5G Services and Sync Importance

Introduction

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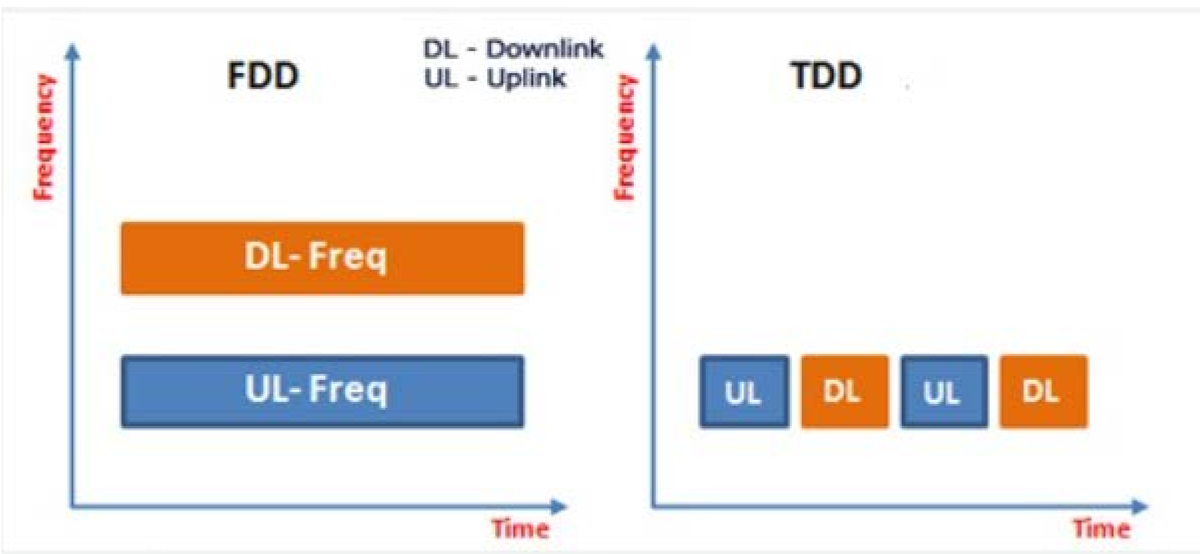
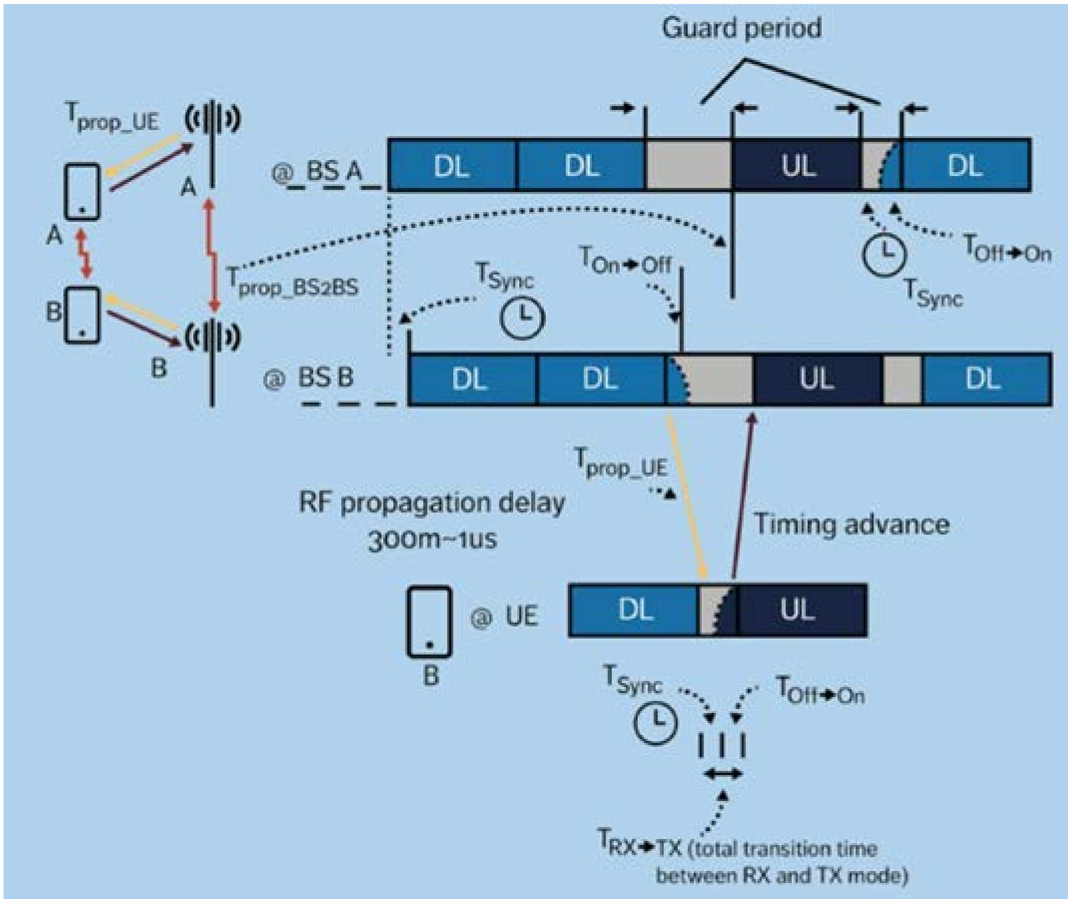
Phase synchronization for 5G networks is directly related to the size of the guard band and the interference of RF signals (Co-Channel Interference).

5G radios use Time Division Duplex (TDD) technology, where the uplink and downlink respectively use the same frequency band. There is a space between transmission time intervals called guard band, which is a period of time of silence.

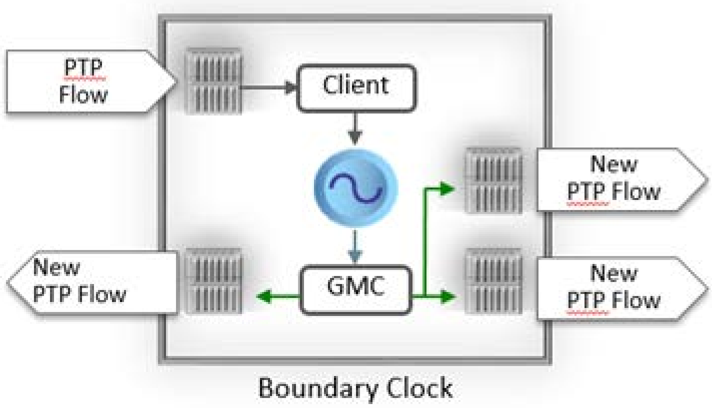


Guard bands are implemented to ensure that there is no overlap in the timeslots transmitting and receiving information, otherwise the frequency overlaps and causes interference between adjacent timeslot channels.

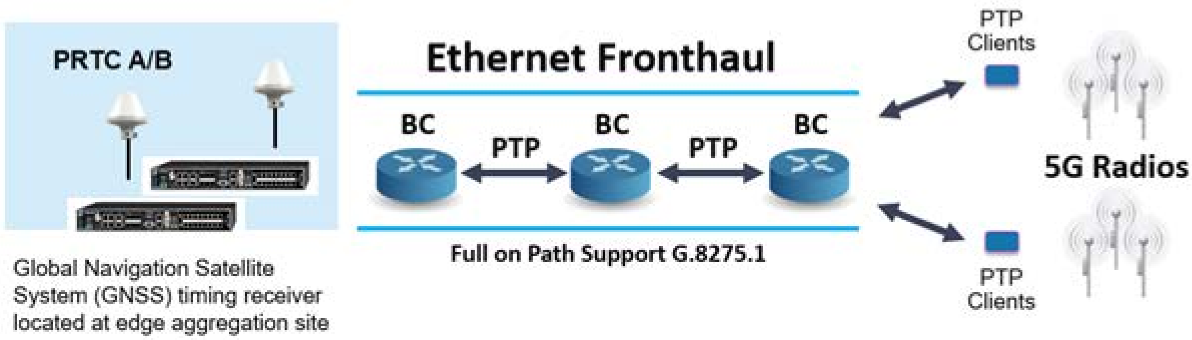
In 5G, guard bands should be as small as possible to allow that extra spectrum to provide more bandwidth to carry more data. Therefore the timing phase alignment specifications are very strict, so if the timing (phase) is poor it will lead to interference issues. The biggest problem is the interference between radios in the same cluster or edge clusters operating in the same spectrum. If the phase alignment is out of the budget (±1.5 μs) at the air interface between the radios and they transmit outside the correct time interval, due to a timing alignment error, there will be interference between the radios called Co-Channel Interference and all the cluster will shutdown 5G coverage.



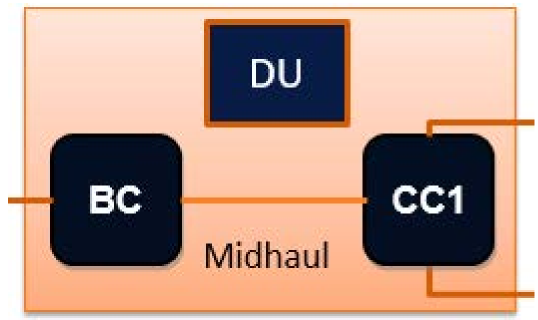
Referencing to transport network and how to distribute PTP over all PTP clients in the cluster now we will have a new network element that will be responsible for this function, based on Telecom-Boundary Clock (T-BC) in a full-on path support architecture.



In a full-on path support architecture, based on ITU-T G.8275.1 all T-BC switches now are part of the PTP transport as common clock to the final client destination the radio unit.



Now, T-BC has an important component of its functionalities called common clock. New T-BCs now can also share DU functionalities.



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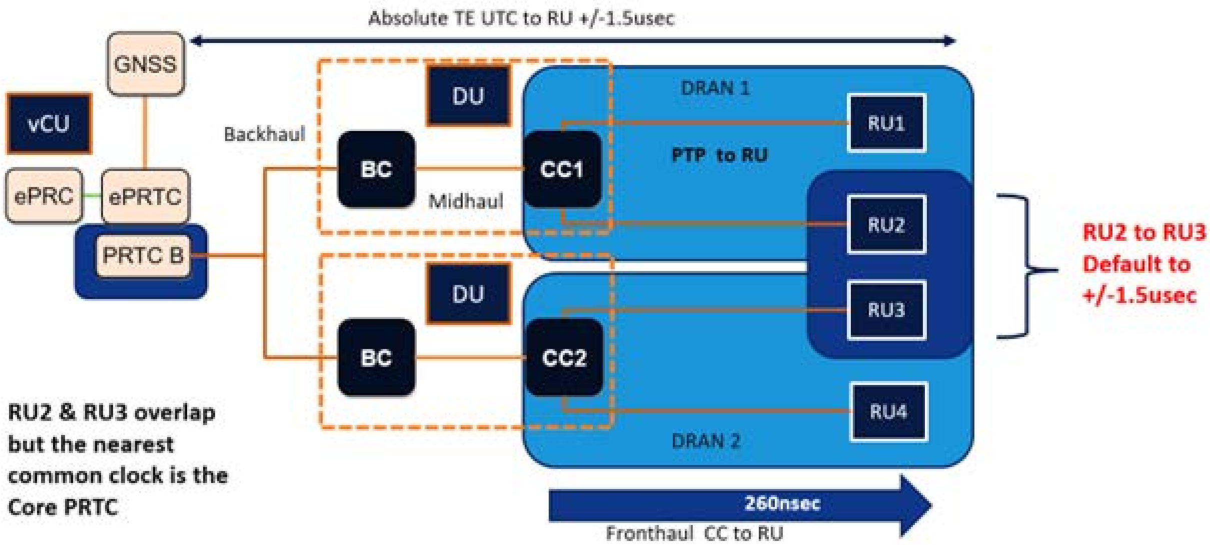
1. 5G Phase Error Budget

5G TDD technology is designed to operate within a maximum time error (hence ±1.5 µs between RUs on the air interface to UTC). The impact of this interference on services depends on the magnitude of the timing offset. For instance, if radio A has an error within ±1 µs to UTC and radio B is within ±2 µs to UTC, it will impact 5G services causing interruption of the 5G coverage.

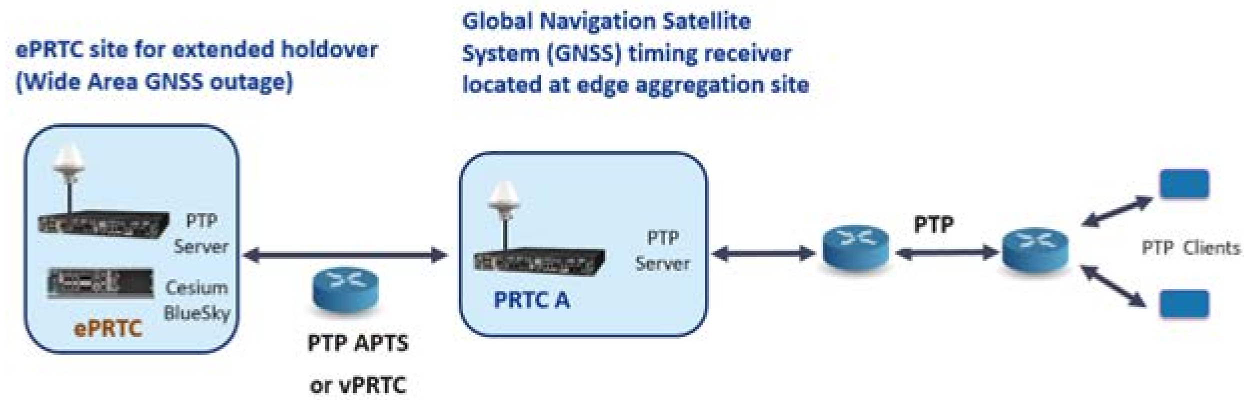


The impact of the timing error goes beyond the radio with time error out of the budget as this will result in interference with adjacent radios. Therefore, the extent of damage from the phase sync timing error is considerably greater than the source node.

The main technical motivation to adopt synchronization with network based timing services using PTP Grandmaster Clocks (GMCs), instead of GNSS receivers in the radios, is related to interference mitigation.

If you have a 5G radio cluster in operation, working with built-in GNSS receivers, and for any reason the GNSS receiver fails and/or is compromised, you must immediately take that radio out of service, as it will start to interfere with other radios. The reason is because the radio are designed with low performance oscillator to keep cost down. Moreover, this kind of network element is not designed for holdover performance (capacity to maintain the sync input quality for a period, once this source is unavailable). We can add it prevents the future deployment of intra-band contiguous CA since it is not possible to meet the TAE 130 ns requirement.

In the case of network-based timing services using PTP protocols, all radios will be connected and aligned to a PTP GNSS source clock. If the source clock Primary Reference Time Clock (PRTC) GNSS receiver fails, all radios will drift in the same rate and same direction as the PRTC source clock. They will not be subject to interference issues unless the GNSS PRTC source clock, which is designed to hold the accuracy of the output signals to UTC for a good period of time, drifts out of the ±1.5 microsecond UTC alignment window. Additionally, radios with overlapping coverage connected to alternate source clocks will experience a large offset and interference issues will surface.

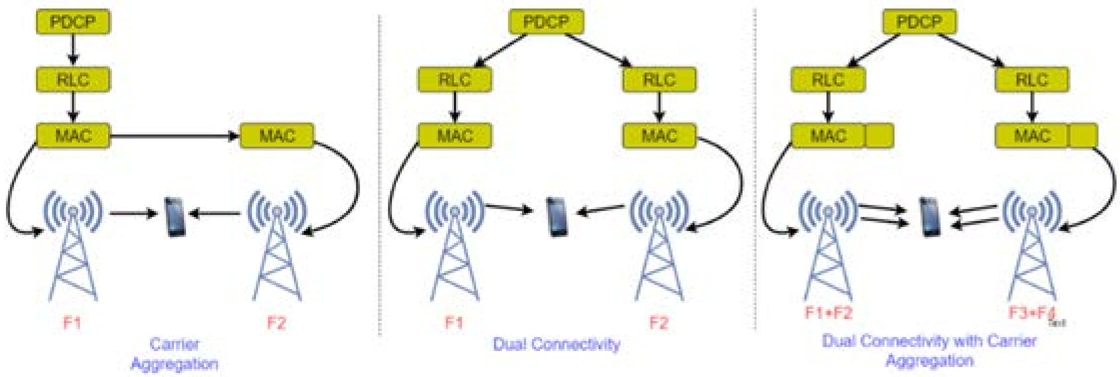


In a use case where the operator uses the Microchip TP4100 GNSS PRTC source clock GMC with a Rubidium holdover oscillator that will guarantee UTC alignment for a long period (43 hours), a GNSS disruption or failure will not impact overlapping radios or radio clusters that are receiving their network-based PTP timing services from a different GNSS PRTC source clock.

2. 5G Services that Requires Phase Synchronization

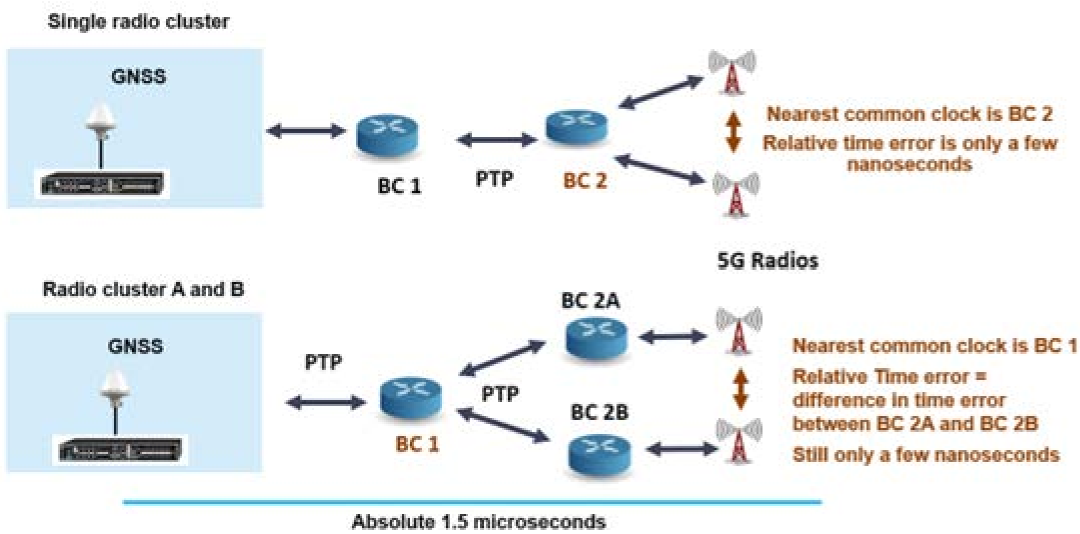
2.1 Carrier Aggregation

Another important aspect regarding phase synchronism is the relative time error required to operate efficiently with carrier aggregation in 5G.

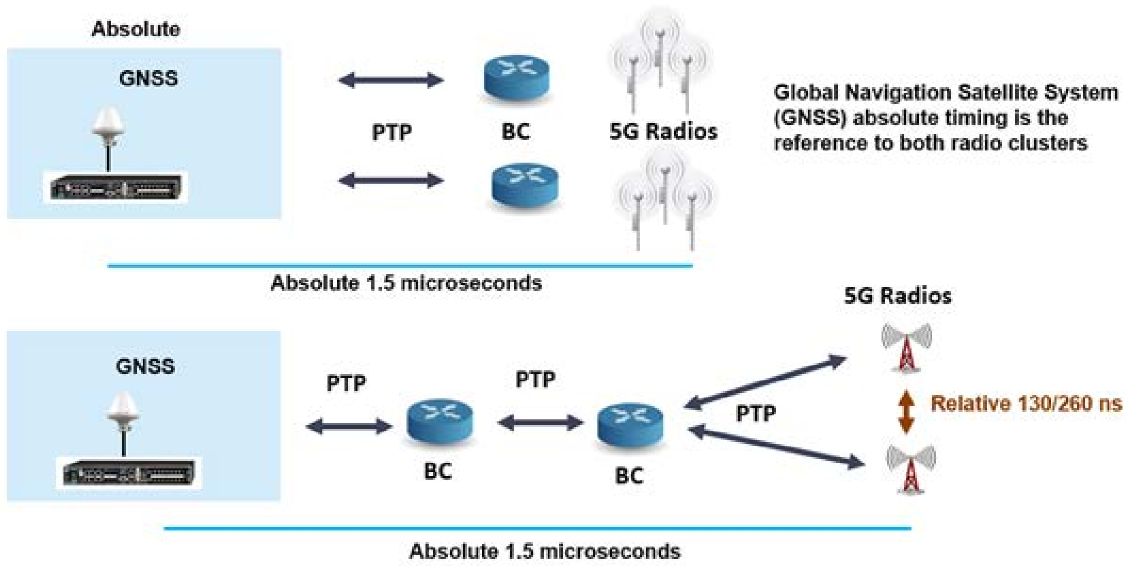


For this technology, 3GPP requires a maximum relative time error between radios of 130 ns (FR1) or 260 ns (mmWaves) (FR2). Due to this extremely restricted numbers, the 3GPP also recommends the use of network based PTP (G.8275.1 protocol) timing services with full-on path support (boundary clocks) as:

1. Adopting GMC, all radios in the cluster will be referenced to the same common clock source, whose initial relative time error is zero.



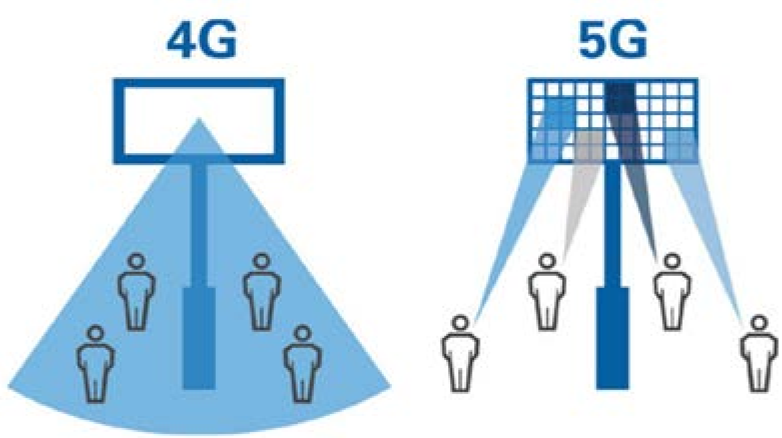
2. Implementation scenarios using only GNSS at cell sites (GNSS everywhere) technically wouldn't work, because the typical phase error of those devices (embedded GNSS) are around 400 ns, which in itself is much higher than what 3GPP standard specifies for fronthaul and is outside the relative time error specifications.

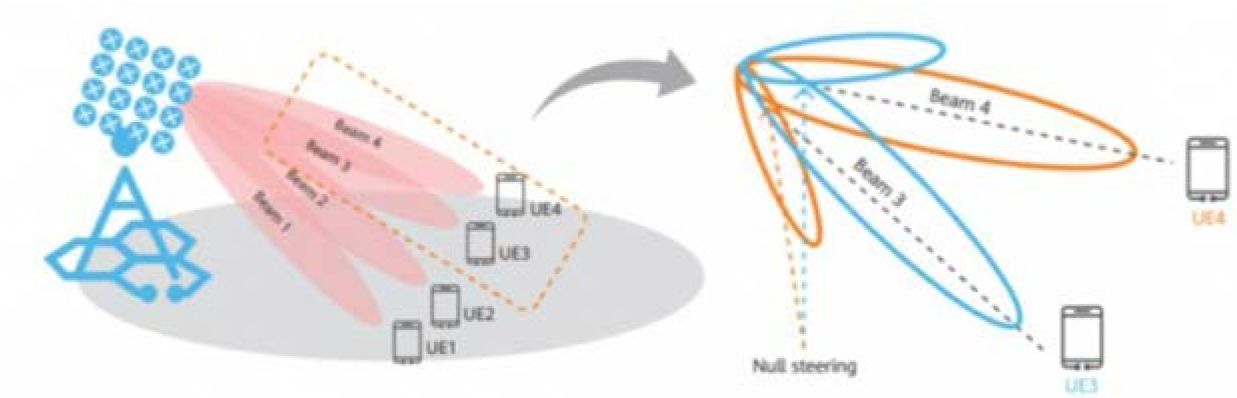


2.2 Massive MIMO and Beamforming

For better use of the spectrum and power consumption of the 5G cell, the beam direction is obtained by changing the phase of the input signal in all radiating elements. The phase shift allows the signal to be directed to a specific receiver.

Different frequency beams can also be directed in different directions to suit different users. In this methodology the phase alignment is crucial to allow the directional beam and no longer a wide coverage, in addition to mitigating interference with adjacent beams, avoiding co-channel interference.





To increase the resilience (Signal-to-Noise Ratio, or SNR) of a transmitted signal and channel capacity, without increasing spectrum usage, a common frequency can be steered simultaneously in multiple directions. We are now applying the MIMO concept.

The successful operation of MIMO systems requires the implementation of powerful digital signal processors and an environment with a lot of spatial diversity, with rich diversity of signals paths between the transmitter and the receiver.

In order to keep track of all the frequencies used, within each one's timeslot, without generating overlap and/or transmission outside the defined timeslot, phase synchronization is mandatory for these technologies added to 5G.

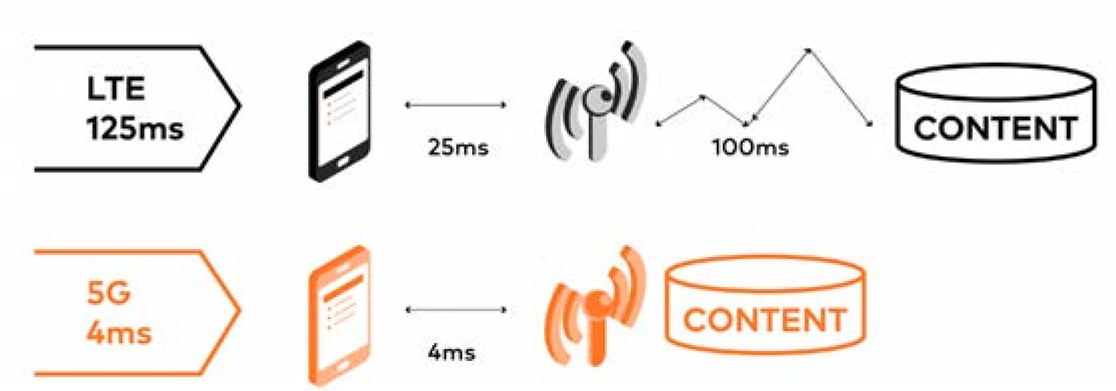
In addition, we have transport equipment with boundary clock requirements that must follow rules according to their class. For 5G, class C or higher is recommended for network elements as shown in the table below.

Parameters	Conditions	Class A	Class B	Class C	Class D
Max |TE|	Unfiltered 1000s.	100ns	70ns	30ns	FFS
Max $\|TE\|_L$	0.1Hz LPF 1000s measurement	-	-	-	5ns
cTE	Averaged over 1000	50ns	20ns	10ns	FFS
dTE_L MTIE	0.1Hz LPF const temp 1000s	40ns	40ns	10ns	FFS
dTE_L TDEV	0.1Hz LPF const temp 1000s	4ns	4ns	2ns	FFS
dTE_H	0.1Hz HPF const temp 1000s	70ns	70ns	FFS	FFS

For source clocks, we can choose PRTC class A (100 ns) or class B (40 ns). As stated earlier, GNSS antennas connected directly to radios cannot achieve these levels of accuracy.

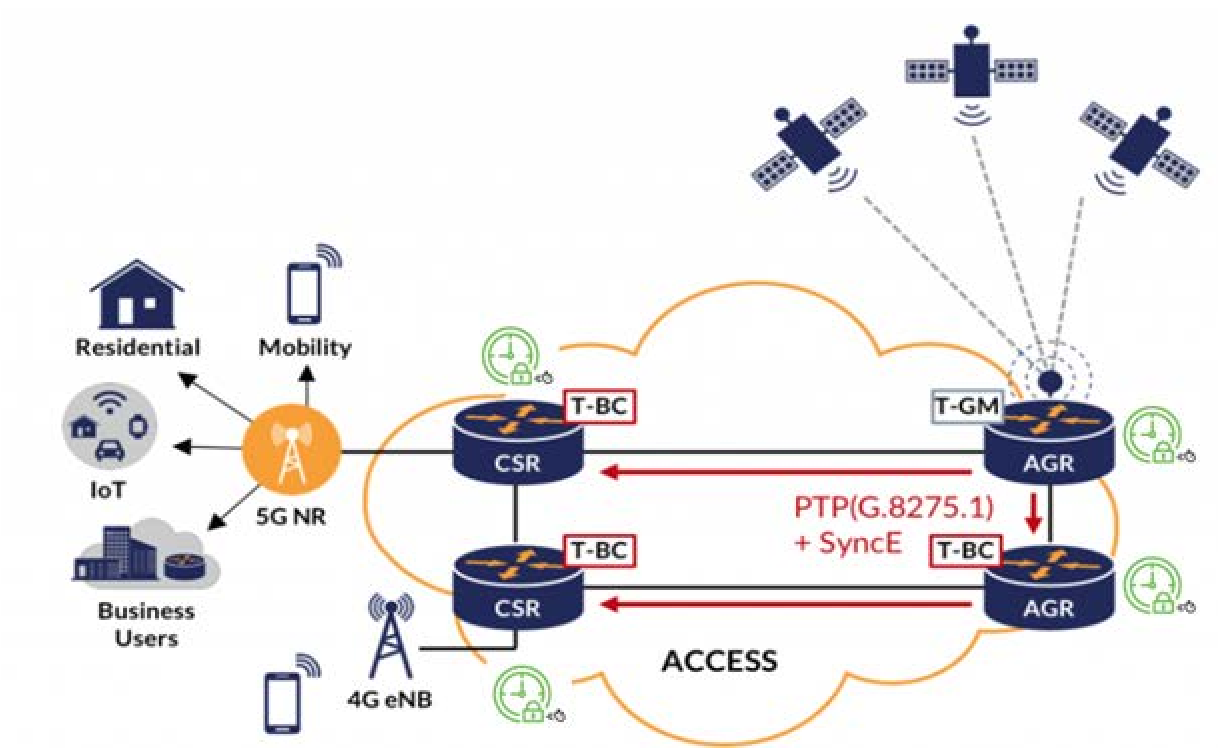
2.3 Latency

Regarding latency, in 5G this is due to the higher speed and bandwidth.



Precise synchronization is directly linked to the system latency, because with the reduced size of the guard bands, we have an improvement in performance. Timing is also important in the formation and direction of 5G radio beams. When an instruction is sent from a centralized server to a certain radio, in order to concentrate more or less bandwidth for an user, this instruction must be executed immediately.

Therefore, the CU or DU that is sending the instruction must be time-aligned to the radios and also all transport must be time-aligned (PTP/SyncE and NTP) in order to guarantee that there are no network elements with oscillators operating in a different frequency and time that will impact the timeout expected between the initial order instruction and execution.



3. Conclusion

Considering the timing source technology, we can take the example of one of the largest North America 5G operators, which switched 5G operation to GMC type model of timing source with PTP protocol based on some drivers:

- Small TCO (Capex & Opex) compared to continuing to expand the network with GNSS across all radios.
- More suited technically to the operation: Much higher operational availability and greater accuracy for the network. Allows indoor installations and in case of failures or interruptions in the GNSS receiver, it does not require taking the radios out of service (GMC has good holdover).
- Timing support with the concept of a the common clock for carrier aggregation, as it allows full on path support boundary clock functions, which support the relative requirements of time/phase alignment for all radios in the cluster.
- Less dependence on GPS/GNSS systems: Reducing risk of failures, disruptions, cyberattacks, bad weather, selective fading, jamming or spoofing.
- Greater operational availability, as it is the only technology that provides synchronization protection, and allows using all network transport backup to keep providing PTP to all clients.
- Scalable, once implemented there is no need to purchase GNSS antennas for every new radio installed, as it has GMC capacity with protection already available in the network.

4. Revision History

The revision history describes the changes that were implemented in the document. The changes are listed by revision, starting with the most current publication.

Revision	Date	Description
A	01/2023	Initial Revision

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