Uplink
UMa	Urban Macrocell
UT	User Terminal
VNA	Vector Network Analyzer

8 Annex I: OOK Codes

Beam ID	OOK Code	Decimal Value
1	00001111	15
2	00010111	23
3	00011011	27
4	00011101	29
5	00011110	30
6	00100111	39
7	00101011	43
8	00101101	45
9	00101110	46
10	00110011	51
11	00110101	53
12	00110110	54
13	00111001	57
14	00111010	58
15	00111100	60
16	01000111	71
17	01001011	75
18	01001101	77
19	01001110	78
20	01010011	83
21	01010101	85
22	01010110	86
23	01011001	89
24	01011010	90
25	01011100	92
26	01100011	99
27	01100101	101
28	01100110	102
29	01101001	105
30	01101010	106
31	01101100	108
32	01110001	113
33	01110010	114
34	01110100	116
35	01111000	120
36	10000111	135
37	10001011	139
38	10001101	141
39	10001110	142
40	10010011	147

41	10010101	149
42	10010110	150
43	10011001	153
44	10011010	154
45	10011100	156
46	10100011	163
47	10100101	165
48	10100110	166
49	10101001	169
50	10101010	170
51	10101100	172
52	10110001	177
53	10110010	178
54	10110100	180
55	10111000	184
56	11000011	195
57	11000101	197
58	11000110	198
59	11001001	201
60	11001010	202
61	11001100	204
62	11010001	209
63	11010010	210
64	11010100	212
65	11011000	216
66	11100001	225
67	11100010	226
68	11100100	228
69	11101000	232
70	11110000	240