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1 Abstract

The objective of this document is to provide text for the TR 38.811 on the introduction of the use cases defined in 5G releases, to clarify what has been already defined in the specifications as physical layer, and to conclude on what is applicable in NR numerology to satellite communication.

2 Background

2.1 5G use cases definition and specification

The standardization of 5G has been divided in 2 phases:

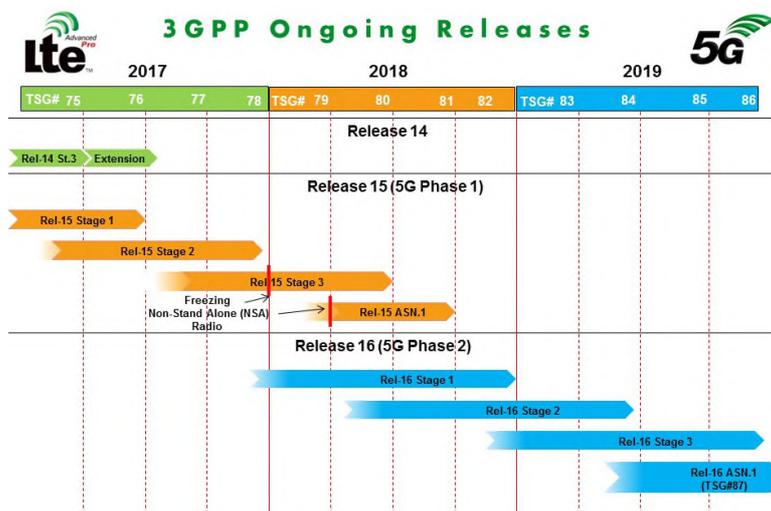


Figure 1: 3GPP phase 1/2 approach, source 3GPP.org

5G phase 1 focuses on:

- Common design covering sub 6 GHz to ~40 GHz

- Support eMBB (enhanced Mobile Broadband) with Forward compatibility to address mMTC (massive Machine Type Communication) and URLLC (Ultra Reliable Low Latency Communications)
- LTE-assisted and standalone operations
- 5G Core Network (NextGen)

Whereas phase 2 tackles:

- Extend up to 100 GHz Spectrum
- Potential new waveforms for mMTC and >40GHz spectrum
- Full support of IMT2020 and 3GPP NR req.

If URLLC seems to be out of scope regarding satellite capacities (i.e. longer delay), eMBB and mMTC are use cases where satellite can extend and complement terrestrial networks. Since at now mainly phase 1 specifications are available, this first analysis is based on current NR specifications done for eMBB use case. For mMTC, a follow up is needed, and this study could propose some recommendations for future mMTC specifications. At now, the consensus is to consider that mMTC will be derived from NB-IOT, and main characteristics of NB-IOT will be taken as basic assumptions in the study item.

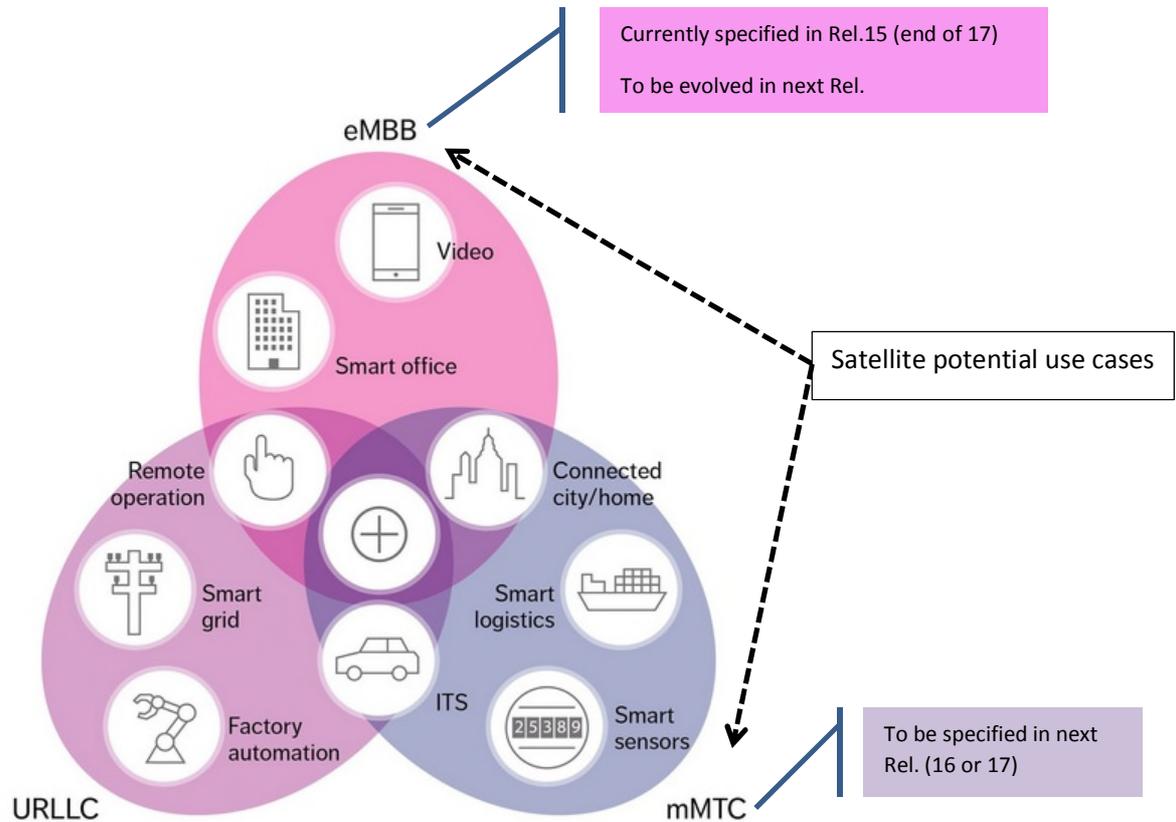


Figure 2: 5G use cases, eMBB, mMTC, URLLC

2.2 5G radio interface: NR

For 5G, many waveforms proposal have been reviewed, most of them being multi-carrier waveforms based on CP-OFDM (Filtered OFDM, Universally filtered OFDM, Pulse shaped OFDM...).

In the end for eMBB DL and UL, CP-OFDM ranks best on the performance indicators that matter most: low complexity with multi antenna technologies, high spectral efficiency and low implementation complexity. CP-OFDM is also robust to phase noise and Doppler compared to other multi carrier waveforms proposed. Main drawback of CP-OFDM is high PAPR, which could be reduced in a receiver agnostic way by using for example known technique like clipping and companding. Windowing is also a possibility to frequency localized OFDM. For more details on this choice, please refer to [1].

Note that for eMBB, DFT-S-OFDM, which has a lower PAPR than CP-OFDM (equivalent to SC-FDMA in LTE), is still possible in UL without MIMO (which corresponds to satellite deployment scenario, where UL transmission is only done through one stream).

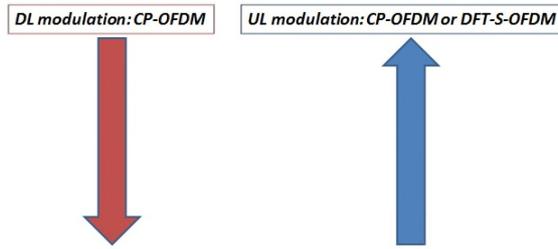


Figure 3: eMBB modulation selection

Regarding mMTC, no modulation has been yet chosen, but requirements could be more beneficial to satellite systems (e.g. modulation with low PAPR should be chosen).

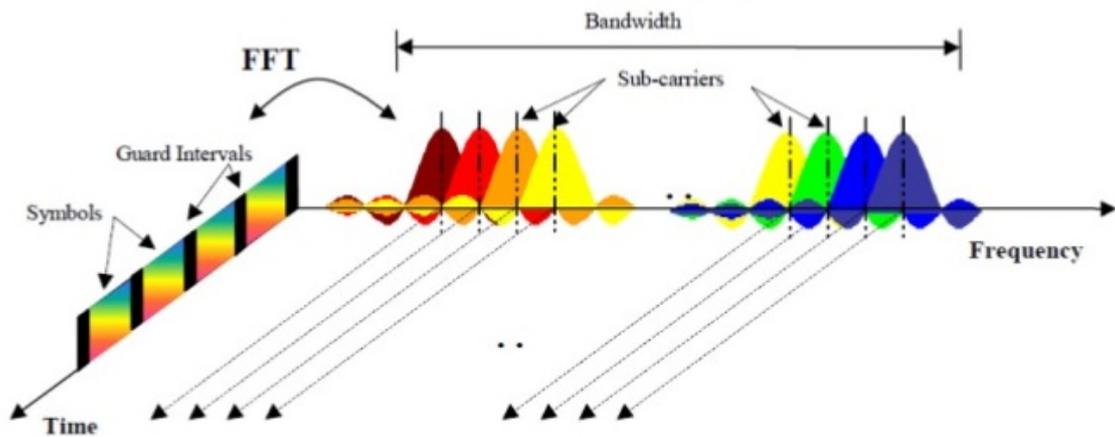


Figure 4: CP-OFDM Time/Frequency representation (where guard intervals are in fact a copy of the end of the OFDM symbol, which explains the name Cyclic Prefix...)

2.3 Flexible numerology defined in NR

Whereas for LTE, Subcarrier Spacing (SCS) was fixed (15 kHz), NR waveforms are more flexible, and new numerologies have been added.

Table 1: NR supported transmission numerologies (source TS 38.211, Table 4.2-1)

μ	$\Delta f = 2^\mu \cdot 15$ [kHz]	Cyclic prefix
0	15	Normal
1	30	Normal
2	60	Normal, Extended
3	120	Normal
4	240	Normal
5	480	Normal

The new defined SCS spacing will have of course an impact on the symbol duration, as in OFDM, both are linked by the following formula:

$$\Delta f = 1/T_{symbol}$$

The Cyclic Prefix will also be shortened proportionally to the symbol duration.

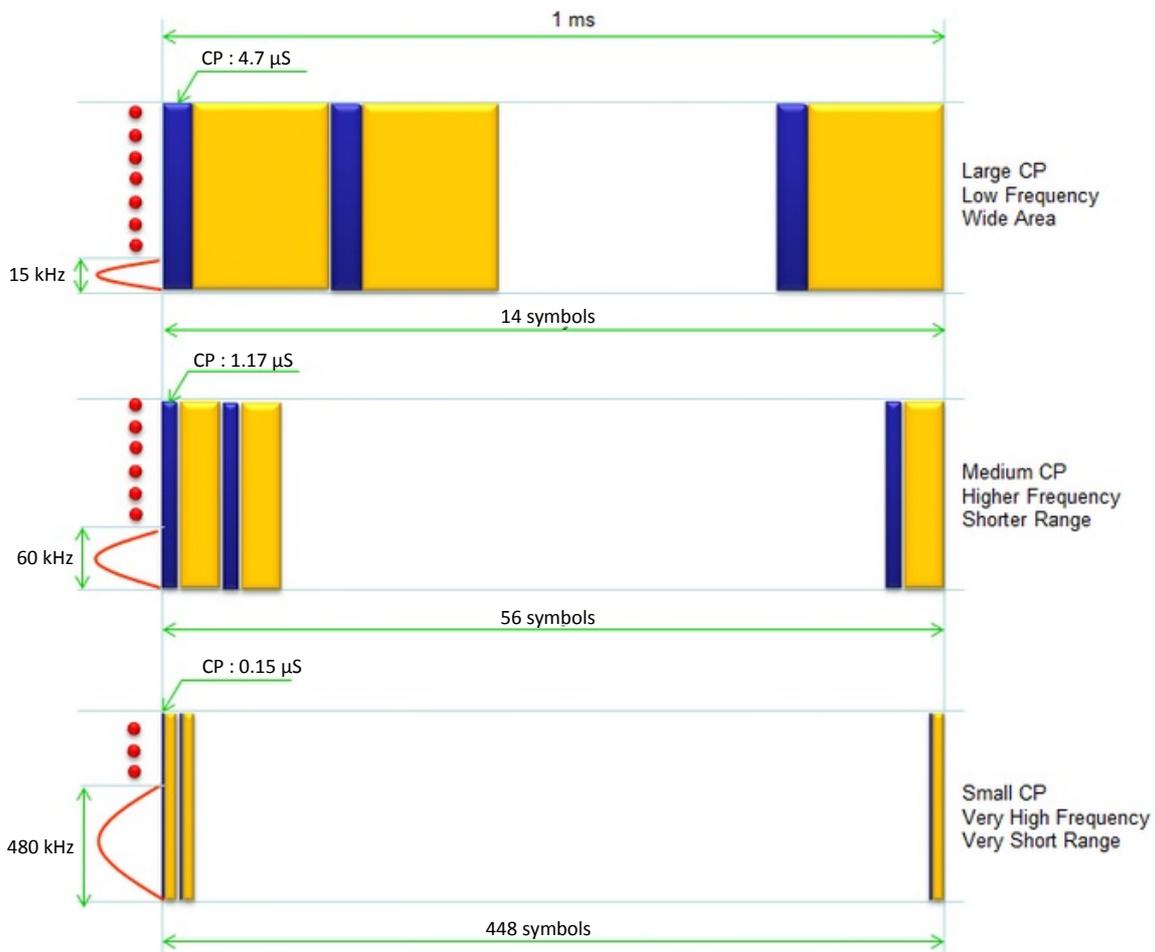


Figure 5: Example of time representation of CP-OFDM with various SCS

To support higher frequencies (up to 100 GHz), higher SCS has been defined. In fact, phase noise increases in proportion of carrier frequency. Moreover frequency drift, due to local oscillator inaccuracy and Doppler spread, also increases with carrier frequency. To decrease Inter Carrier Interference at high frequencies, a higher SCS should be chosen.

The side effect of higher SCS is that Cyclic Prefix (CP) length will be decreased to ensure constant spectral efficiency. The CP length is directly linked to terrestrial propagation delay spread due to multipath, in order to fight Inter Symbol Interference (ISI). It means that higher SCS is also linked to smaller cells in terrestrial environments, which is logic as signals at higher frequencies fade quicker. A technical document from Intel ([2]) describes SCS choice and phase noise issue.



Figure 6: NR targeted spectrum

3 Proposed text for approval

It is proposed to add the following texts to TR 38.811 “Study on NR to support Non-Terrestrial Networks”.

* * * Start of changes * * * * (modified text)

2 References

- [1]: Ali A. Zaidi, Robert Baldemair, Hugo Tullberg, Håkan Björkegren, Lars Sundström, Jonas Medbo, Caner Kilinc and Icaro Da Silva, Ericsson Research, Sweden, “Waveform and Numerology to Support 5G Services and Requirements”, 2016
- [2]: 3GPP Tdoc R1-162386, “Numerology for new radio interface”, source Intel Corporation, 3GPP TSG RAN WG1 Meeting #84bis, Busan, Korea 11th - 15th April 2016
- [3]: 3GPP Tdoc R1-1706877,” LS on SCS for NR”, TSG RAN WG1 Meeting #89, Hangzhou, P.R. China 15th – 19th May 2017
- [4]: ITU-R M.1225, “Guidelines for evaluation of radio transmission technologies for IMT-2000”, 1997
- [5]: E. Lutz, M. Werner, and A. Jahn, “Satellite Systems for Personal and Broadband Communications.”, Berlin, Germany, Springer-Verlag, 2000.
- [6]: T. Rappaport, “Wireless Communications”, New Jersey: Prentice Hall, 1996
- [7]: 3GPP TS 38.211, “Technical Specification Group Radio Access Network; NR; Physical channels and modulation (Release 15)”, v1.2.0 (2017-11)
- [8]: TS 38.213 “NR; Physical layer procedures for control”, v 1.0.0
- [9]: 3GPP TR 38.802 v14.1.0, “Study on New Radio Access Technology Physical Layer Aspects (Release 14)”, June 2016

* * * End of Changes * * * *

* * * Start of changes * * * * (new text)

7.3 NR modifications to support the Non-Terrestrial Network deployment scenarios

This clause identifies the NR specifications that may require some adaptations to support operation via Satellite or HAPS.

7.3.4 Potential NR numerology selection for satellite communication

NR numerologies depends on the spectrum [3]:

- SCS for below 1 GHz:
 - 15 kHz, 30 kHz
- SCS for between 1 GHz and 6 GHz:
 - 15kHz, 30 kHz, 60 kHz
- SCS for above 24GHz and below 52.6GHz:
 - 60 kHz, 120 kHz, where 240 kHz only for synchronization

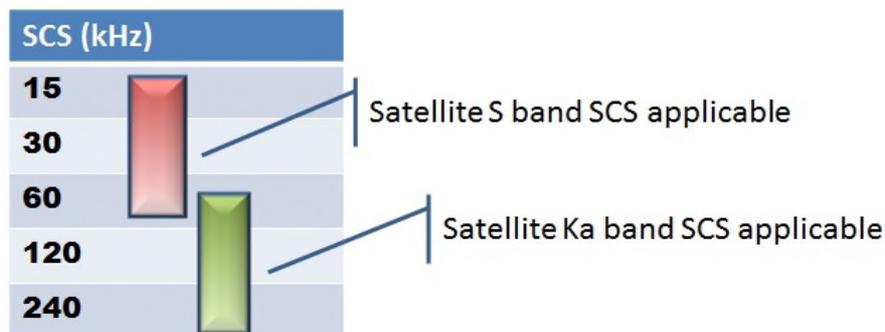


Figure 7: SCS applicable to satellite bands

7.3.5 NR Numerology Selection Criteria

This clause identifies the specific constraints associated to Non-Terrestrial Networks with which the NR radio interface will need to cope with in regard of the selection of the Cyclic Prefix (CP) length, the receiver synchronization regarding Timing Advance procedure, Doppler and phase noise.

7.3.5.1 Cyclic Prefix Dimensioning

This clause describes design constraints of the New Radio Cyclic Prefix (CP) that need to be addressed when considering using New Radio in Non-Terrestrial Network deployment scenarios.

Delay spread in satellite propagation channels

Signal echoes are associated to the presence of indirect rays that reach the receiver antenna and carry a significant energy with respect to the energy of the direct ray.

ITU-R recommendation [4] defines for the 2 GHz band three parameter sets of wideband models, including LOS and NLOS cases, applicable for an elevation range from 15 to 55° and for urban, suburban and rural environments. The delay spread of these three parameter sets ranges between 180 ns to 250 ns, whereas the 250 ns are stated to cover 90% of the cases.

For higher elevations than 55°, we assume that the delay spread of the satellite channel will be in the same range or even lower due to the traveling distances of the echoes arriving at a receiver.

Few papers are available on delay spread measurements in Ka-Band. Reference [5] is stating the coherence bandwidth to be 30 MHz at 40 GHz with omnidirectional antennas. According to [6], the coherence bandwidth $(\Delta f)_c$ of a channel with maximum delay spread T_m is

$$(\Delta f)_c \approx 1 / (5T_m)$$

For the stated coherence bandwidth in [5], this results in a maximum delay spread of $T_m = 25$ ns for omni-directional antennas. For directional antennas, echoes with significant delay are normally filtered out by the antenna radiation pattern, so flat fading can be assumed for Ka-band signals.

CP length defined in NR

The possible CP lengths currently defined for New Radio [6] are summarized in the following table:

Table 2: CP lengths and minimum/maximum RF bandwidth of NR as currently defined in [7].

Subcarrier spacing (SCS) configuration parameter μ	SCS [kHz]	normal CP length [μ s]	extended CP length [μ s]	min RB	min nr of sub-carrier	max RB	max nr of sub-carrier	min occupied bandwidth [MHz]	max occupied bandwidth [MHz]
0	15	4,688	Not defined	20	240	275	3300	3,6	49,5
1	30	2,344	Not defined	20	240	275	3300	7,2	99
2	60	1,172	16,67	20	240	275	3300	14,4	198
3	120	0,586	Not defined	20	240	275	3300	28,8	396
4	240	0,293	Not defined	20	240	138	1656	57,6	397,44
5	480	0,146	Not defined	Not defined in [7]					

It is observed that lower numerologies ($\mu=0, 1$) are associated with CP lengths exceeding the requirement of NTN by far, resulting in a reduced spectral efficiency due to the unnecessary overhead of the CP (e.g. overhead is for $\mu=0$: $(4.688\mu\text{s} - 0.25\mu\text{s}) / 66.67\mu\text{s} = 6.7\%$). The extended CP for a SCS of 60 kHz is not required, because it is significantly larger than required for satellite applications.

High numerologies ($\mu=4, 5$) result in a CP length which is too low for satellite application in L-/S-Band, but not in Ka-band.

As a conclusion, for the selection of the CP length according to the S-Band propagation channel, an SCS of 60 kHz or 120 kHz ($\mu=2, 3$) seems to be a good compromise. In Ka-band, an SCS of 120, 240 or 480 kHz are most efficient in regard of the propagation channel.

However, the selection of the configuration parameter cannot be seen in isolation due to other relevant influencing parameters like RF bandwidth, Timing Advance step size especially for LEO satellites (see next subchapter) and phase noise robustness in Ka-band. To give one example, the minimum RF bandwidth of more than 14.4 MHz does not match to some satellite transponder bandwidths in S-Band. **Chapter 7.3.5.4** summarizes the NR numerology selection findings for different criteria.

7.3.5.2 Timing Advance Procedure in SatCom

This chapter highlights the fact that there is a strong requirement for fast timing advance adjustment in case of Satellite links compared to terrestrial communication, as the distance of the mobile terminal to the base station is only varying slowly (compared to the speed of a spacecraft) due to terminal mobility in terrestrial case. The issues or technical problems to solve, related to timing advance (TA) alignment in Satellite communications, are as follows:

1. A strong delay variation is caused by moving satellites (eg. in LEO and MEO orbits) generating a fast change in the overall distance of the propagation from UE over Satellite to BS.

- The delay is much longer over a satellite link than one Transmission Time interval (TTI, in LTE 1 ms)

Timing Advance Adjustment in Satellite Communication

Downlink and uplink transmissions are organized into frames with $T_f = (\Delta f_{\max} N_f / 100) \cdot T_s = 10$ ms duration, consisting of 10 subframes of $T_{sf} = (\Delta f_{\max} N_f / 1000) \cdot T_s = 1$ ms duration each. The number of consecutive OFDM symbols per subframe is $N_{\text{subframe}, \mu}^{\text{slot}} = N_{\text{slot}}^{\text{slot}} N_{\text{subframe}, \mu}^{\text{slot}}$. Each frame is divided into two equally-sized half-frames of 5 subframes each. There is one set of frames in the uplink and one set of frames in the downlink on a carrier [7].

Timing advance is a negative offset at the UE, between the start of a received downlink subframe and a transmitted uplink subframe. This offset at the UE is necessary to ensure that the downlink and uplink subframes are synchronized at the eNodeB (or gNB in 5G). Transmission of uplink frame number i from the UE shall start $T_{TA} = N_{TA} T_s$ before the start of the corresponding downlink frame at the UE i .

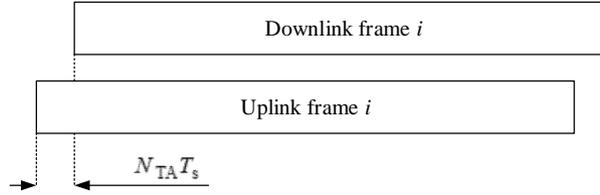


Figure 8: Uplink-downlink timing relation [7]

The delay over satellite links (earth hub station containing a BS \rightarrow satellite \rightarrow mobile terminal) has a strongly variable delay in case of non-geostationary satellites. A requirement for LTE (or NR) is that all mobile terminals have to transmit on the return link such that all signals arrive synchronously at the earth hub station / BS within the cyclic prefix (CP). All signals from the mobile terminals must arrive with a maximum variation within the cyclic prefix time (in LTE 4.7 μ s normal CP, 16.7 μ s extended CP). So, the individual timing advances of the mobile terminals have to be adjusted dynamically over time, according to variable distance between BS and UE, e.g. due to movement by cars, planes, by pedestrians etc. In case of terrestrial communication, the distance (and thus the delay over the transmission link) is determined only by the rather low mobility of the UE (compared to satellite speeds), since all BS are normally static.

A technical issue arises, when satellite links are included in the transmission chain. In this case, the strong delay variation caused by the moving satellite (e.g. in LEO, MEO orbits) is generating a fast change in the overall distance of the propagation from UE over sat to BS. The Figure 9 shows exemplarily the variable one way delay over the link from hub station / BS over LEO satellite (at an orbit speed of ~ 7500 m/s) to mobile terminal with either pure UE functionality or Relay-to-Network type of UE. A high differential delay variation of up to 35 μ s/s is experienced in this scenario, requiring a very fast update of the timing advance adjustment in the mobile terminal, thus creating a high load on the control plane (see table below, up to 2150 TA steps per second per UE are required to synchronize over this exemplarily LEO satellite link).

If higher numerologies with higher subcarrier spacing (SCS) are selected, the timing synchronization requirements are even more stringent due to the shorter CP. On the other hand in case of Satellite, the

delay drift of individual non-GEO satellites is quite predictable because the motion of the satellites follow known paths. It has to be noted, that this very fast update of the TA is not required in terrestrial links, because the distance of the terminal to the base station is only varying slowly due to the terminal mobility. In case of GEO satellite links, the terminal mobility is also dominating the TA requirements.

Another technical issue that arises is that the delay variation over the satellite link is much more than a Transmission Time Interval (TTI; in LTE: 1 ms and is even lesser for New Radio, where higher numerologies are considered). E.g. if the subcarrier spacing (SCS) is increasing from 15 kHz (numerology 1) to 60 kHz (numerology 4), the TTI goes down from 1 ms to 250 μ s. The required TA adjustment range for satellite links (~3 ms in the example in Fig. 9) will become larger than the TTI with any SCS selection and so the transmission timing of the UE has to be adjusted over the borders of individual TTIs.

Table 3: TA granularity, and step size with SCS according to [7].

Subcarrier spacing (SCS) configuration parameter, μ	SCS [kHz]	RB bandwidth [kHz]	TA granularity [Ts]	T_{step} [ns]	Required TA steps per UE at a drift of 35 us/s
0	15	180	1024	520,83	67,2
1	30	360	512	260,42	134,4
2	60	720	256	130,21	268,8
3	120	1440	128	65,10	537,6
4	240	2880	64	32,55	1075,2
5	480	5760	32	16,28	2150,4

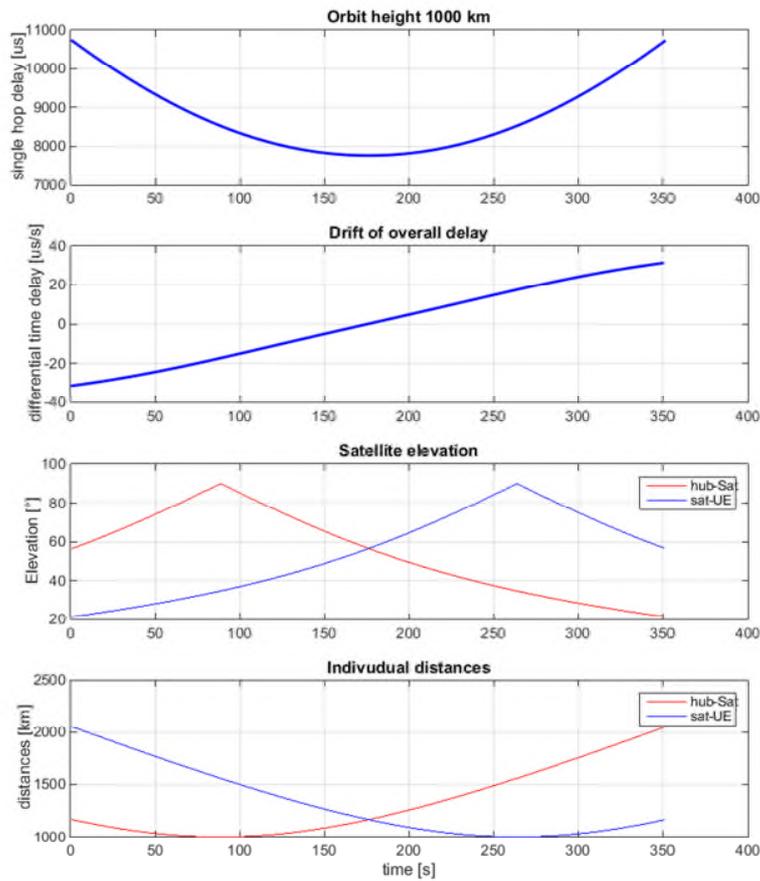


Figure 9: Exemplarily delay variation over satellite Link in LEO constellation

Conclusions for Timing Advance

A strong delay variation is caused by moving satellites (e.g. in LEO and MEO orbits) generating a fast change in the overall distance of the radio link between UE and BS via Satellite. The delay is much higher and variable over a satellite radio link than over a terrestrial radio link. This delay largely exceeds the Transmission Time interval (Equivalent to one frame) of NR which is equal to or less than 1 ms. However, the delay variation is quite predictable knowing the satellite orbits and UE position.

Hence, Timing Advance (TA) alignment is an important feature of NR that will be impacted by introduction of NTN in 5G to ensure that all uplink transmissions are synchronized at gNB reception point. Especially for non-GEO satellites, the overhead created by the TA procedure is expected to be significant, unless countermeasures are introduced. Solutions towards aligning uplink signals over satellite links to overcome the predictable delay in NTN need to be investigated in future. Future analysis shall estimate the TA update rate.

7.3.5.3 Doppler

In satellite context, studies need to be done to ensure that with SCS defined in 7.3.4, Doppler shift and variation rate can be tight, during initial synchronization phase, and later when demodulating the data.

7.3.5.3.1 Cell search and synchronization

7.3.5.3.1.1 Procedure defined in eMBB specifications

In order to connect to the 5G network, the UE or RN needs to perform initial cell search. This cell search consists in 4 main phases. First one is to detect power on a specific frequency. Then a radio frame is opened and sampled to find the Primary Synchronization Signal (PSS) and the Secondary Synchronization Signal. Those synchronization signals allow time and frequency correction, radio pattern detection, and Cell Id detection. The next step is to decode the PBCH containing the Master Information Blocks. The MIB describe main cell characteristics (total bandwidth, System Frame Number, higher layer information...) and allow for decoding the next System Information Blocks for more information on the cell.

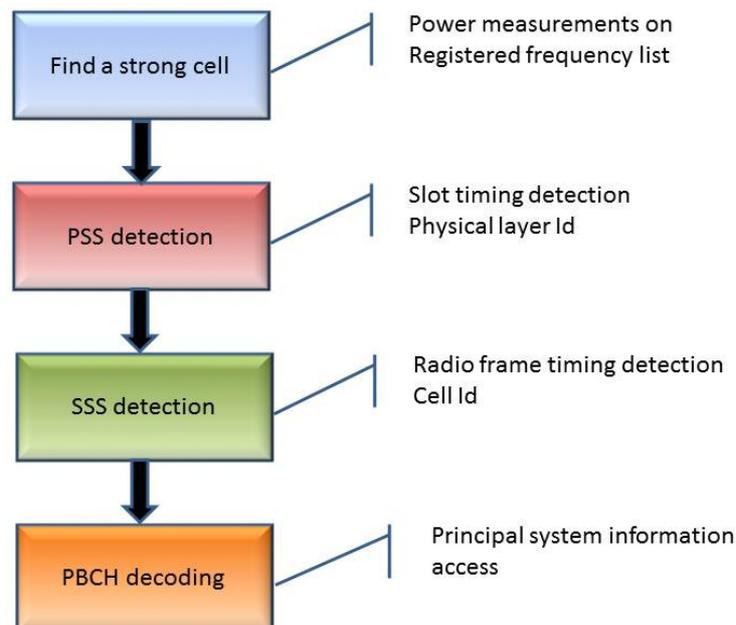


Figure 10: Cell search procedure

In this document we will focus on PSS and SSS detection. Decoding the PBCH will be studied in a separate paper dedicated to demodulation aspects. In fact, once PSS and SSS are processed, main Doppler shift

and timing error are removed. So to keep on decoding the data, and track continuously frequency and timing error, reference symbols (known by the receiver) inserted in the radio frame are used.

To be able to detect PSS and SSS and derive the radio frame timing, those signals are located at a fixed place.

In 4G, only one Sub Carrier Spacing (SCS) was used (15 kHz), so the radio frame structure was fixed, as the bandwidth of the PSS and SSS:

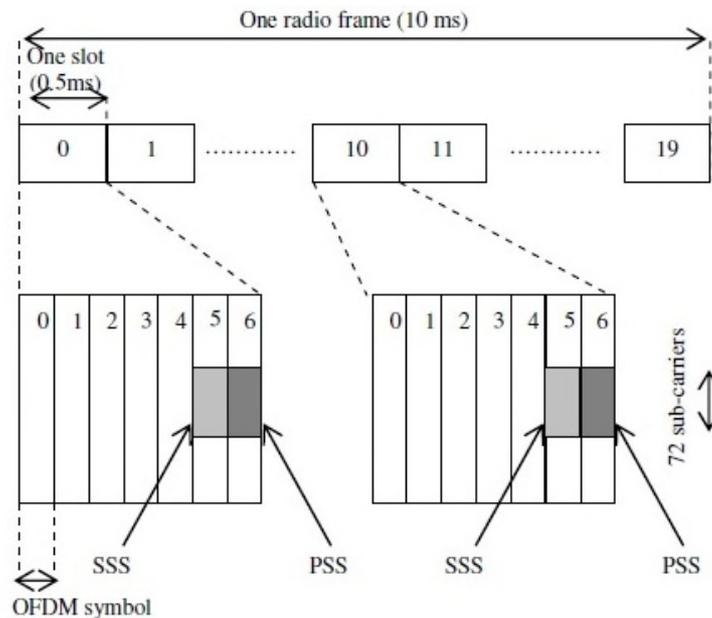


Figure 11: 4G radio frame structure with PSS and SSS

The bandwidth of PSS and SSS in LTE is:

$$Bw = 72 \times 15 \text{ kHz} = 1.08 \text{ MHz}$$

In 5G, due to NR numerology allowing more flexibility, the frame structure depends on SCS (Δf) chosen in the following table:

Table 4: NR supported transmission numerologies (source Table 4.2-1 of [7])

μ	$\Delta f = 2^\mu \cdot 15$ [kHz]	Cyclic prefix
0	15	Normal
1	30	Normal
2	60	Normal, Extended
3	120	Normal
4	240	Normal
5	480	Normal

Depending on SCS chosen, the frame structure is defined as followed:

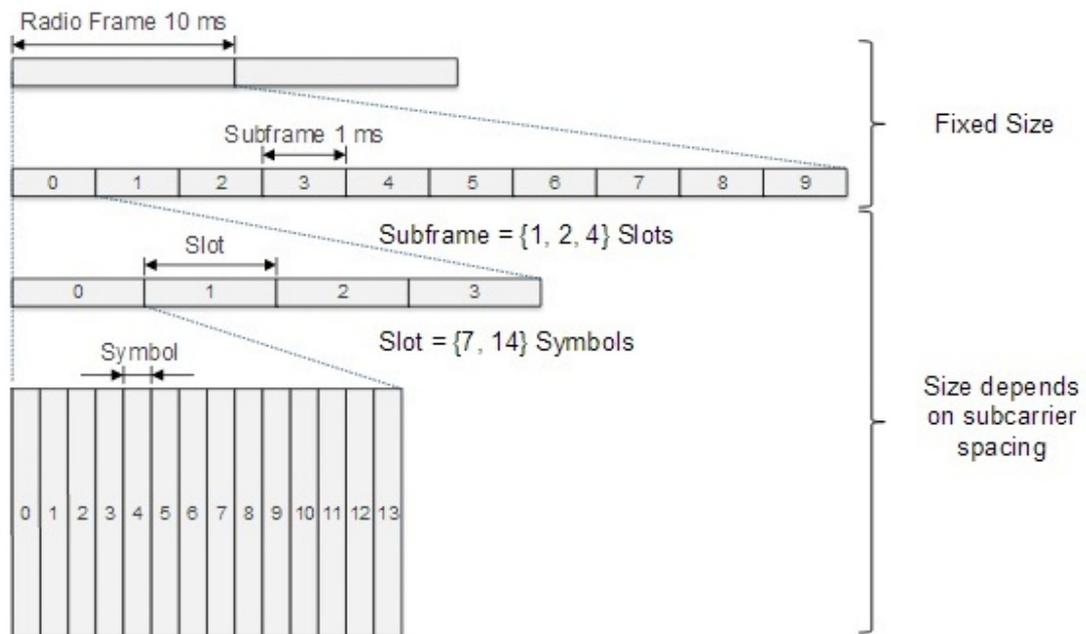


Figure 12: 5G frame structure

Within this frame structure, PSS and SSS are located at a fixed position. From the following table, extracted from chapter 7.4.3.1 of [7]:

Table 5: Resources within an SS/PBCH block for PSS, SSS, PBCH, and DM-RS for PBCH

Channel or signal	OFDM symbol number l	Subcarrier number k
PSS	0	80, 81, ..., 206
SSS	2	80, 81, ..., 206
PBCH	1, 3	0, 1, ..., 287
DM-RS for PBCH	1, 3	$0 + v_s, 4 + v_s, 8 + v_s, \dots, 280 + v_s, 284 + v_s$

We can deduce the following position for PSS, SSS and PBCH:

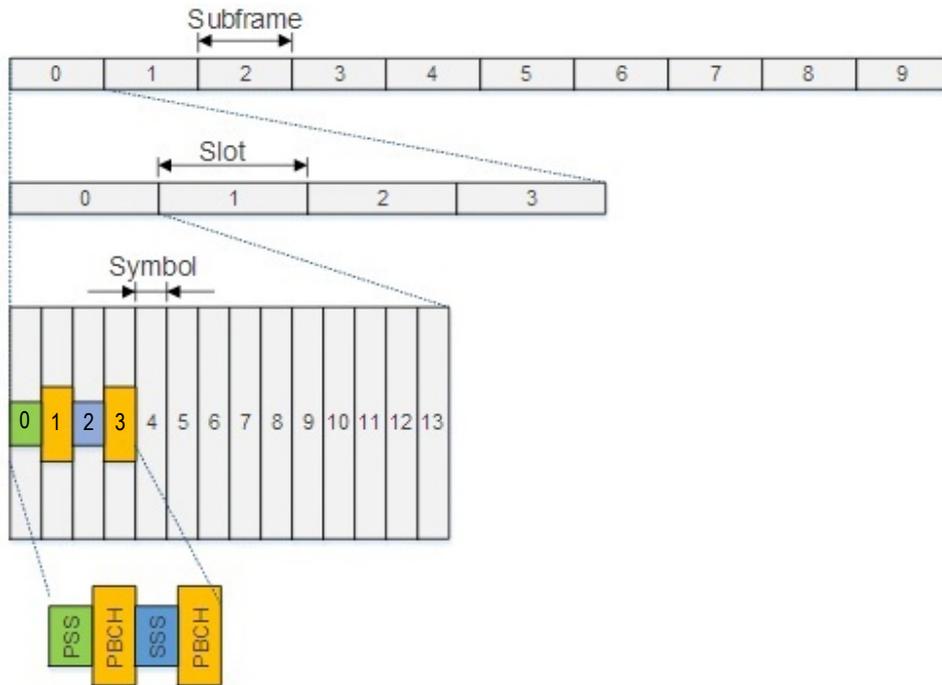


Figure 13: PSS, SSS and PBCH location

PSS, SSS and PBCH are referred as Synchronization Signals (SS) blocks in the specifications.

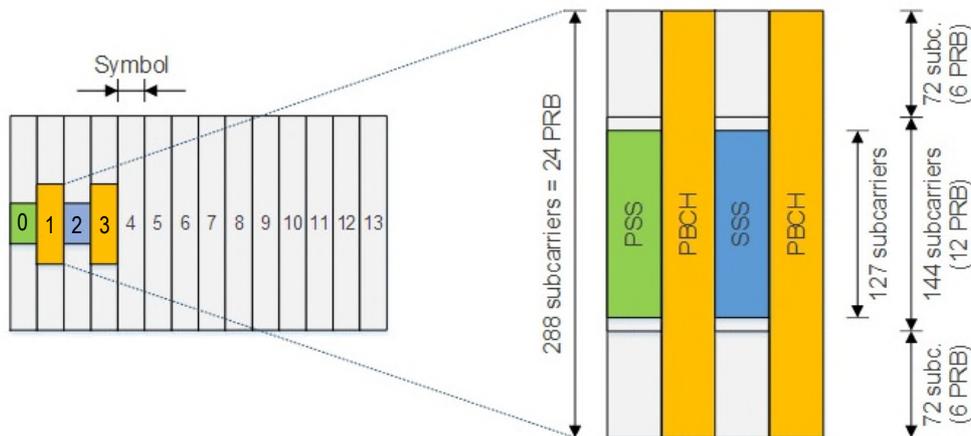


Figure 14: PSS, SSS, PBCH bandwidth

It is written in [7] that the UE shall assume for PSS, SSS and PBCH decoding the following:

- subcarrier spacing configuration $\mu = \{0,1,3,4\}$, where $\mu = 2$ is missing (FFS if $\mu=2$ is really not usable)
- the same cyclic prefix length and subcarrier spacing for the PSS, SSS, and PBCH

We can deduce the following table regarding the bandwidth of PSS/SSS and PBCH:

Table 6: PSS/SSS and PBCH bandwidth

SCS (kHz)	PSS/SSS bandwidth (127 subcarriers)	PBCH bandwidth (288 subcarriers)
15	1.905 MHz	4.32 MHz
30	3.08 MHz	8.64 MHz
60	7.62 MHz	17.28 MHz
120	15.24 MHz	34.56 MHz
240	30.48 MHz	240 kHz is reserved for synchronization signals

For each SCS configuration, the minimal bandwidth supported will be superior or equal to the bandwidth of the PBCH.

7.3.5.3.1.2 Direct Satellite to UE deployment scenarios: potential limitations due to link budget

To be completed

7.3.5.3.1.3 Satellite to Relay Node deployment scenarios: eMBB should be supported

Regarding Relay Node deployments scenarios, there is no bandwidth limitation. We should then support eMBB specifications regarding synchronization and cell search procedure.

7.3.5.3.1.4 Satellite specific Doppler shift constraints in non-geostationary deployments scenarios

Subcarrier Spacing choice is a compromise between Inter Symbol interference and frequency error robustness. Inter Symbol Interference is less stringent in satellite access than terrestrial, as the angle of arrival is higher for satellite deployments than terrestrial, and so generating less multipath and delay spread in satellite case:

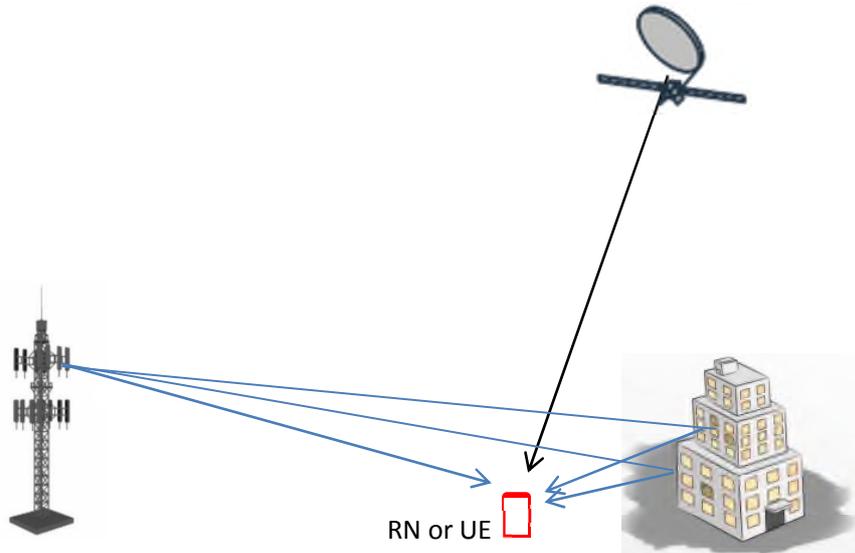


Figure 1516: terrestrial/satellite angle of arrival

Even if LoS is a prerequisite in our study item for satellite use cases, reflections are still possible, adding interference, especially for a UE with an omnidirectional antenna. This will be studied in a paper separately.

For geostationary deployments, no specific added Doppler is foreseen compared to terrestrial deployments. But, for non-geostationary satellites deployments, the Doppler shift is also due to satellite speed, whereas for terrestrial networks, gNodeB are supposed to be motionless.

The computation of Doppler shift due to UE or RN speed when satellite is supposed to be motionless (as for geostationary) is, as mentioned in 5.3.1.3:

$$\Delta f = f_0 \times V \times \frac{\cos \theta}{c}$$

Where Δf is the Doppler shift, V the speed of UE or RN, c the speed of light and θ the angle defined in figure below:

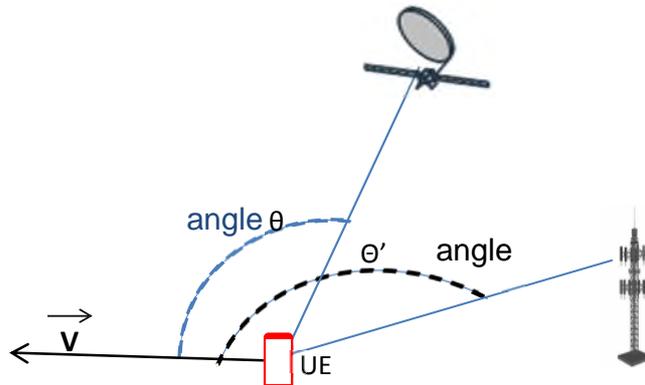


Figure 1617: angle definition

Since for terrestrial systems angle θ' should be inferior to angle θ from satellite systems, the Doppler shift due to UE or RN speed will be lower. Satellite system should not induce new requirements, except for airplane use case, surpassing the 500 km/h requirements set in 5G.

But when studying non-geostationary deployments, UE or RN mobility is in fact negligible compared to satellite speed (up to 7.5 km/s in LEO at 600 km). This could lead in worst case (LEO at 600 km in Ka band) to 480 kHz Doppler shift depending of the elevation angle of the satellite...

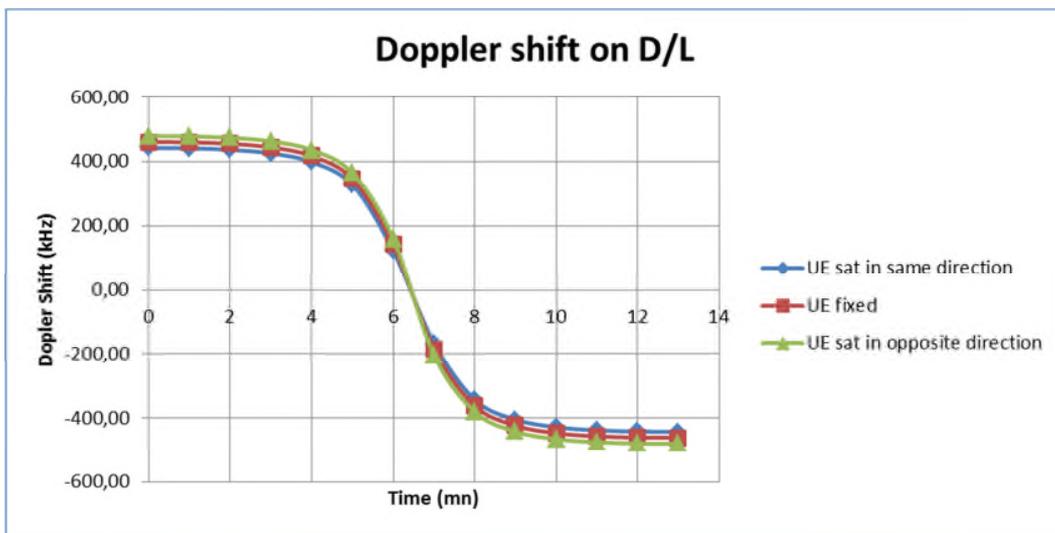


Figure 1718: Doppler shift for LEO satellite at 600 km in Ka band (extract from TR 38.811)

7.3.5.3.1.4 Satellite specific Doppler shift constraints in non-geostationary deployments scenarios

In those cases, some technique need to be put in place, as original error shall be, at least, less than SCS/2 with a simple auto correlation algorithm applied to Primary Synchronization Signal to be able to synchronize:

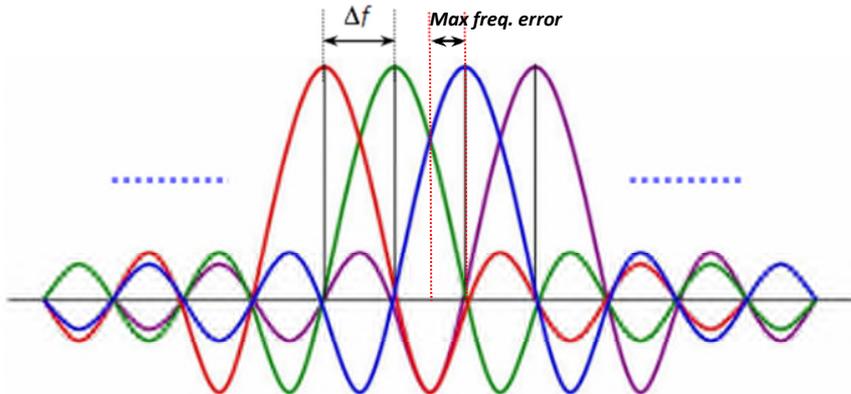


Figure 1819: OFDM subcarriers frequency representation

Even with highest SCS defined in NR, this is not possible:

- 60 kHz SCS for S band, the maximum error is then 30 kHz whereas the maximum Doppler shift is 48 kHz
- 240 kHz in Ka band, the maximum error is then 120 kHz whereas the maximum Doppler shift is 480 kHz

Moreover, the requirements for successful synchronization in 3GPP specifications (TableA.1.5-1 of [9]) regarding SNR level are quite low: about -7 dB. In that case, to get good synchronization performance (>95%), a common rule-of-thumb (used as simulations are not ready yet but will be done later to confirm this assumption) is to consider a maximum Doppler frequency error of 10% of the SCS.

So, with SNR of -7dB, the maximum frequency shift that can be handled is:

- for S band (with 60 kHz SCS), the maximum error is then 6 kHz
- in Ka band (with 240 kHz SCS), the maximum error is then 24 kHz

To fall back on those maximum frequency errors, 2 techniques could be used:

- Frequency shift pre-compensation in satellite
- Search for PSS signal with different frequency offset

7.3.5.3.1.4.1 Frequency shift pre-compensation in satellite

Each satellite has to serve a relatively large angular area.

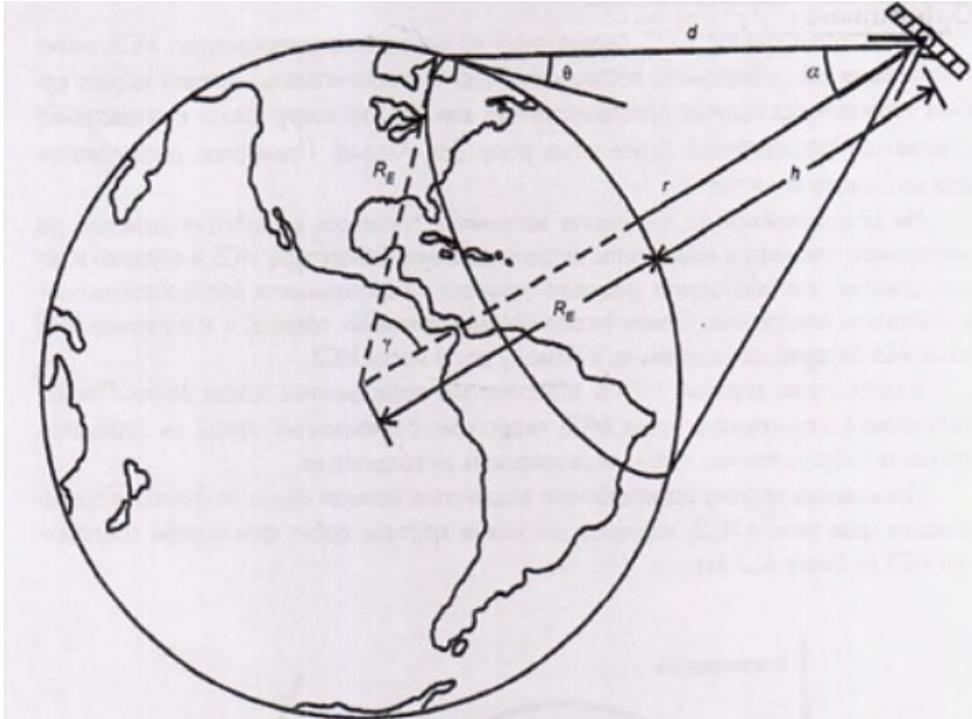


Figure 1920: Satellite coverage area

To achieve the required budget of radio link, each satellite has to use multi beam onboard antenna.

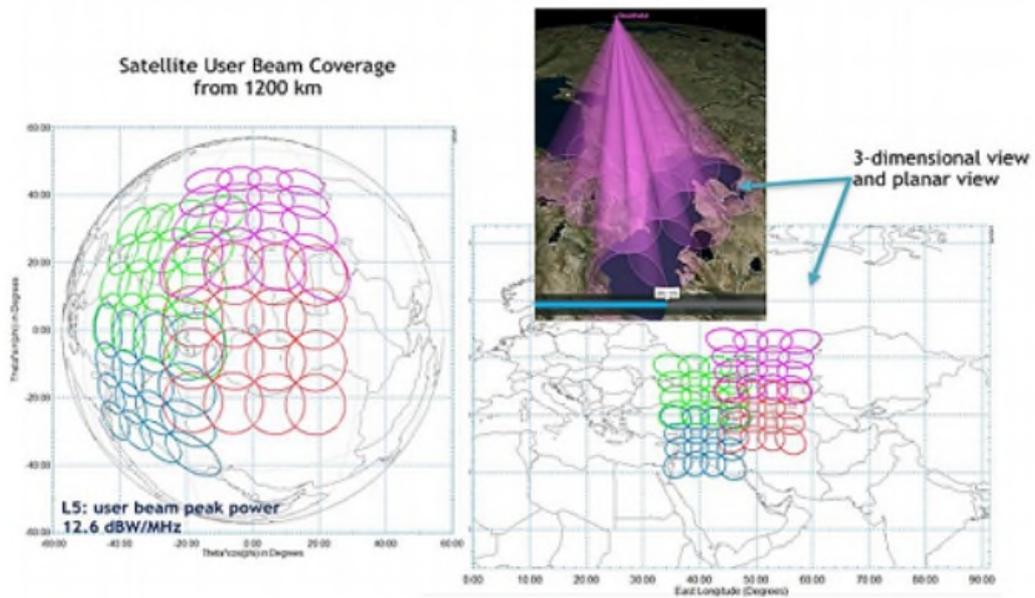


Figure 2021: multi beam satellites

In [Figure 20: multi beam satellites](#)[Figure 12](#), each color corresponds to one satellite coverage (so 4 satellites represented). Each satellite coverage is composed of 16 beams in this example. Overlapping beams are isolated by using different frequencies (with a certain re use factor).

Note that a beam for satellite will correspond to a cell in the context of terrestrial system. Since in 5G the number of beam is limited to 64, and in satellite the number of beams could be higher, each satellite beam will correspond to a cell as if 16 gNodeB were producing this pattern in the previous example.

A frequency pre-compensation can be achieved per cell. Knowing the ephemeris of the satellite and the ground pattern, each satellite beam can have a specific frequency correction.

Looking at the curve from [Figure 17: Doppler shift for LEO satellite at 600 km in Ka band \(extract from TR 38.811\)](#)[Figure 9: Doppler shift for LEO satellite at 600 km in Ka band \(extract from TR 38.811\)](#), we clearly see that the number of beams is not sufficient in [Figure 20: multi beam satellites](#)[Figure 12](#) to achieve, for example in Ka band, a resulting frequency error of 24 kHz. To achieve 24 kHz, the number of beams to be crossed, from the center to the edge of the cell coverage, should be around 20 (instead of 2 in [Figure 20: multi beam satellites](#)[Figure 12](#)).

In S band, to fall back from 48 kHz to 6 kHz, the number of beams to be crossed from center to the edge should be 8.

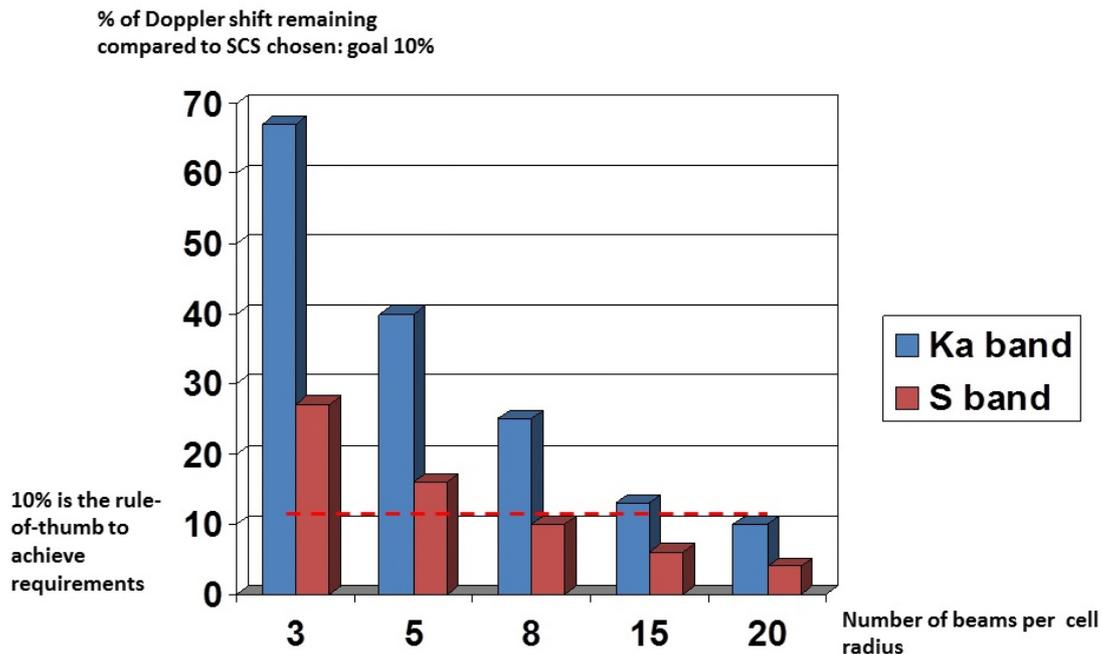


Figure 2122: remaining frequency offset (in % of SCS chosen) compared to the number of beams on the coverage radius

Note that a similar solution could be adopted with RN deployments, where the pre-compensation is done in the RN, if there is a geo-localization system associated, and ephemeris of satellite constellation stored. This could avoid the increase of beams needed.

Another mitigation is to mix satellite pre-compensation with the methods described in the following paragraph.

7.3.5.3.1.4.2 Search for PSS signal with different frequency offset

For example in S band, the maximum Doppler shift is 48 kHz. To fall back on 6 kHz maximum offset, different search could be run with $k=\{-4;-3;-2;-1;0;1;2;3;4\}$, and central frequency of search is: $F = F_0 + k \times 12 \text{ kHz}$.

The same could be done in Ka band: the maximum Doppler shift is 480 kHz. If SCS is 240 kHz, to get good performance, 24 kHz residual error should be obtained. In that case, different search could be run with $k=\{-10;-9;-8;-7;-6;-5;-4;-3;-2;-1;0;1;2;3;4;5;6;7;8;9;10\}$, and central frequency of search is: $F = F_0 + k \times 48 \text{ kHz}$. There is of course an increase of processing complexity by doing so, but for satellite, less frequencies have to be scanned compared to terrestrial. Hence the added complexity should be acceptable and could be implemented in UE.

7.3.5.3.1.4.3 Conclusion

For UE with omnidirectional antenna, the link budget analysis is showing a maximum bandwidth supported in DL of 200 kHz. If this is confirmed, since current minimum bandwidth of PSS/SSS is 1.905 MHz, it means that those UE will not be able to synchronize. As what has been done for NB-IOT, a possible solution is to define specific channels (including synchronizations) that could fit in the bandwidth supported in DL (200 kHz).

For Relay Node scenarios, the PSS/SSS bandwidth can be supported. So the following has been studied only for Relay Node scenarios:

A previous study, done in TR 38.811, characterized the worst Doppler shift in DL (obtained with LEO satellite at 600 km). This Doppler shift to overcome in synchronization procedure is 48 kHz in S band and 480 kHz in Ka band.

A common rule-of-thumb gives 10% of maximum frequency error compared to SCS to obtain 95% of correct PSS/SSS detection at an SNR of -7 dB which is the 3GPP requirement in [9]. Note that this rule-of-thumb will be replaced by simulations in future proposal.

SCS choices in S band are 15, 30 and 60 kHz. SCS choices in Ka-band are 60, 120 and 240 kHz for synchronization only. So if we take for example the highest SCS available, and 10% from the rule-of-thumb, it gives a maximum frequency error to be handled by autocorrelation algorithm of 6 kHz in S band and 24 kHz in Ka band.

To achieve such a low frequency offset before applying the synchronization algorithm, 2 techniques have been described in 7.3.5.3.1.4.1 and 7.3.5.3.1.4.2:

- Frequency shift pre-compensation by the satellite
- Different frequency offsets applied in the terminal

Since pre-compensation in the satellite requires a lots of satellite beams, which has a cost, this technique could be mixed with search frequency with different offsets on the terminal side, in order to mitigate the number of beams for the satellite and complexity in the terminal.

Then, with current SCS, and for Relay Node deployment scenarios, even with worst case scenarios (LEO at 600 km in Ka or S band), techniques, that are implementable at reasonable cost in satellite and Relay Node, could be put in place to achieve cell search requirements defined at 3GPP for NR.

7.3.5.3.2 Demodulation [FFS]

7.3.5.4 Phase Noise [FFS]

7.3.5.5 Conclusion on NR numerology selection

The following tables summarize the key findings for different aspects of the NR numerology selection for satellite communication, both for S-Band and Ka-Band.

- The CP range of current NR specification is matching satellite requirements. For lower numerologies, the CP is too long and resulting is slightly reduced spectral efficiency
- Performance of NR over satellite links with additional introduction of phase noise by the satellite components is FFS. Higher SCS is preferred to be more robust against phase noise, but increases the required Timing Advance update rate.
- Regarding Doppler, there is an additional Doppler shift is introduced by the satellite (depending on the satellite constellation). Mitigation techniques have been introduced in the previous chapter on Doppler.
- The minimum RF bandwidth / minimum number of resource blocks as specified for NR is limiting the selection for satellite application, but appropriate NR numerologies are found for S-Band and Ka-Band.
- Receiver synchronization and timing advance procedure for NR over satellite is fine for GEO satellites, but need further investigations for non-GEO satellite constellations due to the high speed of the spacecraft (up to 7.5 km/s) compared to terrestrial speeds.

As a conclusion, Satellite and HAPS deployment scenario foresee to use S and Ka bands. In S-band an SCS to be chosen could be 15, 30 or 60 kHz, and for Ka band, 60, 120 kHz and potentially 240 kHz for synchronization.

Table 7: Overview for selection of SCS configuration in Ka-Band.

Subcarrier	Satellite	Phase noise	Doppler shift	Minimum RF	TA update for	TA update for
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spacing (SCS) configuration parameter μ , SCS	propagation channel Ka-band		for LEO, MEO	transponder bandwidth	LEO, MEO	GEO
0 (15 kHz)	Ok, but CP too long	FFS	Ok, but lot of processing needed	Ok	FFS, more challenging with higher SCS	Ok
1 (30 kHz)	Ok, but CP too long	FFS	Ok, but lot of processing needed	Ok		Ok
2 (60 kHz)	Ok, but CP too long	FFS	Ok	Ok		Ok
3 (120 kHz)	Ok	FFS	Ok	Ok		Ok
4 (240 kHz)	Ok	Ok	Ok	FFS		Ok
5 (480 kHz)	Ok	Ok	Ok	FFS		Ok

Table 8: Overview for selection of SCS configuration in S-Band

Subcarrier spacing (SCS) configuration parameter μ	Satellite propagation channel S-band	Phase noise	Doppler shift for LEO, MEO	Minimum RF transponder bandwidth	TA update for LEO, MEO	TA update for GEO
0 (15 kHz)	Ok, but CP too long	Ok	Ok	Ok	FFS, more challenging with higher SCS	Ok
1 (30 kHz)	Ok, but CP too long	Ok	Ok	Ok		Ok
2 (60 kHz)	Ok	OK	Ok	FFS		Ok
3 (120 kHz)	Ok	OK	Ok	Not ok		Ok
4 (240 kHz)	FFS	Ok	Ok	Not ok		Ok
5 (480 kHz)	Not ok	Ok	Ok	Not ok		Ok

* * * End of Changes * * * *