3GPP Release 15 Overview

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3rd Generation Partnership Project (3GPP) members meet regularly to collaborate and create cellular communications standards. Currently, 3GPP is defining standards for 5G. Different groups, each with a specific focus area, make up 3GPP. Figure 1 shows an overview of the structure. It focuses on the lower layers, the physical (PHY) layer as defined by RAN1, the MAC layer as defined by RAN2, and, in some cases, the PHY layer test as defined by RAN4.

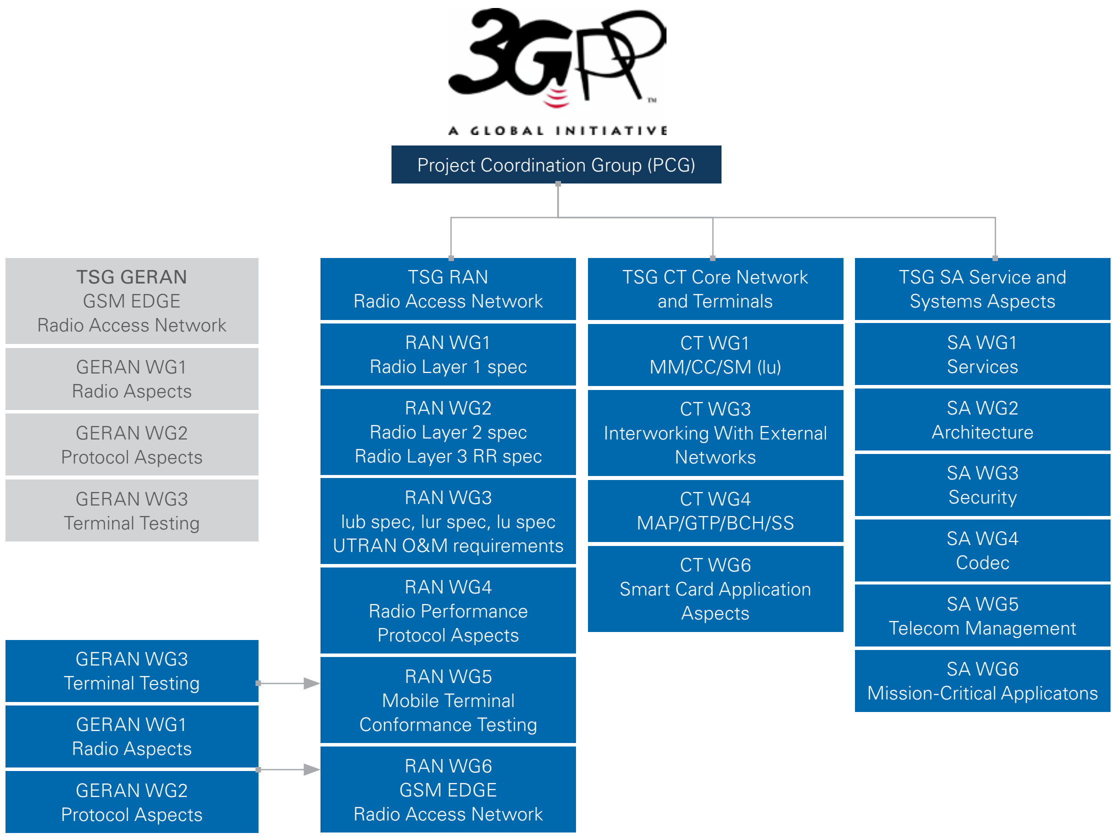

Figure 1. 3GPP Structure Overview From 3gpp.org

5G KPIs and 3GPP's Timeline

The International Telecommunication Union (ITU) has put forth some requirements for 5G that focus on fulfilling three key performance indicators (KPIs):

- >10 Gb/s peak data rates for the enhanced mobile broadband (eMBB)
- >1 M/km^2 connections for massive machine-type communications (MMTC)
- <1 ms latency for ultra-reliable low-latency communications (URLLC).

The table below provides an overview of specific technical requirements laid out as the 2020 minimum requirements.

Metric	Requirement	Comments
Peak Data Rate	DL: **20 Gb/s** UL: 10 Gb/s	Single eMBB mobile in ideal scenarios assuming all resources utilized
Peak Spectral Efficiency	DL: **30 b/s/Hz** (assuming 8 streams) UL: 15 b/s/Hz (assuming 4 streams)	Single eMBB mobile in ideal scenarios assuming all resources utilized
User Experienced Data Rate	DL: 100 Mb/s UL: 50 Mb/s	5% CDF of the eMBB user throughput
Area Traffic Capacity	Indoor hotspot DL: 10 Mb/s/m^2	eMBB
User Plane Latency	eMBB: 4 ms URLLC: **1 ms**	Single user for small IP packets, for both DL and UL (eMBB and URLLC)
Control Plane Latency	20 ms (encouraged to consider **10 ms**)	Transition from Idle to Active (eMBB and URLLC)
Connection Density	1M devices per km^2	For mMTC
Reliability	99.9999% success prob.	32 L2 bytes within 1 ms at cell edge
Bandwidth	>100 MHz; up to **1 GHz in > 6 GHz**	Carrier aggregation allowed

Table 1. IMT-2020 Minimum Requirements (Source: DRAFT NEW REPORT ITU-R M.[IMT-2020.TECH PERF REQ], "Minimum requirements related to technical performance for IMT-2020 radio interface(s)," Document 5/40-E, 22 February 2017)

3GPP has a specified release timeline, shown in Figure 2, to ensure that the regular cadence of releases between 4G and 5G continues and that the standard is delivered on time. The schedule for Release 15 has been accelerated since the timeline was initially released, but Release 16 is still planned for 2020 to align with the ITU.

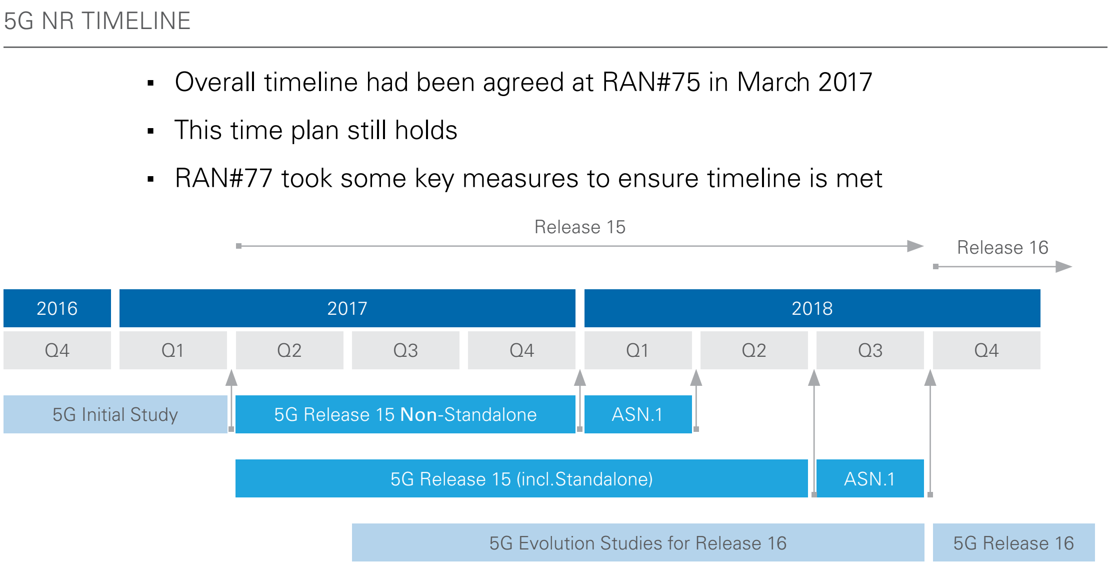

Figure 2. 3GPP Timeline (Source: 3GPP)

Release 15 was concluded at the June 2018 RAN plenary meeting. However, some issues still need to be treated and solutions need to be formalized. A late drop is scheduled in December 2018 to discuss New Radio to New Radio (NR-NR) dual connectivity (DC). Specifically, options 4 and 7 for DC are planned to be treated. Figure 3 shows Illustrations for these two options.

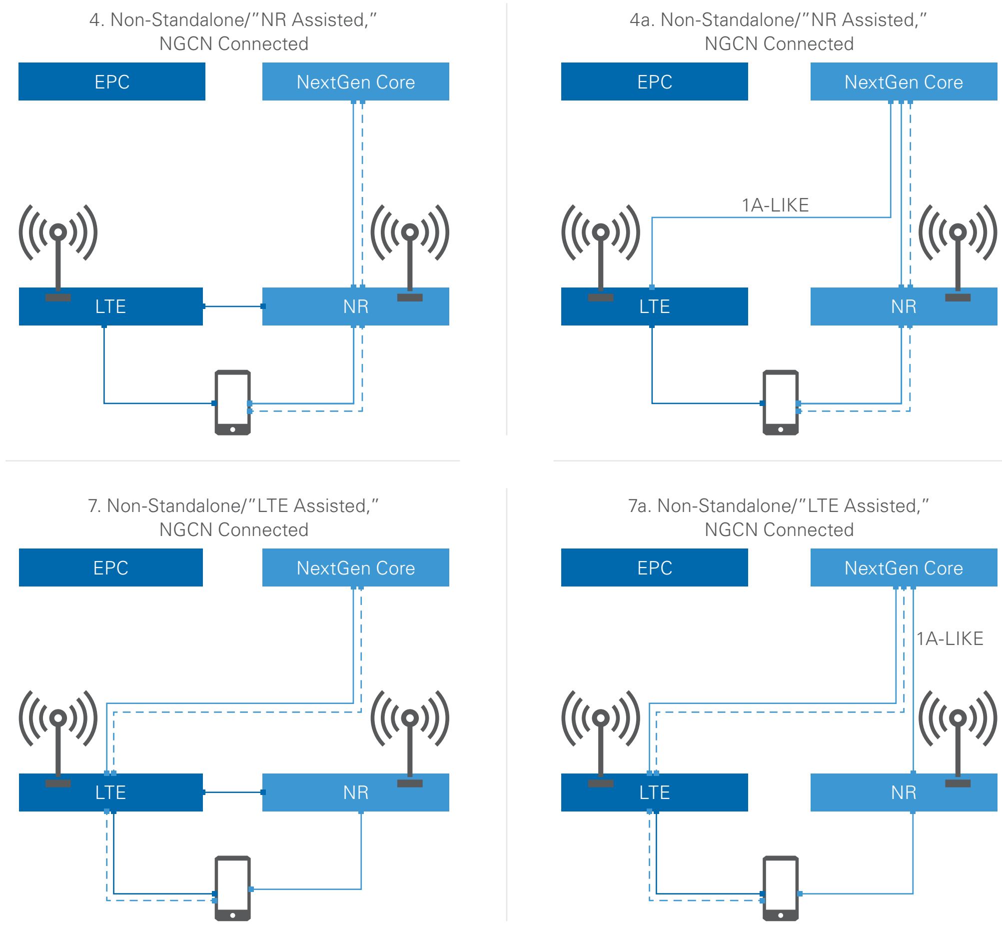

Figure 3. NR-NR DC Options 4 and 7 (Source: RP-161266, Deutsche Telekom, T-Mobile)

Release 15 Detailed Overview

Defining an entire new standard for 5G is a large undertaking. 3GPP has split the 5G standard into two releases: Release 15, which corresponds to NR Phase 1, and Release 16, which corresponds to NR Phase 2. In NR Phase 1, there are common elements between LTE and NR, such as both using orthogonal frequency division multiplexing (OFDM). However, there are also differences as summarized in Table 2.

	LTE	NR
Frequency of Operation	Up to 6 GHz	Up to 6 GHz, ~28 GHz, ~39 GHz, other mmWave bands (Upto 52 GHz)
Carrier Bandwidth	Max: 20 MHz	Max: 100 MHz (at <6 GHz) Max: 1 GHz (at >6 GHz)
Carrier Aggregation	Up to 32	Up to 16
Analog Beamforming (dynamic)	Not Supported	Supported
Digital Beamforming	Up to 8 Layers	Up to 12 Layers
Channel Coding	Data: Turbo Coding Control: Convolutional Coding	Data: LDPC Coding Control: Polar Coding
Subcarrier Spacing	15 kHz	15 kHz, 30 kHz, 60 kHz, 120 kHz, 240 kHz
Self-Contained Subframe	Not Supported	Can Be Implemented
Spectrum Occupancy	90% of Channel BW	Up to 98% of Channel BW

Table 2. Key Differences Between LTE and NR

To truly implement the full version of NR, a massive amount of new hardware must be deployed. To continue using existing hardware, a phased approach has been proposed. There is a non-standalone (NSA) version that will use the LTE core and a standalone (SA) version that will use an NR core and be completely independent of the LTE core network. To keep straight which devices can communicate with each other, new terminology has been introduced:

- **LTE eNB**—Device that can connect to the EPC or the current LTE core network
- **eLTE eNB**—Evolution of the LTE eNB that can connect to the EPC and NextGen core
- **gNB** —5G NR equivalent of the LTE eNB
- **NG**—Interface between the NextGen core and the gNB
- **NG2**—Control plane interface between core network and RAN (S1-C in LTE)
- **NG3**—User plane interface between the core network and RAN (S1-U in LTE)

Keeping this terminology in mind, the three diagrams from 3GPP TR 38.804 (draft v0.4) shown in Figure 4 and Figure 5 illustrate various deployment scenarios for 5G NR.

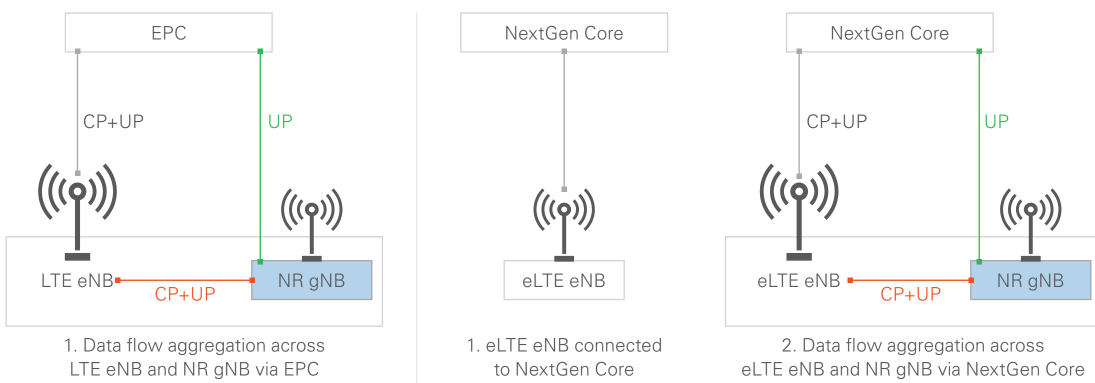

Figure 4. NSA Deployments With LTE eNB as Master (left) and Evolution to Add NextGen Core (right)

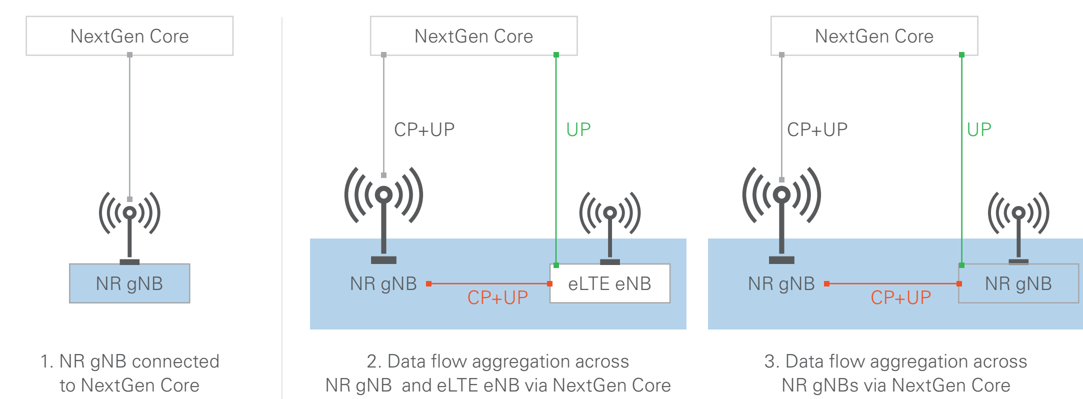

Figure 5. Phased Evolution to Add SA Operation

Figure 4 shows in the left diagram a setup where a secondary cell NSA operation of the NR gNBs connects to the LTE EPC. The image on the right shows a scenario where the NextGen core is added. The eLTE eNB acts as the master. The NR gNBs are in NSA mode with a defined path for data flow between the eLTE eNB and the NR gNB with the NextGen core as the master. Figure 5 shows an alternative deployment scenario with a phased evolution to add standalone operation. All the deployment types can operate simultaneously as this phased approach is enacted. The exact timing and phasing of the new deployments depend on individual network providers.

For NSA operation, there needs to be a coordinated frequency plan between LTE and NR for dual connectivity. Table 3 shows how various LTE bands correspond to proposed NR frequency ranges.

		LTE Band														
		1	2	3	5	7	8	19	20	21	25	26	28	39	41	66
NR Freq. Range	3.3 GHz–4.2 GHz	YES		YES	YES	YES	YES	YES	YES	YES		YES	YES	YES	YES	
	4.4 G Hz–4.99 GHz	YES		YES	YES		YES	YES		YES		YES	YES	YES	YES	
	24.25 GHz–29.5 GHz	YES		YES	YES	YES	YES	YES	YES	YES		YES	YES	YES	YES	YES
	31.8 GHz–33.4 GHz			YES		YES			YES				YES			
	37 GHz–40 GHz															YES
	Band 7			YES			YES		YES							
	Band 28			YES		YES			YES							
	Band 41	YES	YES	YES	YES						YES	YES			YES	

Table 3. Release 15 LTE-NR Band Combinations (Source: RP-170847, RP-170826, R4-1702504 [DCM])

There is convergence around particular bands for NR, but the frequencies are still not firmly set, especially for mmWave. From the RAN4 meeting held in May 2018, Table 4 shows the proposed operating bands. Of note, band n261 has been added and, more interestingly, band n259, defined in the old versions as 31.8 GHz–33.4 GHz TDD, has been removed. This band was originally called out as a band for study, but CEPT removed it for consideration for 5G in November 2017.

NR Operating Band	**Uplink (UL) and Downlink (DL) operating band** **BS transmit/receive** **UE transmit/receive** FUL_low–FUL_high FDL_low–FDL_high	**Duplex Mode**
n257	26,500 MHz–29,500 MHz	TDD
n258	24,250 MHz–27,500 MHz	TDD
n260	37,000 MHz–40,000 MHz	TDD
n261	27,500 MHz–28,350 MHz	TDD

Table 4. NR Operating Bands in FR2 (Source: 38.104, R4-1806932)

Other bands, such as 24.25 GHz–29.5 GHz, are being actively studied for use in 5G NR. This is being tracked and actively updated as a part of Technical Report 38.815. The below frequency chart, taken from that report, provides a good visual overview of the frequencies of interest in various locations.

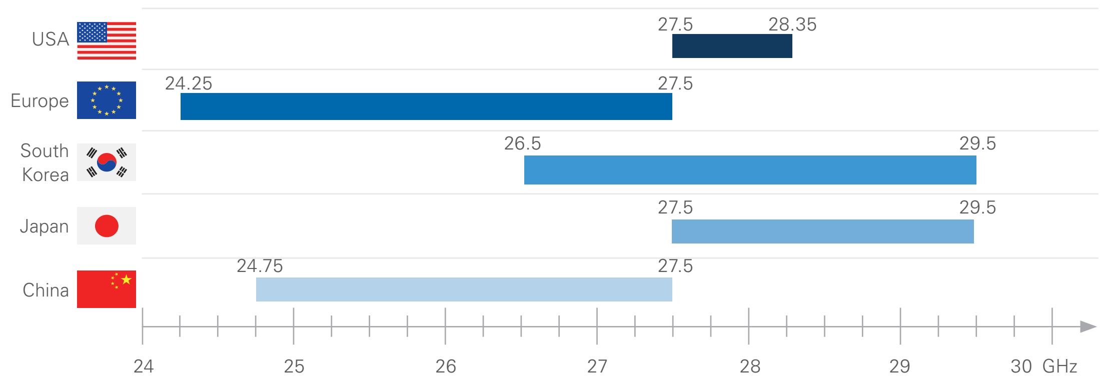

Figure 6. 5G NR mmWave Frequencies by Region (Source: TR 38.815)

The numerology for NR is designed to function in both the sub-6 GHz bands as well as mmWave bands. This is achieved by creating multiple numerologies formed by scaling a basic subcarrier spacing (SCS) by integer N where 15 kHz is the baseline SCS and N is a power of 2. The numerology is selected independently of the frequency band, with possible SCS of 15 kHz to 480 kHz.

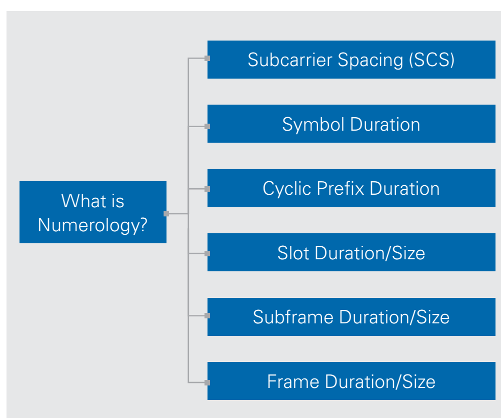

Figure 7. Numerology Components

Not all SCS options are being proposed for all frequencies. For sub 6 GHz, only 15 kHz, 30 kHz, and 60 kHz are to be used. Above 6 GHz, there is no decision yet. The candidate SCSs are 60 kHz, 120 kHz, and 240 kHz with 480 kHz marked for future study. The feasibility of each of these will be studied based on phase noise models, channel bandwidth, fast Fourier transform (FFT) size, and which service they are to support (eMBB, URLLC, or mMTC). These SCSs are not applicable to all bands and are applicable to common/dedicated data channels. Table 5 summarizes these combinations.

R4-170xxxx	2 GHz	2.5 GHz	3.5 GHz	6 GHz	24 GHz	43.5 GHz	52.3 GHz
Qualcomm (1797	15k, 30k, 60k					120k, 240k	
Nokia (0724)	15k						
		30k					
			60k				
				120k			
				240k			
Ericsson (1166)	15k, 30k, 60k				60k, 120k, 240k, 480 (*)		
Huawei (1314)	15k, 30k, 60k						
Intel (2031)	15k, 30k, 60k					60k, 120k	

Table 5. Feasible Subcarrier Spacing by Band and Company (Source: R4-1702374 [Docomo, Samsung])

Some parts of the numerology are flexible, like the SCS, while others are fixed. The subframe duration is fixed to 1 ms and the frame length is 10 ms. Given subcarrier spacing of 15 kHz* 2^n, each symbol length, including the CP, of 15 kHz equals the sum of the corresponding 2n symbols of the SCS. The first OFDM symbol in 0.5 m is longer by 16 T_s (assuming 15 kHz and FFT size of 2,048) compared to other OFDM symbols. 16 T_s is used for the CP for the first symbol. NR supports an extended CP.

For NR, a slot is defined as 7 or 14 OFDM symbols for subcarriers up to 60 kHz and 14 OFDM symbols for subcarrier spacing higher than 60 kHz. A slot can contain all downlink, all uplink, or at least one downlink part and at least one uplink part. Data transmission can span multiple slots. Figure 8 shows an example numerology in a slot that uses mixed numerology in both frequency domain and time domain.

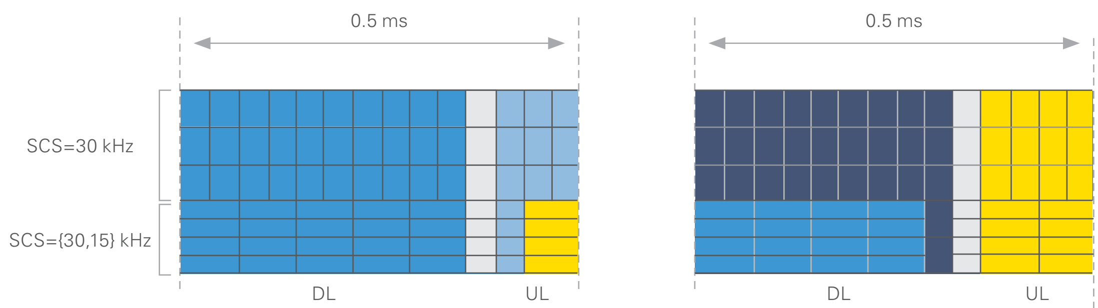

Figure 8. Example of Numerology in a Slot (Source: Fujitsu, R1-166676)

The NR modulation and waveforms have some commonalities with LTE but aim to have much higher spectral efficiency. NR supports QPSK, 16 QAM, and 256 QAM with the same constellation mapping as LTE. An OFDM-based waveform is support. At least up to 40 GHz, CP-OFDM waveform supports spectral utilization of Y greater than that of LTE, where Y=90% for LTE. Y as a percent is defined as transmission bandwidth configuration divided by channel bandwidth* 100%. The proposed Y, for example is 98 percent. For uplink only, DFT-S-OFDM-based waveforms are also supported, but they are limited to single stream transmissions. Both CP-OFDM- and DFT-S-OFDM-based waveforms are mandatory for user equipment (UE).

NR defines physical resource block (PRB) where the number of subcarriers per PRB is the same for all numerologies. The number of subcarriers per PRB is N=12. Below is a diagram of this.

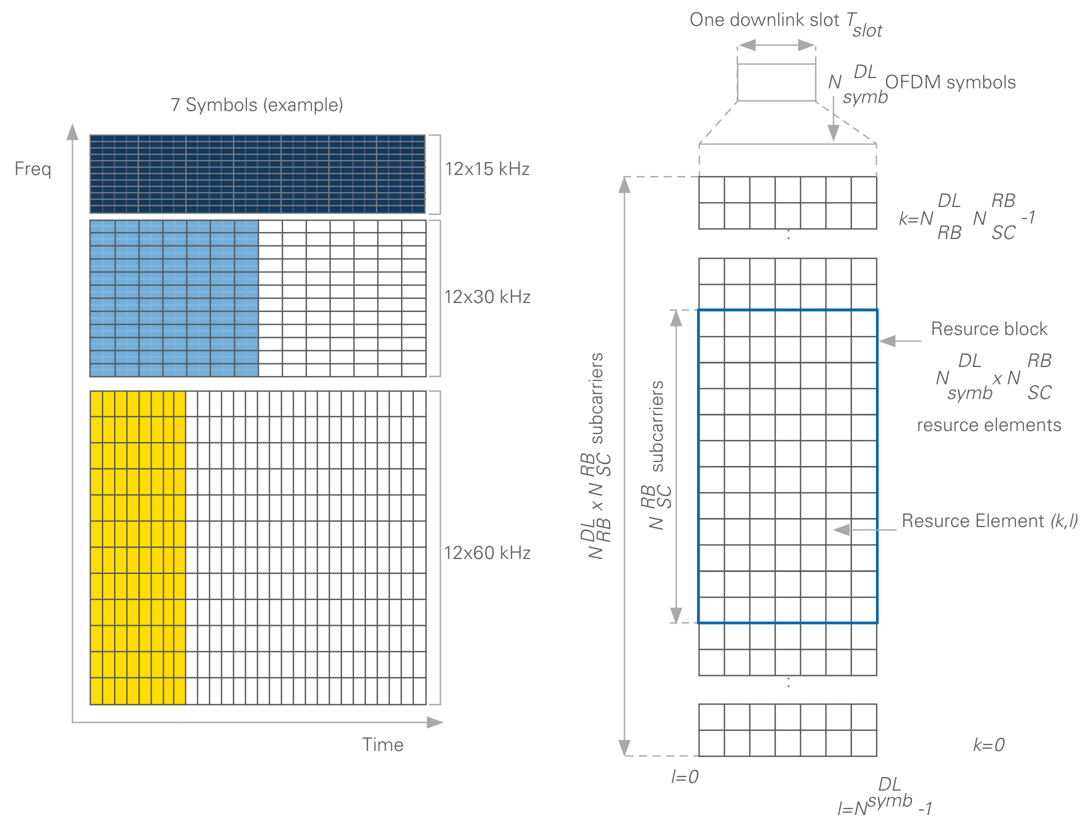

Figure 9. Resource Blocks in NR (Source: Nokia, R1-167260)

An area that has not yet been solidified for NR is the maximum channel bandwidth. RAN1 agreed to a maximum channel bandwidth of 400 MHz in Release 15, but the following are listed for further study:

- Sub 6 GHz: 100 MHz –200 MHz range
- Above 6 GHz: 100 MHz–1 GHz range
- Possibility to support maximum channel bandwidth with carrier aggregation

Carrier aggregation allows for the use of spectrum that is larger than the maximum channel bandwidth. This is of particular interest for mmWave where there are 800 MHz- and 1.2 GHz-wide channels available for use. Table 6 shows the companies proposing maximum channel bandwidths across different frequencies.

R4-170xxxx	2 GHz	2.5 GHz	3.5 GHz	6 GHz	24 GHz	43.5 GHz	52.3 GHz
Qualcomm (1797	100 M					400 M	
Nokia (0724)	20 M						
		50 M					
			100 M				
				200 M			
				400 M			
Samsung (1075)	200 M				1G		
MediaTek (1824)	200 M				1G		
Intel (2031)	100 M					400 M	

Table 6. Proposed Maximum Channel Bandwidth by Company (Source: R4-1702374 [Docomo, Samsung])

Multiple input, multiple output (MIMO) operation is a key component of NR. The gNB has two TXRUs per polarization, which are connected to cross polarized Tx antenna panels. The gNB selects one analog beam on each antenna panel polarization for the downlink data transmission (that is, MIMO transmission). The UE should be able to measure multiple Tx beams swept on different time units on each panel polarization and then select one Tx beam that is determined to be the "best" beam on each.

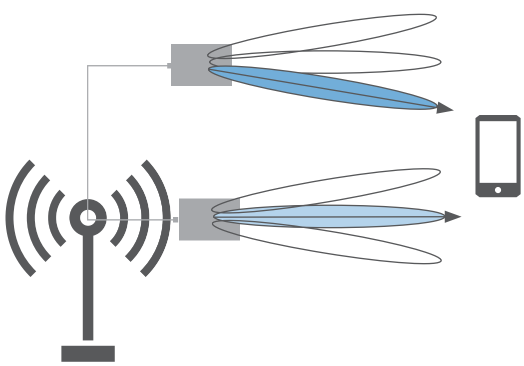

Figure 10. Working of Analog Beam Based on MIMO Operation (Source: R1-1705351)

Synchronization in NR is defined by synchronization signal (SS) blocks, bursts, and burst sets. The NR-PSS, NR-SSS, and/or the NR-PBCH signal are transmitted within an SS block. One or multiple SS blocks compose an SS burst. One or multiple SS bursts further compose an SS burst set. From the UE perspective, the SS burst set transmission is periodic. This concept is best described visually. Figure 11 shows the makeup of an SS burst and Figure 12 shows the SS burst set structure.

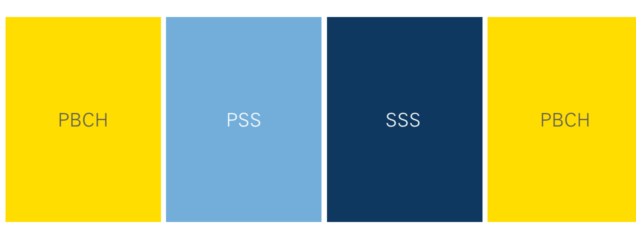

Figure 11. Components of an SS Burst (Source: Qualcomm, R1-1700784)

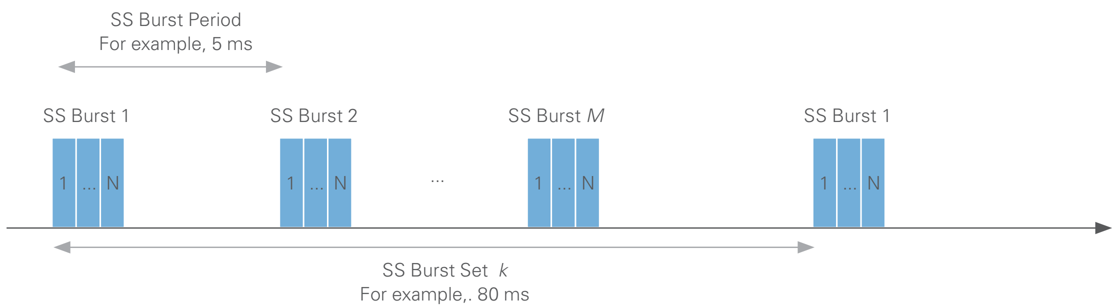

Figure 12. Illustration of SS Burst Set Structure (Source: Ericsson, R1-1700294)

Finally, to complete Release 15, the channel coding for NR has been decided and it differs from LTE for both the data and the control channels. LTE uses turbo coding for the data channel and NR uses LDPC coding. For the Downlink Control Information (DCI) control channel, LTE uses convolution coding and NR uses polar coding. These coding techniques are defined for the eMBB use case. It is possible that different coding techniques may be used in the other NR use cases in the future.

Channel coding techniques for NR should support info block size K flexibility and codeword size flexibility. Rate matching like puncturing and/or repetition supports 1-bit granularity in codeword size. The channel coding technique for data channels of NR supports both incremental redundancy (IR) and chase (C). For very small block lengths where repetition/block coding is used, it may be preferred to use combining (CC) HARQ.

Looking Forward: Release 16 Study Items and Trends

Work for Release 16 has already begun and some trends are emerging. There is increasing support of vertical industries such as non-terrestrial networks (NTN), vehicle to everything (V2X), public safety, and Industrial Internet of Things (IoT). For NTN, NR Release 15 will need to be modified to support satellite communications, specifically at mmWave bands. For V2X, further study is proposed for dynamic support for sidelink (PC5) as well as access network (Uu) interfaces. New evaluation methodology is being defined for V2X use cases including vehicle platooning, advanced driving to enable semi-automated or fully automated driving, and remote driving. Other trends and open study items include unlicensed access (NR-U), enhanced MIMO studies (in particular >6 GHz), integrated access and backhaul (IAB), and non-orthogonal multiple access (NOMA) waveforms. Other applications and study items will surely emerge as work for Release 16 continues. The 2020 goal for finalization of 5G is ambitious given the amount of effort still required to make Release 16 successful. But, if the pace stays at the rate it was for Release 15, it is an achievable goal.