VIAVI Solutions

Application Note

# 5G Timing and Synchronization Handbook for TDD Deployment

Synchronization is one of the most critical functions of a communication system; however, in the context of 5G, especially for Time Division Duplex (TDD) where both uplink and downlink transmission is on the same frequency, the possibility of interference is much more significant. As a result, we see more stringent requirements for timing and synchronization for both TDD LTE and 5G-NR. In this paper we will discuss the relationship of TDD, timing and synchronization, and frame synchronization especially for 5G TDD deployments.

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## Weighing the Spectrum Pros and Cons

Not all radio spectrums are equal. Sub 1GHz offer the best coverage profile; however, the amount of low band spectrum available is limited. Frequency range two (FR2), i.e. greater than 6GHz, offers a large amount of spectrum with significantly wide bandwidth (up to 400MHz), but it offers limited coverage. In fact, it is an excellent radio channel for gigabit throughput, but the coverage is limited to hundreds of feet. C-band spectrum, which is part of frequency range one (FR1), and also called mid band spectrum, offers a good compromise between coverage and high throughput. As part of 3GPP release 15, three bands n77, n78 and n79 were identified for 5G operation in the C-band, with a potential service bandwidth of up to 100 MHz. See Table 1.

| Band | Band Name | Duplex Type | Freq (GHz) | Ul/DL Freq (GHz) | Channel Bandwidth (MHz) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| n77 | C-Band | TDD | 3.7 | 3.3-4.2 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| n78 | | | 3.5 | 3.3-3.8 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| n79 | | | 4.7 | 4.4-5.0 | | | | | ■ | ■ | ■ | | ■ | | ■ |

Table 1 - C-Band spectrum

With 100 MHz of bandwidth, C-Band can truly enable the enhanced mobile broadband (eMBB) use case for 5G. One thing to note is that C-band offers only Time Division Duplexing (TDD). TDD delivers a full-duplex communication channel over a half-duplex communication link. This means both the transmitter and receiver use the same frequency but transmit and receive traffic at different times by using synchronized time intervals. Advances in digital signal processing and computation speed of hardware allows for TDD operations, but it does offer some challenges. Let's review the benefits of TDD and some of the timing and synchronization requirements to ensure it can deliver the similar quality of RF services as Frequency Division Duplexing (FDD).

TDD turns out to be a more attractive option from spectral efficiency point of view because it requires only an unpaired spectrum for operation which is beneficial considering the scarcity of frequency resources. Also, physical layer features such as massive MIMO, beamforming, and precoding, that rely on channel state information (CSI) measurement in the uplink, are more robust due to channel reciprocity.

While it brings spectral efficiency, TDD introduces a critical challenge: Timing and synchronization. Stringent timing restrictions are imposed on a TDD system to avoid interference as both downlink (DL) and uplink UL share the same spectrum.

## Understanding the TDD Slot Format

Just like LTE, 5G radio frames have a fixed duration of 10ms. Each radio frame contains ten 1ms subframes. How it differs from LTE is that in 5G-NR, slot and symbol duration depends on the numerology. See Figure 1.

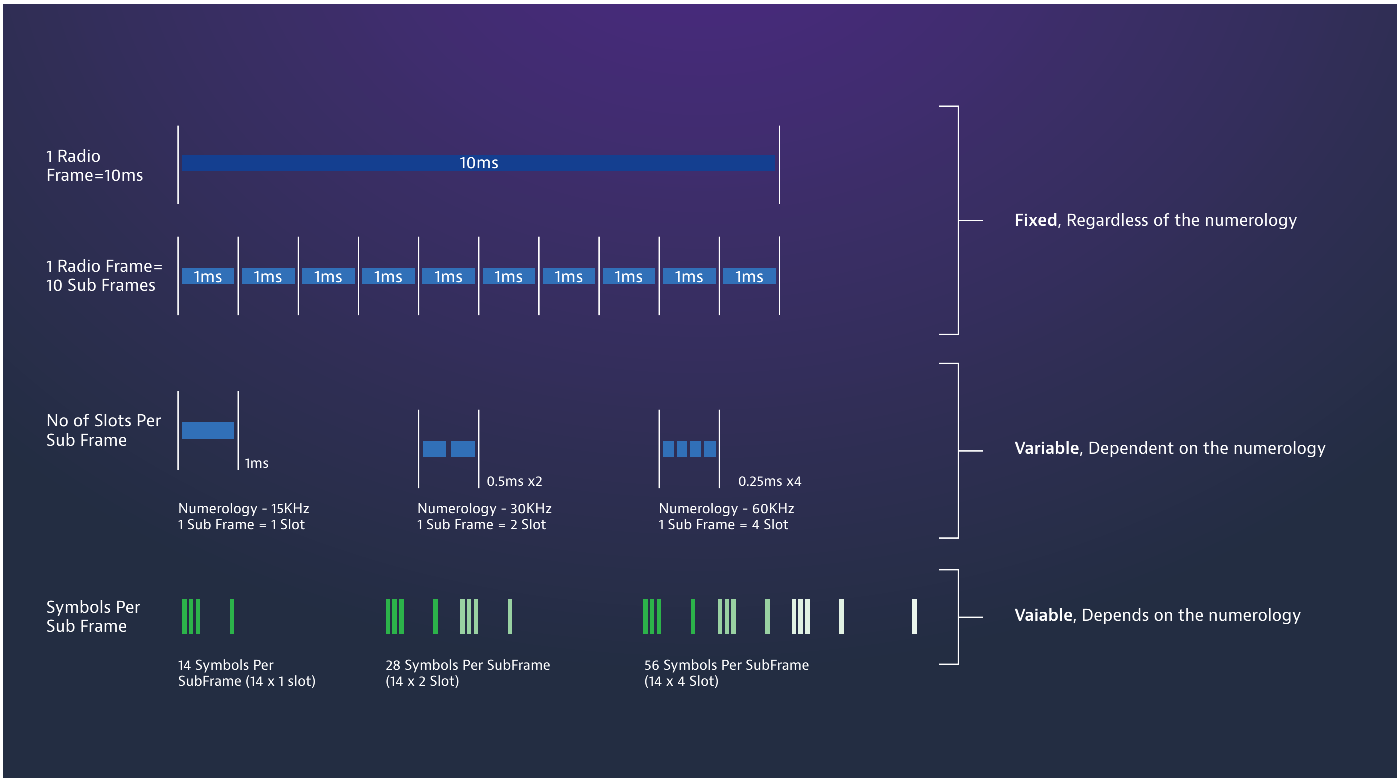



Figure 1 - 5G NR slot relation with sub carrier spacing (numerology)

As subcarrier spacing changes so does the number of slots and symbols per subframes. For example, 15KHz has one subframe of 1ms duration which is equal to one slot carrying 14 symbols. For 30KHz subcarrier spacing, one subframe is equal to 2 slots of 0.5ms duration each and 28 symbols and so on (for normal cyclic prefix). For different type of services, ultra-reliable low latency communication (URLLC) versus eMBB, for example, the service provider may decide to use different slot and frame configuration. Release 15 version of 3GPP 38.213 has defined 56 slot formats (Table 2) each of which is a predefined pattern of downlink/flexible/uplink symbols during one slot. The following table provides a quick reference.

| Format | Symbol number in a slot | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 0 | D | D | D | D | D | D | D | D | D | D | D | D | D | D |
| 1 | U | U | U | U | U | U | U | U | U | U | U | U | U | U |
| 2 | F | F | F | F | F | F | F | F | F | F | F | F | F | F |
| 3 | D | D | D | D | D | D | D | D | D | D | D | D | D | F |
| 4 | D | D | D | D | D | D | D | D | D | D | D | D | F | F |
| 5 | D | D | D | D | D | D | D | D | D | D | D | F | F | F |
| 6 | D | D | D | D | D | D | D | D | D | D | F | F | F | F |
| 7 | D | D | D | D | D | D | D | D | D | F | F | F | F | F |
| 8 | F | F | F | F | F | F | F | F | F | F | F | F | F | U |
| 9 | F | F | F | F | F | F | F | F | F | F | F | F | U | U |
| 10 | F | U | U | U | U | U | U | U | U | U | U | U | U | U |
| 11 | F | F | U | U | U | U | U | U | U | U | U | U | U | U |
| 12 | F | F | F | U | U | U | U | U | U | U | U | U | U | U |
| 13 | F | F | F | F | U | U | U | U | U | U | U | U | U | U |
| 14 | F | F | F | F | F | U | U | U | U | U | U | U | U | U |
| 15 | F | F | F | F | F | F | U | U | U | U | U | U | U | U |
| 16 | D | F | F | F | F | F | F | F | F | F | F | F | F | F |
| 17 | D | D | F | F | F | F | F | F | F | F | F | F | F | F |
| 18 | D | D | D | F | F | F | F | F | F | F | F | F | F | F |
| 19 | D | F | F | F | F | F | F | F | F | F | F | F | F | U |
| 20 | D | D | F | F | F | F | F | F | F | F | F | F | F | U |
| 21 | D | D | D | F | F | F | F | F | F | F | F | F | F | U |
| 22 | D | F | F | F | F | F | F | F | F | F | F | F | U | U |
| 23 | D | D | F | F | F | F | F | F | F | F | F | F | U | U |
| 24 | D | D | D | F | F | F | F | F | F | F | F | F | U | U |
| 25 | D | F | F | F | F | F | F | F | F | F | F | U | U | U |
| 26 | D | D | F | F | F | F | F | F | F | F | F | U | U | U |
| 27 | D | D | D | F | F | F | F | F | F | F | F | U | U | U |
| 28 | D | D | D | D | D | D | D | D | D | D | D | D | F | U |
| 29 | D | D | D | D | D | D | D | D | D | D | D | F | F | U |
| 30 | D | D | D | D | D | D | D | D | D | D | F | F | F | U |
| 31 | D | D | D | D | D | D | D | D | D | D | D | F | U | U |
| 32 | D | D | D | D | D | D | D | D | D | D | F | F | U | U |
| 33 | D | D | D | D | D | D | D | D | D | F | F | F | U | U |
| 34 | D | F | U | U | U | U | U | U | U | U | U | U | U | U |
| 35 | D | D | F | U | U | U | U | U | U | U | U | U | U | U |
| 36 | D | D | D | F | U | U | U | U | U | U | U | U | U | U |
| 37 | D | F | F | U | U | U | U | U | U | U | U | U | U | U |
| 38 | D | D | F | F | U | U | U | U | U | U | U | U | U | U |
| 39 | D | D | D | F | F | U | U | U | U | U | U | U | U | U |
| 40 | D | F | F | F | U | U | U | U | U | U | U | U | U | U |
| 41 | D | D | F | F | F | U | U | U | U | U | U | U | U | U |
| 42 | D | D | D | F | F | F | U | U | U | U | U | U | U | U |
| 43 | D | D | D | D | D | D | D | D | D | F | F | F | F | U |
| 44 | D | D | D | D | D | D | F | F | F | F | F | F | U | U |
| 45 | D | D | D | D | D | D | F | F | U | U | U | U | U | U |
| 46 | D | D | D | D | D | F | U | D | D | D | D | D | F | U |
| 47 | D | D | F | U | U | U | U | D | D | F | U | U | U | U |
| 48 | D | F | U | U | U | U | U | D | F | U | U | U | U | U |
| 49 | D | D | D | D | F | F | U | D | D | D | D | F | F | U |
| 50 | D | D | F | F | U | U | U | D | D | F | F | U | U | U |
| 51 | D | F | F | U | U | U | U | D | F | F | U | U | U | U |
| 52 | D | F | F | F | F | F | U | D | F | F | F | F | F | U |
| 53 | D | D | F | F | F | F | U | D | D | F | F | F | F | U |
| 54 | F | F | F | F | F | F | F | D | D | D | D | D | D | D |
| 55 | D | D | F | F | F | U | U | U | D | D | D | D | D | D |
| 56 – 254 | Reserved | | | | | | | | | | | | | |
| 255 | 255 UE determines the slot format for the slot based on tdd-UL-DL-ConfigurationCommon, tdd-UL-DLConfigurationCommon2, or tdd-UL-DL-ConfigDedicated and, if any, on detected DCI formats | | | | | | | | | | | | | |

Table 2 - Slot formats for normal cyclic prefix

These formats allow flexibility in terms of the application supported on a 5G node B (gNB), for example a DL heavy traffic with UL part can implement format 28. This also creates a challenge if two networks are offering different types of service are located next to each other. Interference can result even though they may be synchronized in time but their slot formats are not synchronized. (This is discussed in the following section.)

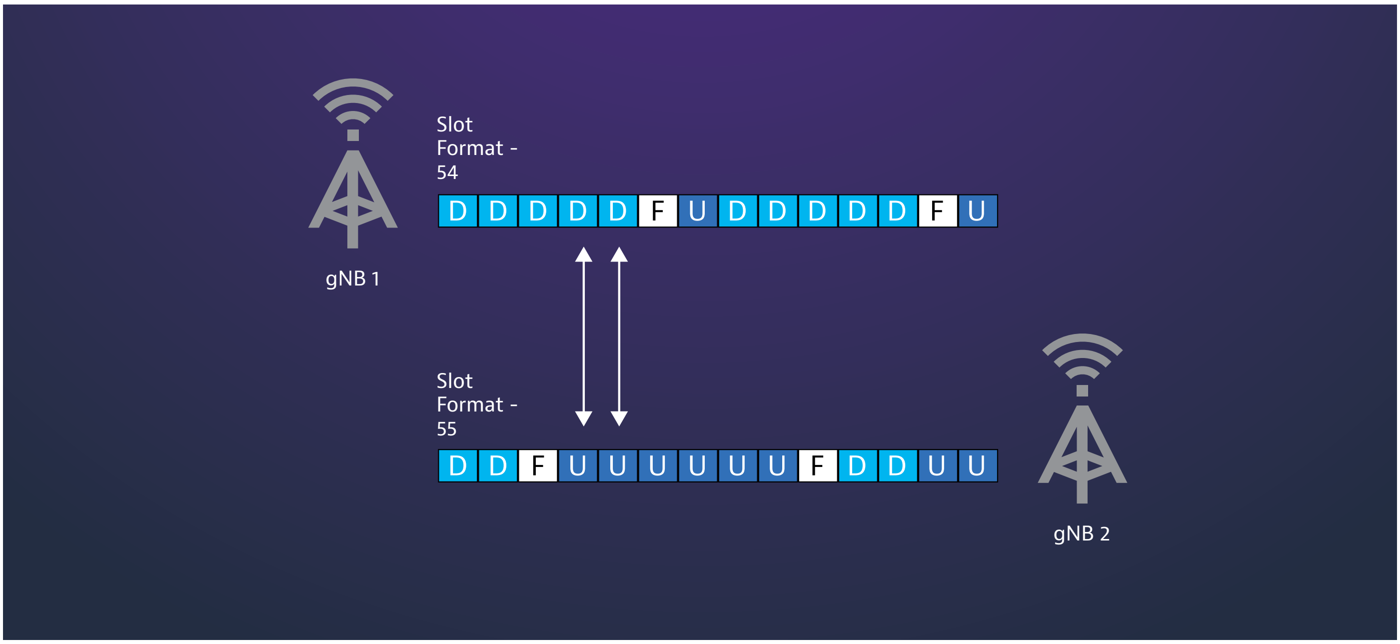



Figure 2 - Two networks with unsynchronized Slot format

## Synchronization and Its Importance

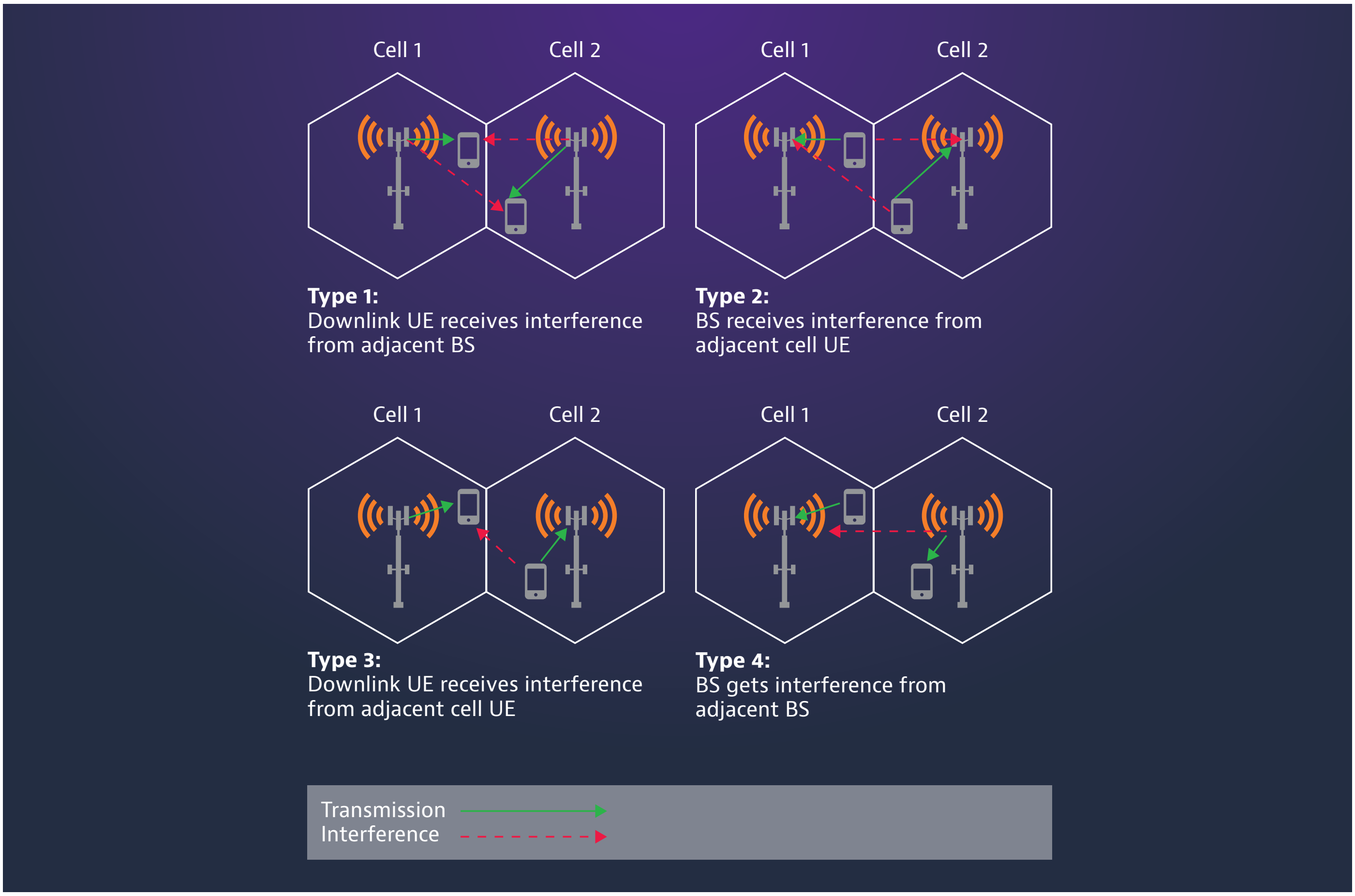
It is worthwhile to discuss the importance of synchronization in a communication network—especially a radio communication network. If the radio clock loses synchronization accuracy, or the radios are not synchronized, in a TDD channel TDD framing will drift outside the guard period and interfere with adjacent cell-sites. The less accurate the clock source, the higher the probability for time shifts which ultimately bring performance and interference challenges. Following are the types of interference issues that can occur in a TDD environment:

### Intra-cell Interference

Interference caused within the same cell due to large timing inaccuracies. The probability of intra-cell interference is low because in a TDD cell, different users are scheduled on different slots by the scheduler.

### Inter-cell Interference

When users in the adjacent cells are scheduled on the same subcarriers but with different DL/UL slots, inter-cell interference is a possibility, particularly if cells are not synchronized to a common clock. Figure 3 reveals the four possible scenarios as mentioned in the paper Interference analysis and performance evaluation for LTE TDD system.




**In the Type 1 scenario**, cell 1 is assigned on a DL time slot and the adjacent cell 2 is also assigned on DL time slot at the same time. In this scenario, both the UEs on the cell edge receive interference from the neighbor cells.

**In the Type 2 scenario**, which is the inverse of Type 1, both cell 1 and cell 2 is assigned an UL time slot. This results in the reception of weak interference at the cells from the adjacent neighbor UEs. Remember, UE power is limited compared to the gNB.

**In the Type 3 scenario**, cell 1 is assigned DL time slot and cell 2 is assigned UL time slot. The cell edge UE in cell 1 experiences strong interference from the cell edge UE in cell 2. This is the most serious type of interference of all the cases.

**In Type 4 scenario**, cell 1 is assigned on UL time slot and cell 2 is assigned DL time slot. Cell 1 experiences interference from cell 2. However, the strength of interference is relatively low as the path loss between the cells are high due to the large separation between them.

Figure 3 - Inter-cell interference scenarios

In general, to avoid such use cases of interference all base stations in a network should be synchronized with a common phase clock reference (e.g. UTC - Coordinated Universal Time). Per ITU-T standards recommendation, both 5G-NR TDD and LTE-TDD networks need to be phase synchronized in order to limit the end-to-end time error to under 1.5μs. This 1.5μs comprises of 1.1μs absolute time error up to the access point and 0.4μs over the fronthaul to the radio. Different timing synchronization solutions can be used to ensure all the radio units in the network are synchronized which will allow the schedular at the base stations to make sure interference is minimized.

### Cross-slot/link Interference

Another potential instance of TDD network interference is inter-network cross link interference. This occurs when two TDD networks are deployed in blocks within the same band causing interference when simultaneous transmissions in uplink and downlink directions take place in different TDD networks as shown in Figure 4. In this case, the base station (BS) or UE belonging to one network transmits while another BS or UE belonging to the other network receives, this scenario is referred to as simultaneous UL/DL transmission.

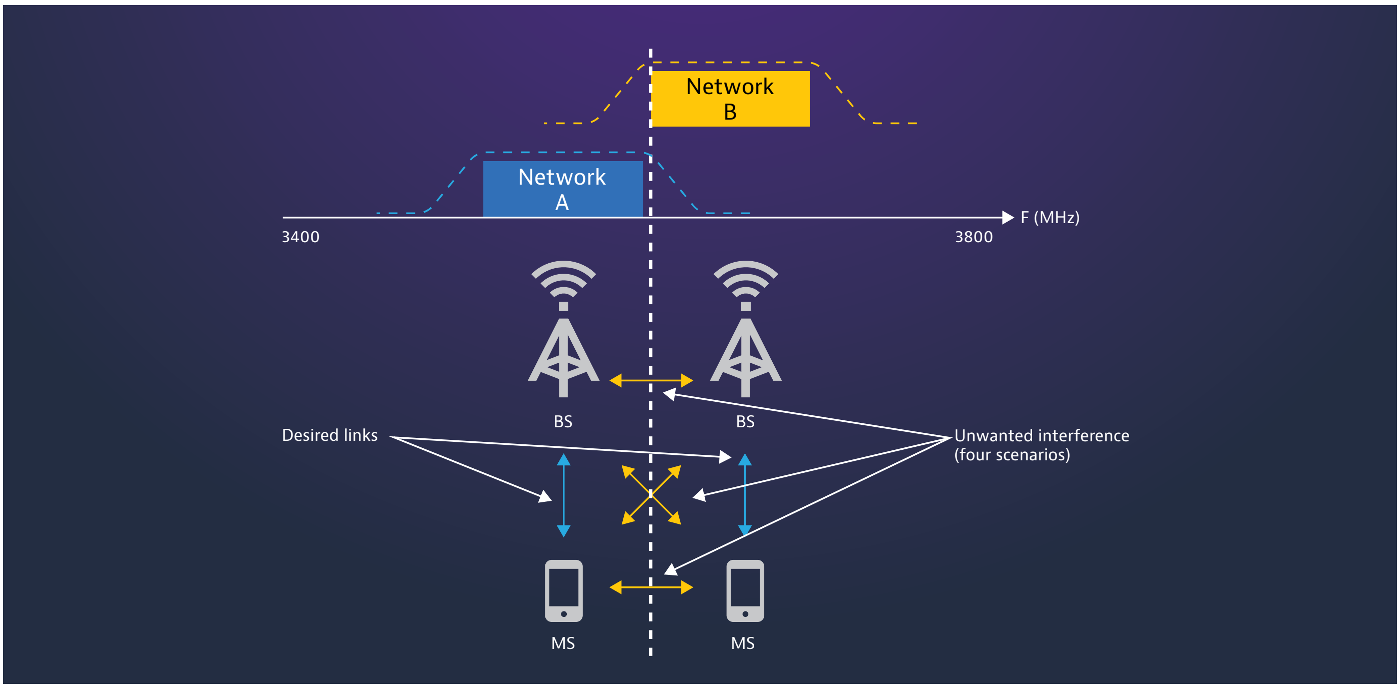



Figure 4 - Interference scenarios in case of simultaneous UL/DL transmissions

If the two networks are phase and frame synchronized such issues can be avoided; however, it is challenging to deploy multi operator synchronized networks. In cases where LTE networks are already deployed, this may become more challenging as 5G-NR new frame structures bring new compatibility and performance issues. The purpose of synchronized operation where co-channel adjacent networks or collocated adjacent channel networks are synchronized is to prevent BS-BS and MS-MS interference scenarios. Synchronized in this scenario means more than just have a common Coordinated Universal Time (UTC) reference; rather it also requires compatible frame structure across operators. Frame and slot synchronization will help in avoiding performance degradation due to cross link interference without requiring additional mitigation techniques such as additional filtering, inter-operator guard bands, geographical separation between base stations, etc. Hence, inter-network synchronization can simplify deployment as less coordination for cell-site radio planning is required.

In summary, for a TDD LTE or 5G-NR network (where TDD is the only option for C-band), we not only need frequency and phase synchronization, but also frame and slot synchronization to avoid inter-network interference. Understanding the different types of synchronization and some of the requirements and recommendations proposed by 3GPP, ITU-T and other regulatory bodies such as ECC is essential to understand the complexity of deploying a 5G-NR TDD network. Additionally, with the evolution of RAN to an open RAN (O-RAN) architecture, timing and sync requirements and testing of timing and sync will be even more important because additional delays from open interface network nodes may need to be considered for seamless 5G services.

## Types of Synchronization

In a communication channel for coherent detection, a receiver needs an estimate for frequency and phase shifts of the received signal with respect to the local oscillator so that it can compensate for that frequency and phase shift. This phenomenon is called synchronization. Synchronization can be identified as the following types:

### Frequency Synchronization

Two clocks that are aligned in terms of their repeating interval (i.e. frequency) but not in terms of phase or time.

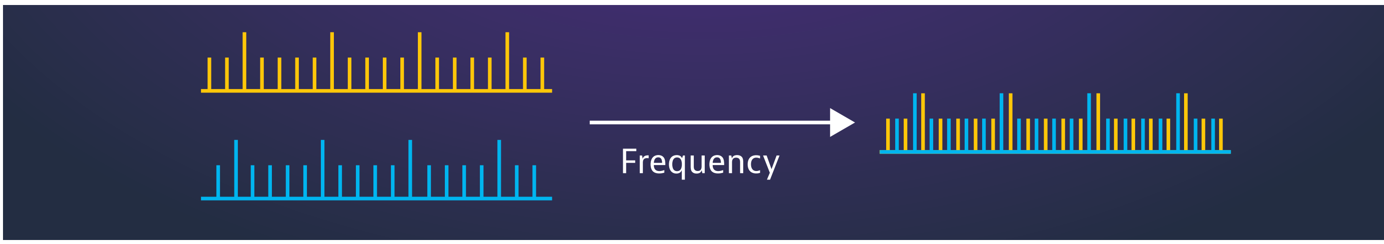



Figure 5 - Frequency Synchronization

### Phase Synchronization

Two clocks that are aligned in terms of their repeating interval (i.e. frequency) and also phase (a one second interval), but without a common time origin.

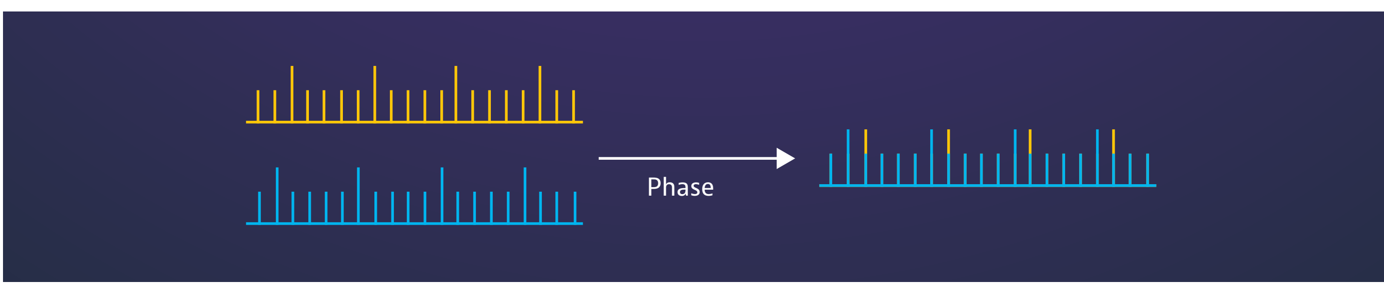



Figure 6 - Phase Synchronization

### Time Synchronization

Two clocks that are aligned in terms of their repeating interval (i.e. frequency), their phase (a one second interval), and share a common time origin

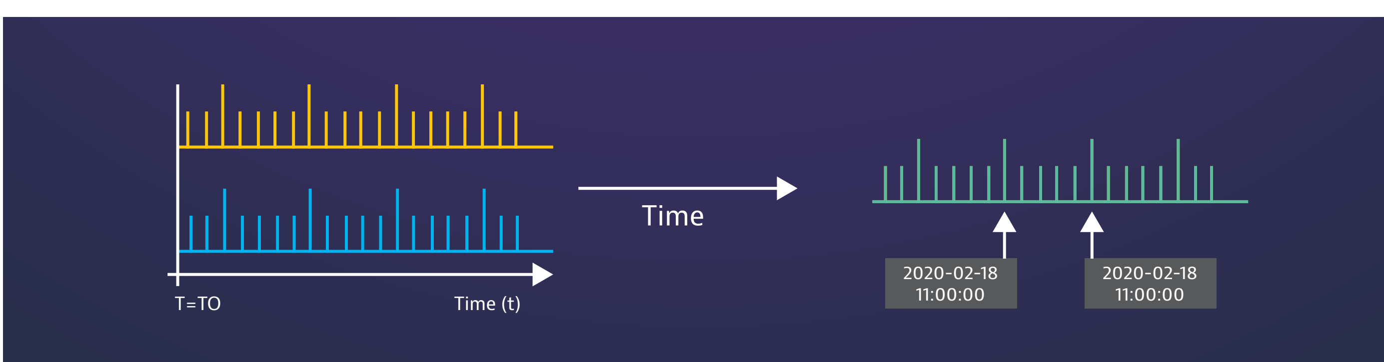



Figure 7 - Time Synchronization

**Frame Synchronization**

A compatible frame structure to avoid simultaneous UL/DL transmission, which determines a specific DL/UL transmission ratio and frame length. Basically no simultaneous UL and DL transmissions occur, i.e. at any given moment in time either all networks transmit in DL or all networks transmit in UL adopting a single frame structure for all TDD networks involved as well as synchronizing the beginning of the frame across all networks.

## Standard Requirements for Timing and Synchronization

Synchronization of different nodes within a network means distribution of time and frequency over a network of clocks, spread over a wide geographical area with a common primary source. All communication networks require nodes to be in sync to be able to properly demodulate received signals.

In wireless communications, the receiver does not have prior knowledge of the physical wireless channel or propagation delay associated with the transmitted signal. Typical communication receivers use low-cost oscillators to keep the cost of the devices manageable. These oscillators inherently have some drift. Hence, using timing synchronization as a process by which a receiver node determines the correct instance of time at which to sample the incoming signal and carrier synchronization as a process by which a receiver adapts the frequency and phase of its local carrier oscillator with those of the received signal, the receiver node can demodulate received signals properly.

Synchronization definition and procedures may vary depending on the specific communication system. For example, in terms of OFDMA, timing synchronization may consist of frame, slot, and symbol synchronizations, residual timing tracking, first arrival path search etc. Similarly, carrier synchronization may imply integer or fractional frequency offset estimation, etc. In 5G NR a carrier accuracy of 50 parts per billion and timing accuracy of 10μs is required. However, for LTE/5G NR TDD this requirement goes to a more stringent 1.5 μs. For advanced features such as MIMO, location-based services, etc., timing accuracy of a few 100ns is required. See Table 2 for timing and sync requirements, type of synchronization, and whether absolute verses relative synchronization is needed and the effects of noncompliance.

| Use case | Sync Type | Synchronization Requirement | Need for Compliance | Impact of Non-Compliance |
|---|---|---|---|---|
| LTE/ 5G-NR FDD | Freq | 50 PPB<br>Absolute | Accessibility and Retainability | Interference and high drop connections |
| LTE/ 5G-NR FDD | Time | ~10 μs<br>Absolute | Time slot Alignment | Packet Loss collision,<br>Performance degradation |
| LTE/ 5G-NR/ eMBMS/ Carrier Aggregation | Time | ~3–5 μs<br>Absolute | Time Alignment between multiple carriers and cells for video decoding and a Carrier Aggregation | Poor video quality and CA failure,<br>Low throughput |
| LTE/ 5G-NR TDD/ eCIC | Time | ~1.5 μs<br>Absolute | Interference Management/ Interference Co-ordination | Network Interference,<br>Reduced capacity, Poor performance |
| LTE/ 5G-NR CoMP/LBS | Time | <1 μs relative<br>OTA measurement | Coordination of signals to/ from cell sites | LBS Accuracy, spectral efficiency |
| LTE/ 5G-NR TDD | Frame | Depends on the Adjacent TDD network (LTE vs. 5G) | Coordination with Adjacent LTE or 5G Network | Network Interference,<br>Reduced capacity, Poor performance |

Table 3 - Timing requirements for LTE/5G-NR for different features/services

### Absolute vs. Relative Synchronization

What is the difference between absolute and relative synchronization? To understand this, let us review Figure 8. Time Error (TE), which is defined as the time difference between two nodal clocks, has two distinct yet equally important components in a 5G network

1. Absolute TE – Time difference between a node and Primary Reference Time Clock (PRTC) which is the Grand Master time reference. It can be measured using precision timing protocol (PTP) for 5G-NR TDD system, ITU-T recommends 1.1 microseconds up to the access point.
2. Relative TE – Time difference between inputs into two radio units. As identified in Table 4, meeting relative TE requirements is essential for advanced features including carrier aggregation, MIMO, CoMP, and location-based services.

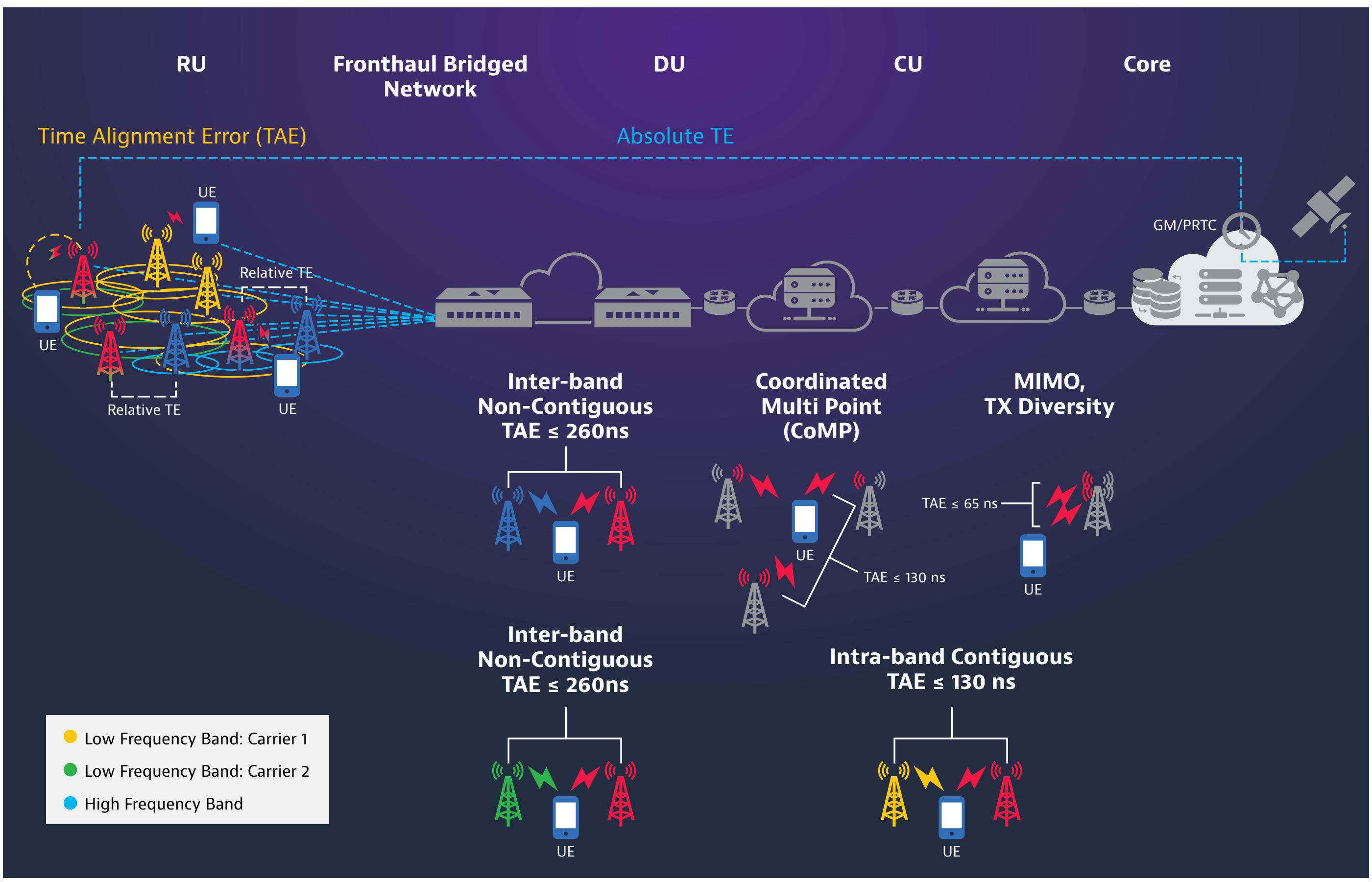



Figure 8 - Timing and sync requirements across a 5GNR network

Another component to understand is the Time Alignment Error (TAE), which is the time difference between two antenna ports, measured over the air using GPS or a common timing source as a reference. Over the air TAE measurements limits differ between two RUs, carriers or antenna ports (for MIMO) as shown in Figure 8.

Although timing and carrier synchronization are necessary for successful communication, they cannot provide a common notion of time across distributed nodes. Clock synchronization is the process of achieving and maintaining coordination among independent local clocks to provide a common notion of time across the network. For example, GPS receivers have been used as the most common time synchronization source at the cell-sites in the past. This may not be a cost-effective option in 5G.

### CPRI vs. Ethernet

5G is introducing many changes with respect to network topology. CPRI, (a synchronous fronthaul interface) which is the technology used today for LTE, may not be practical for all 5G use cases. CPRI enforces stringent delay requirements which is well-suited for centralization, but it creates challenges in terms of bandwidth and node flexibility. CPRI provides a dedicated transport protocol specifically designed to transport radio waveforms between the radio unit and the digital unit. CPRI frames expand with increased radio channel bandwidth and the number of antenna elements. However, CPRI is not very efficient in terms of statistical multiplexing and cannot scale to the demands of 5G, especially for massive MIMO and larger bandwidth increments. The required bandwidth and antennas in a 5G scenario would push the CPRI bandwidth above 100 Gbps. That is why using Ethernet for fronthaul and midhaul is very practical.

Ethernet is backwards compatible which allows for commodity equipment, enabling greater convergence of access networks, and enabling statistical multiplexing which will help lower the aggregate bit-rate requirements. Use of standard IP/Ethernet network switching/routing will also make functional virtualization and overall network orchestration relatively easy. The challenge is that Ethernet is not synchronous. In the brave new world of 5G (either eCPRI or O-RAN), the synchronization plane will be carried independently over an Ethernet layer and will not be restricted to specific protocol. Global positioning system (GPS), precision time protocol (PTP), synchronous Ethernet, or something similar can be used for timing and synchronization.

## Options for Synchronization

As shown in Figure 9, in 3G and 4G cellular networks, satellite receivers are embedded in NodeBs and BBUs. These controllers take the time of day messages and propagate them over the air to UEs. They also take the accurately timed pulse received every second (1PPS) and use this to keep all cell towers frequency synchronized. 3G and 4G networks need line of site to only one satellite to frequency synchronize. 5G cellular networks use the same GPS satellites – up to 32 satellites worldwide depending on the number in service – that the 3G and 4G networks use, however they use them slightly differently.

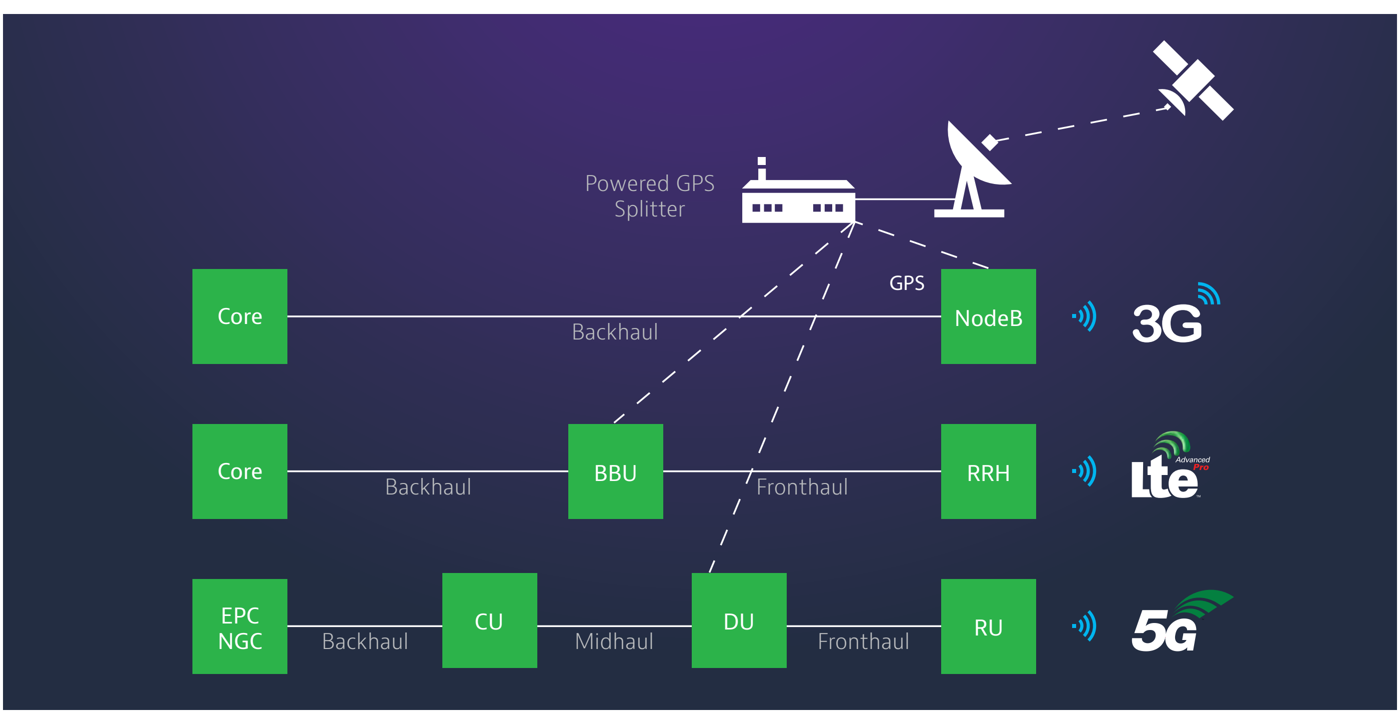



Figure 9 - GPS based synchronization. For 4G BBU and RRH are synced using CPRI

The time of day messages will still be received and sent over the air to UEs and the Distributed Units (DUs) which are the name of the controllers used in 5G networks. The DUs will also still use the 1 pulse per second (PPS) received from the satellite to stay frequency synchronized. However, for phase synchronization of overlapping cells, we need the network equipment to have access to the same time source, and the time of day messages from that source. For this type of synchronization, line of sight to multiple satellites is required. The same challenge is also present in a 4G network that uses LTE-TDD technology which also requires phase synchronization.

To fully understand the exact time of day at the satellite receiver, we need to be able to compensate for the delay between the time when the satellite sends the time of day message and when that message arrives at the satellite receiver. However, this becomes challenging because satellites are not stationary above us.

The challenge is handled as follows. All satellites periodically transmit an ephemeris. The ephemeris of a satellite is a mathematical description of its orbit. All satellite receivers calculate an accurate position of where they are. This calculation is called conducting a survey and uses the mathematical technique trilateration which is similar in concept to triangulation. Once an accurate position is calculated, in other words once the survey is complete, then the delay between the satellites and the satellite receiver can be computed to "correct" the time of day that it was received.

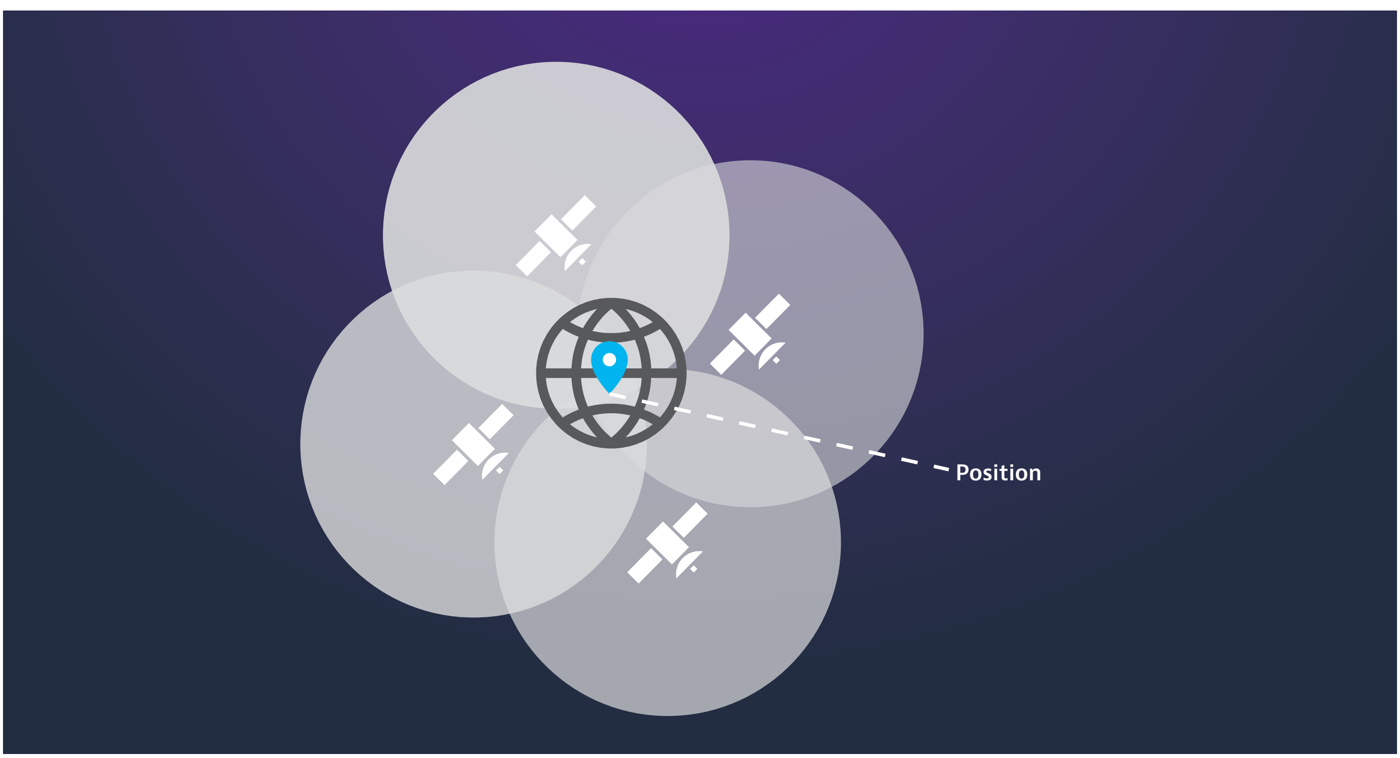



Figure 10 - GPS based synchronization

To accurately perform this calculation and establish an accurate position, a minimum of four satellites, as shown in Figure 10, is required. There are four variables to account for – longitude, latitude, altitude, and time, hence the need for four satellites. The longer a survey runs the more accurate the position calculated will be. The more accurate the position of the satellite receiver, the smaller the time error between cells and the lower the chance that overlapping cells will interfere with each other.

## Challenges for 5G Fronthaul

In 5G, synchronization for backhaul will be very similar to that of LTE; however, in the absence of a synchronous fronthaul, deploying satellite receivers at every RU will not be cost effective, especially for small cells, C-band radios, and mm-wave radios. We will still see satellite connections at the C-RAN hub location with tight timing controls out to the radios. Basically, timing and synchronization distribution is collapsed to work over Ethernet. In most cases PTP (IEEE 1588v2) will be used to distribute time of day (ToD) and SyncE will be used to distribute frequency so that RUs will be synchronized over Ethernet (Figure 11).

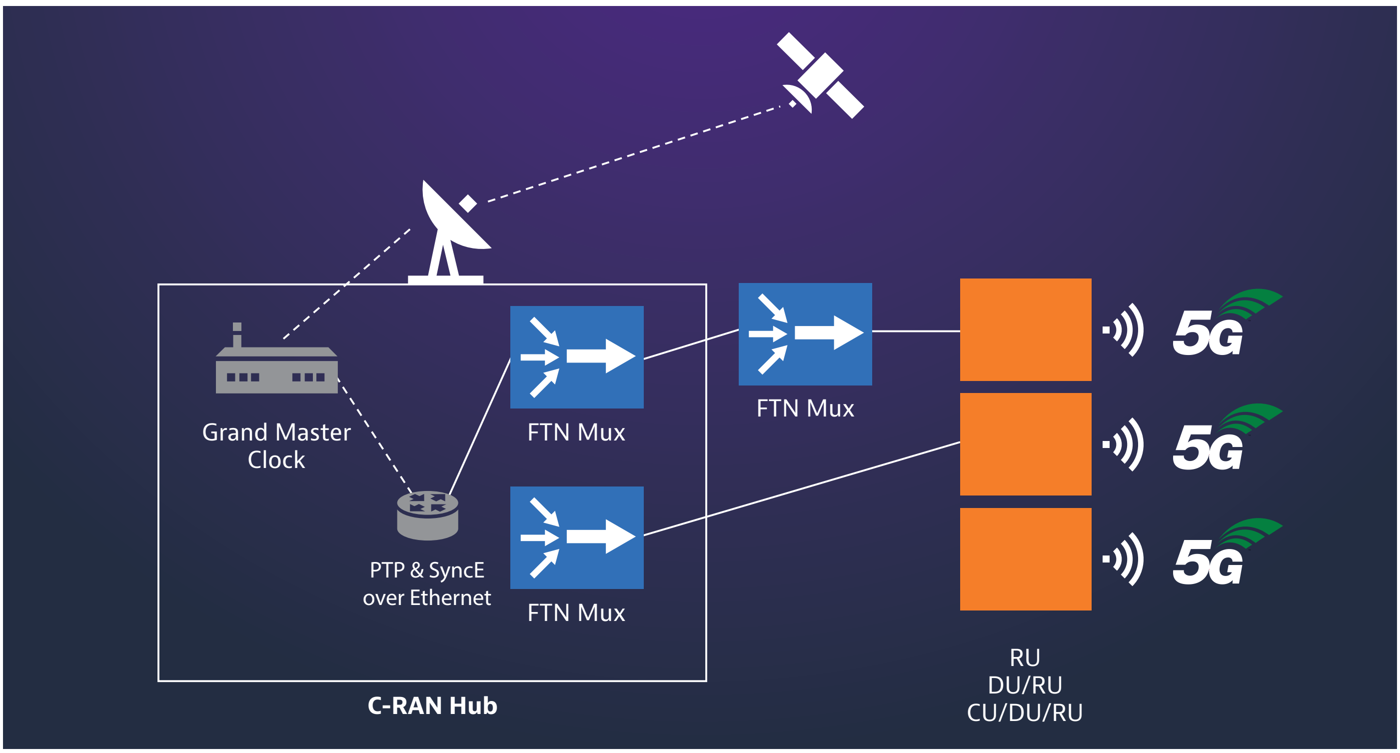



Figure 11 - Timing distributed over 5G-NR network

Multiple options to meet the stringent phase and time synchronization requirements exist, i.e., to choose the S-plane configuration. The intent is to ensure all nodes are synchronized to the PRTC source. The location of the source may vary depending on the network topology, cost, and application. By using a grand master clock synced to a satellite source and a combination of boundary clock and slave clocks, network nodes can be aligned to a common time and phase. Options include:

1. Install GNSS/GPS at all cell site. This can be expensive and may not be a practical option in some cases. (Figure 12, Case 4)

1. GNSS at some RAN or Transport sites with full timing support (FTS) from the transport network using PTP1588v2. Every node in the transport network must have a boundary or transparent clock. Careful placement of GNSS and reference clocks is required to cover the network within the timing budget (Figure 12 case 1 to 3)

Other options such as assisted partial timing support can also be implemented with appropriate consideration for the network topology and cost.

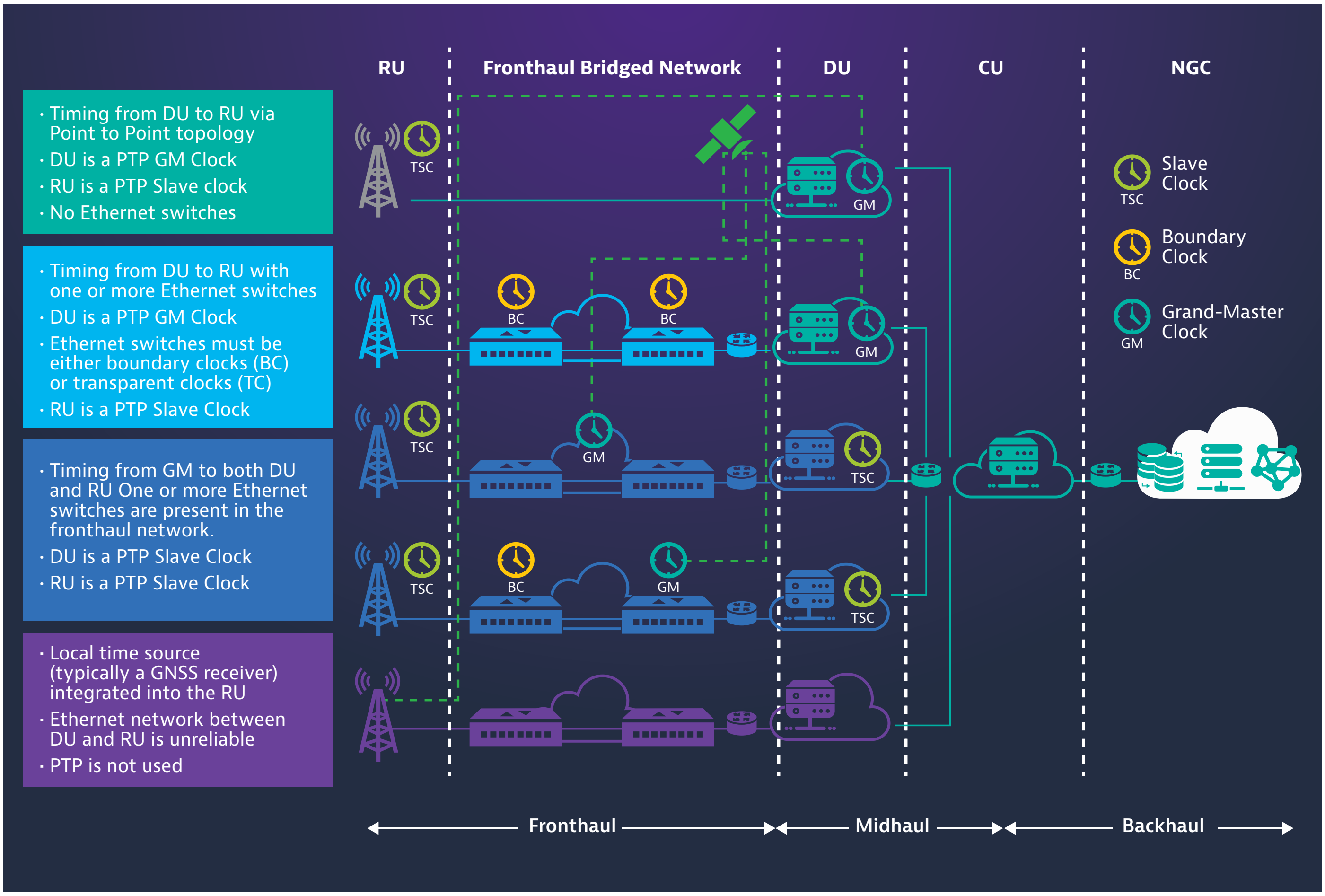



Figure 12 - Synchronization options over a 5G network

## TDD 5G NR Synchronization

As mentioned above, with TDD deployments, in addition to frequency and phase synchronization, to avoid intercell interference a compatible frame structure should be used between collocated networks with adjacent frequency assignments, or adjacent networks sharing the same frequency or adjacent channels. Essentially carriers must prevent simultaneous UL and DL transmission occurrence. I.e., at any given moment in time, either all networks transmit in DL or all networks transmit in UL adopting a single frame structure for all TDD networks involved as well as synchronizing the beginning of the frame across all networks. Refer to ECC Report 296 and its recommendations for more details.

To summarize, DL spectrum may leak onto the adjacent channels. For FDD, this is acceptable since UL and DL channels are separated by a guard band. For TDD, UL and DL share the same channel. Any DL spectral imperfection may thus create interference in the UL signal of the adjacent operator, especially when the two cells are at the boundaries of each other.

Hence, if two 5G networks operating in adjacent channels are not synchronized, an additional guard band of 25MHz, as well as extra filters on the emitters may need to be provisioned.

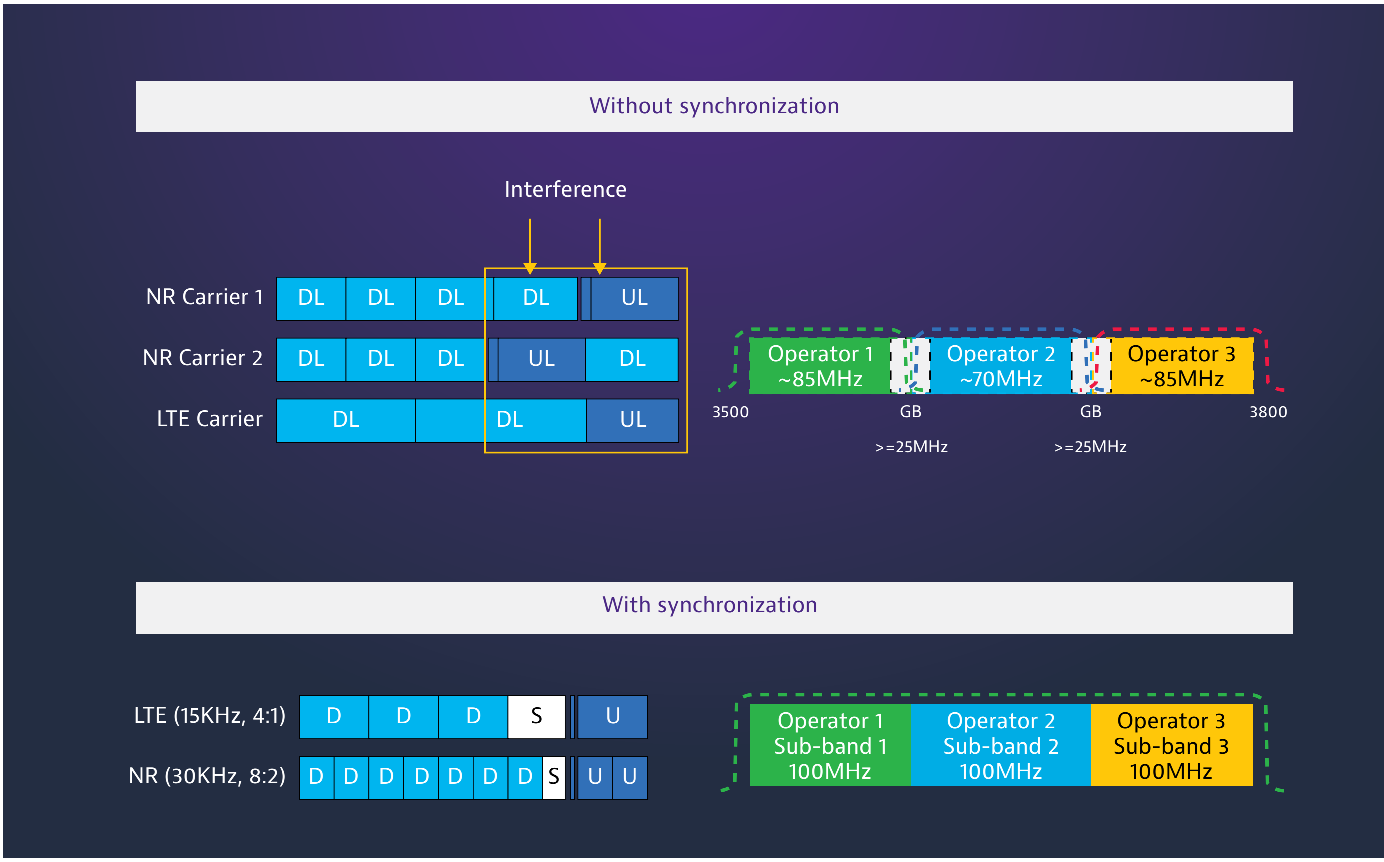



Figure 13 - Frame synchronization

## Testing Timing and Synchronization for 5G

Synchronization requirements are derived from several bodies, including the 3rd Generation Partnership Project (3GPP). 3GPP technical specifications 36.104/38.104 represent two key documents that describe base station radio transmission and reception requirements. More specifically, section 6.5 (Transmit signal quality) lists several requirements that are essential for synchronization network design including time alignment error (TAE). Some of those timing and sync requirements are summarized above in Table 3.

The VIAVI T-BERD®/MTS-5800 (100G) along with CellAdvisor® 5G (CA5G) can perform all required timing and synchronization test for all types of 5G networks. They measure throughput, delay, packet jitter, timing, and frame synchronization to ensure backhaul, midhaul, fronthaul, and air interface meet designed network specifications. For fronthaul test applications, the VIAVI T-BERD/MTS-5800:

- Generates and analyzes eCPRI signals (10/25GE)
- Generates/filters eCPRI sub-headers
- Performs one-way delay measurement
- Tests PTP/SyncE/GPS for synchronization
- Emulates PTP slave/master
- Measures Time Error, Wander, PDV, MTIE/TDEV
- Measures GPS Signal Strengths, Trails

### GPS test (GPS signal/satellite coverage test)

It is important to check GPS signal stability and suitability for the GPS antenna location at the time of installation, and periodically after installation as conditions around the site may have changed. The VIAVI T-BERD/MTS-5800 tests GPS signals using an integrated GPS receiver and provides the following results:

- Number of visible satellites
- Signal strengths
- CNO map spectrogram plots line of sight to satellites as they move around the orbit over time

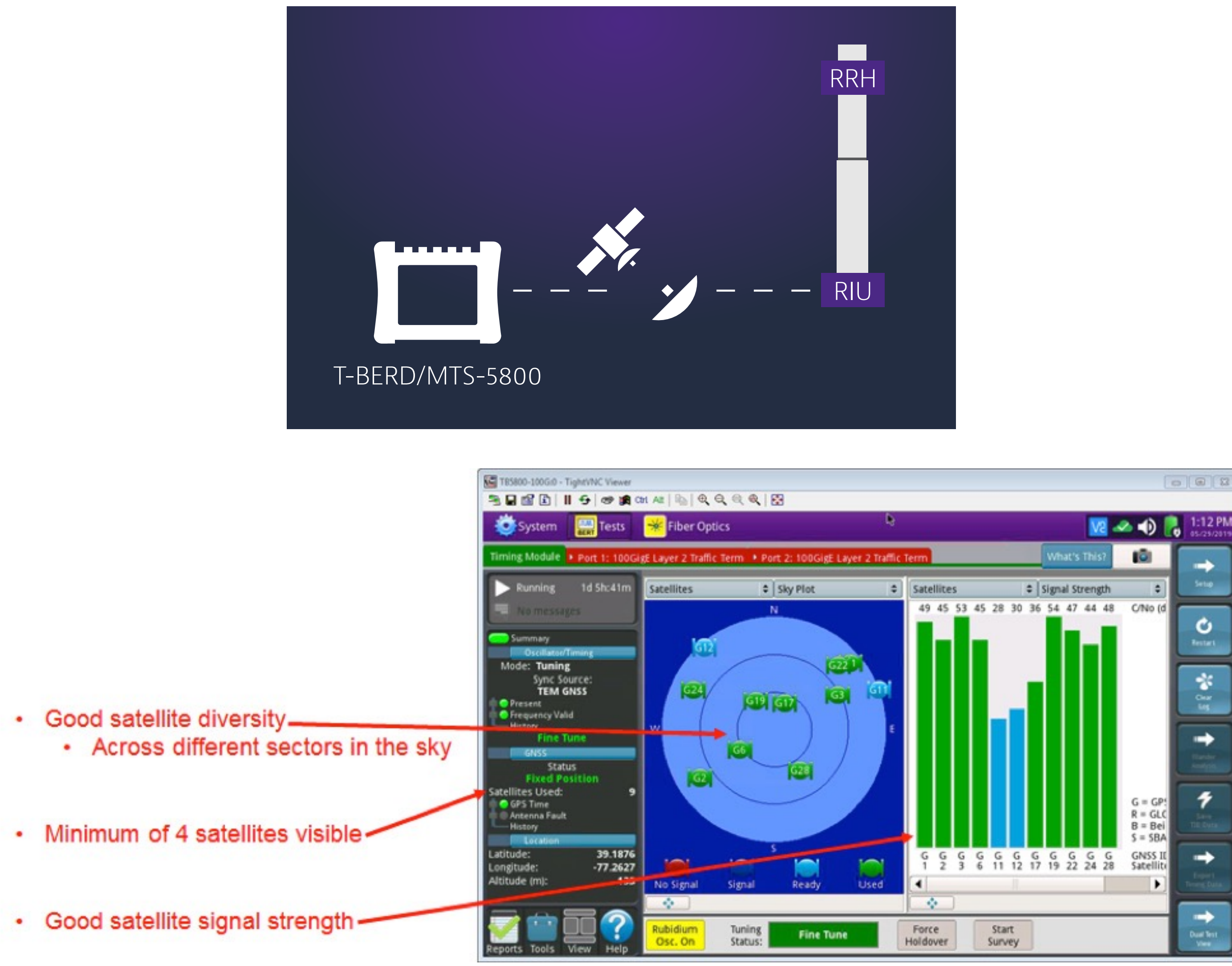



Figure 14 - GPS Test using VIAVI T-BERD/MTS-5800

### PTP Test (PTP timing error test)

As discussed earlier, wireless service is dependent upon reliable synchronization. For PTP to reliably work, the PTP slave needs to be able to connect to its assigned PTP grand-master and comply to PTP frequency profile network limits such as floor packet percentile. Additionally, PTP time/phase profile, needs to conform to the time error network limits. Using a VIAVI T-BERD/MTS, which works as a PTP slave, an engineer can check connectivity to the PTP grand-master and check whether timing error is within requirements by using a step-by-step guide.

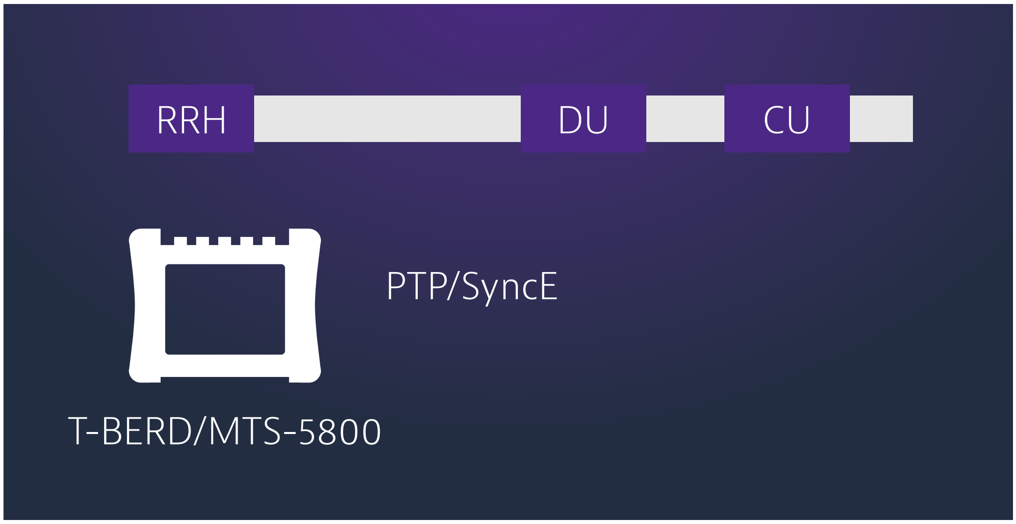



Figure 15 - PTP Check using VIAVI T-BERD/MTS-5800

### Validate Frequency and Time Error versus UTC Over the Air

Using a VIAVI CellAdvisor 5G, an RF engineer or a technician can quickly validate the over the air frequency and time errors, ensuring synchronization conforms to the +/- 1.5µs vs UTC. This can be tested for the adjacent channel network as well.

- Frequency Error < +/- .05 ppm versus GPS
- Time Error < +/-1.5µs versus GP

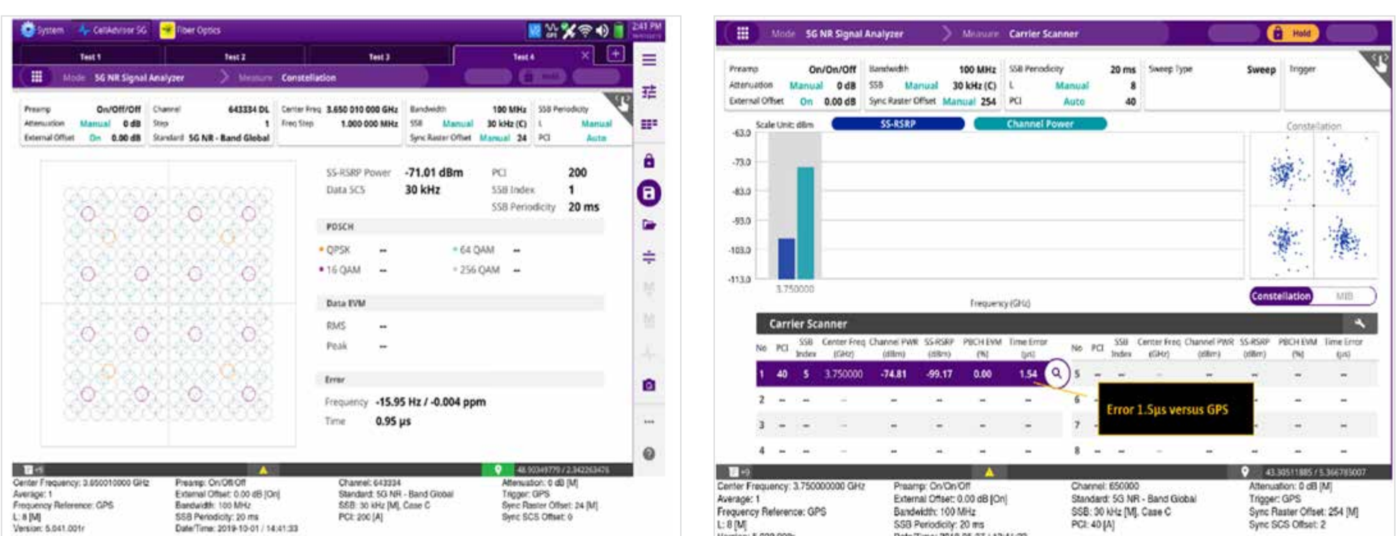



Figure 16 - Over the Air Frequency and Time Error measurement

### Validation of 5GNR Frame Format

To prevent intercell interference between adjacent networks, validating that adjacent networks conform to the agreed slot and frame formats is critical. Using a CA5G, service providers can easily validate frame format for multiple operators by making over the air measurements.

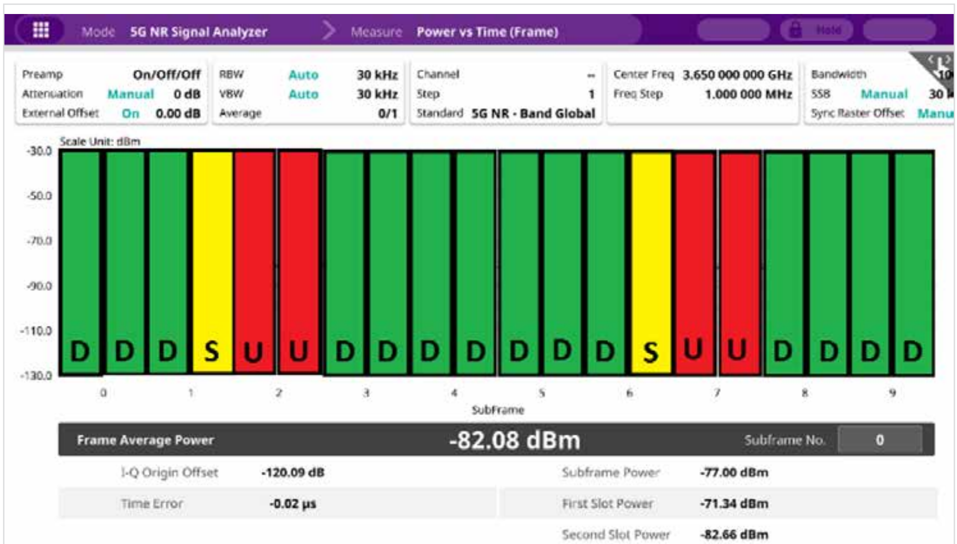



Figure 17 - Over the Air Frame Synchronization validation using a CA5G

## Identifying Synchronization Issue in the Field with CellAdvisor-5G—A Real-life Example

A service provider experienced RF performance issues related to handover failure, poor throughput, accessibility and retainability in a specific area of the network. The RF signal tested strong proving it was not a coverage issue. Unfortunately, the problem was present on all channels, and for both LTE and 5GNR technologies. VIAVI engineers were invited into the field to troubleshoot with the service provider RF engineering team.

Using the CellAdvisor 5G with NSA Signal Analysis to perform over the air tests revealed synchronization issues at one site. These sync issues, in turn, were causing poor performance not only in the immediate coverage area but also in the surrounding cells which were correctly synchronized. As shown in Figure 18, Physical Cell Identifier (PCI) 326, Timing Errors (TE) and Offsets are within specs, whereas neighboring sites with PCI 138 and 139 are completely outside the specification requirements.

A lack of synchronization, as found with this provider's site, results in lower QoS, which can cause lower user data throughputs, inability to perform proper handover from cell to cell, and in some cases, even prevent users from connecting to the network due to cross link interference caused by uplink slots interfering with adjacent cells slots.

Upon arming the RF engineers with this information, the service provider was able to identify the source of the synchronization issue and brought it to resolution quickly. Figure 19 shows before and after measurements.

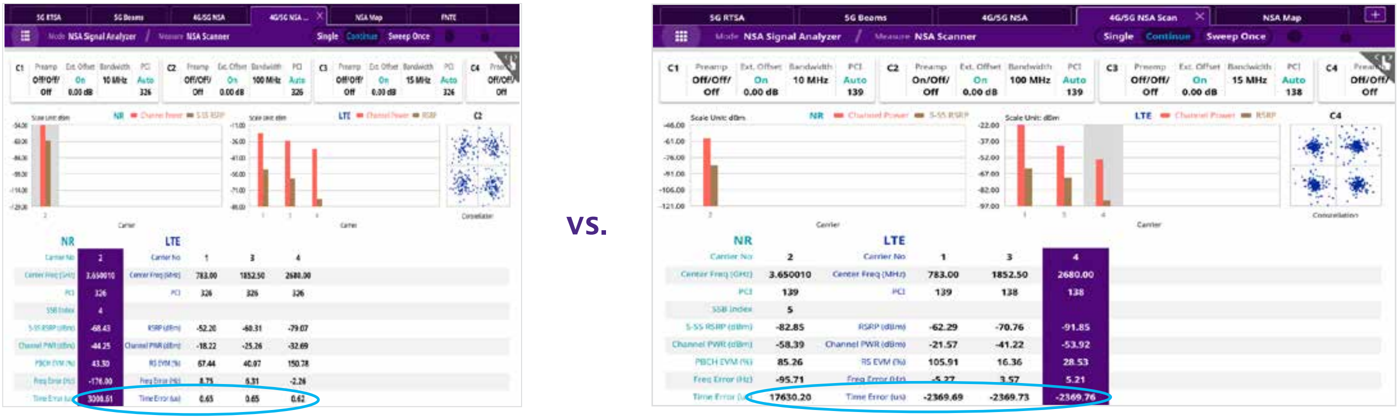



Figure 18 - Over the Air Timing Error measurements at two neighboring cell-sites using a CA5G

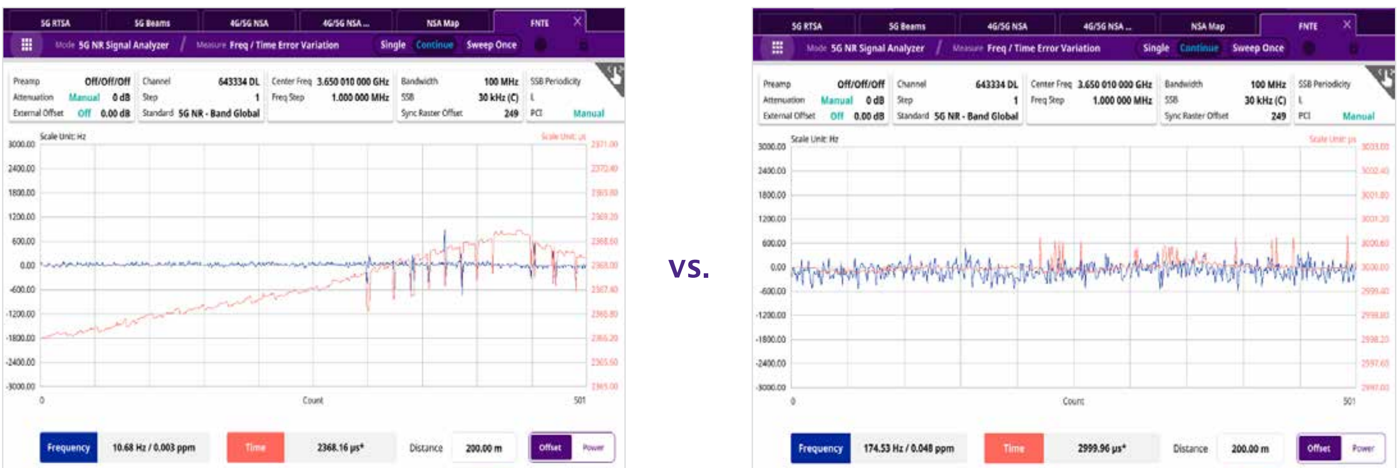



Figure 19 - Before and after timing and sync measurements using CA5G

## Conclusion

Synchronization is fundamental to the performance of a cellular network and the services it offers. Both 3G and 4G cellular technology required frequency synchronization primarily to prevent interference when cells overlap. However, 5G cellular technology and 4G LTE-TDD require phase and frame synchronization, with much stricter synchronization requirements. Further, the need for validation of timing error has become an essential test for cell site installation and maintenance. This holds true for slot and frame synchronization for TDD deployments as well.

VIAVI Solutions is the industry leader in test and measurement and offers the most comprehensive timing and sync validation solution. With the fully integrated VIAVI portfolio of cloud-enabled instruments and systems, software automation, and services for network testing, performance optimization, and service assurance, operators and their partners can be assured of a smooth network roll-out and sustainable network lifecycle.

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