VIAVI Solutions

White Paper

Satellite Synchronization is Critical to 5G Mobile Cellular Network Operation

Introduction

Synchronization in carrier networks has been in use forever, but because of its elevated role in 5G, it is now getting more attention. Mobile cellular networks must be synchronized so that towers (base stations) with overlapping coverage do not interfere with each other causing dropped calls or service degradation. The NodeBs used in Third Generation (3G) cellular communications rely on satellite communications for synchronization, as do the Baseband Units (BBUs) used in Fourth Generation (4G) cellular communications.

Since keeping networks in sync has been relatively straightforward for years, we tend to take it for granted. Over that time the principles of synchronizing networks have remained unchanged, even for terrestrial transport networks. In North America, most mobile network operators (MNOs) rely on the Global Positioning System (GPS) satellite constellation for synchronization which is owned and operated by the United States Government. Satellite antennas are present in telephony central offices as well as in most cell towers to receive the time of day messages and an accurately timed pulse every second.

The 5G Network Changes the Synchronization Requirements

With the advent of 5G cellular networks, the connection speed between the cell towers and the user equipment (UE) such as cell phones, hotspots, etc. is increasing considerably. Enhanced Mobile Broadband (eMMB) is the name given to connection speeds that support peak data rates up to 20 Gbps. This means that the radios will need to be closer to the users and more antennas will be required creating even more scenarios where signals overlap and interference could occur.

The latency, or delay, in getting messages across the network is decreasing. This is Ultra Reliable Low Latency Communications (URLLC) and enables other upcoming applications such as autonomous vehicles by facilitating communication between cars and between sensors. To bring this technology to fruition more radios and antennas will be required to shorten communication distances. More radios and antennas mean more overlapping coverage and greater opportunity for signal interference.

Lastly, the number of devices that the network is supporting is increasing exponentially. For the Internet of Things (IoT) to occur, massive Machine Type Communications – mMTC – must be supported by the 5G cellular network. This implies that many more sub-frequencies will be in use to support the large number of devices communicating which will in turn increase the opportunity for signal interference. In order to minimize and even avoid interference, the timing and synchronizations techniques used in the cellular network will need to evolve to support the new 5G requirements. The time of day messages and the timing pulse received from the GPS satellite constellation will also be used differently.

As shown in Figure 1 below, 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. 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 1PPS received from the satellite to stay frequency synchronized. However, the time of day messages will also have a second use. They will be used to keep overlapping cells phase synchronized to avoid interference. For this type of synchronization, line of sight to multiple satellites is required.

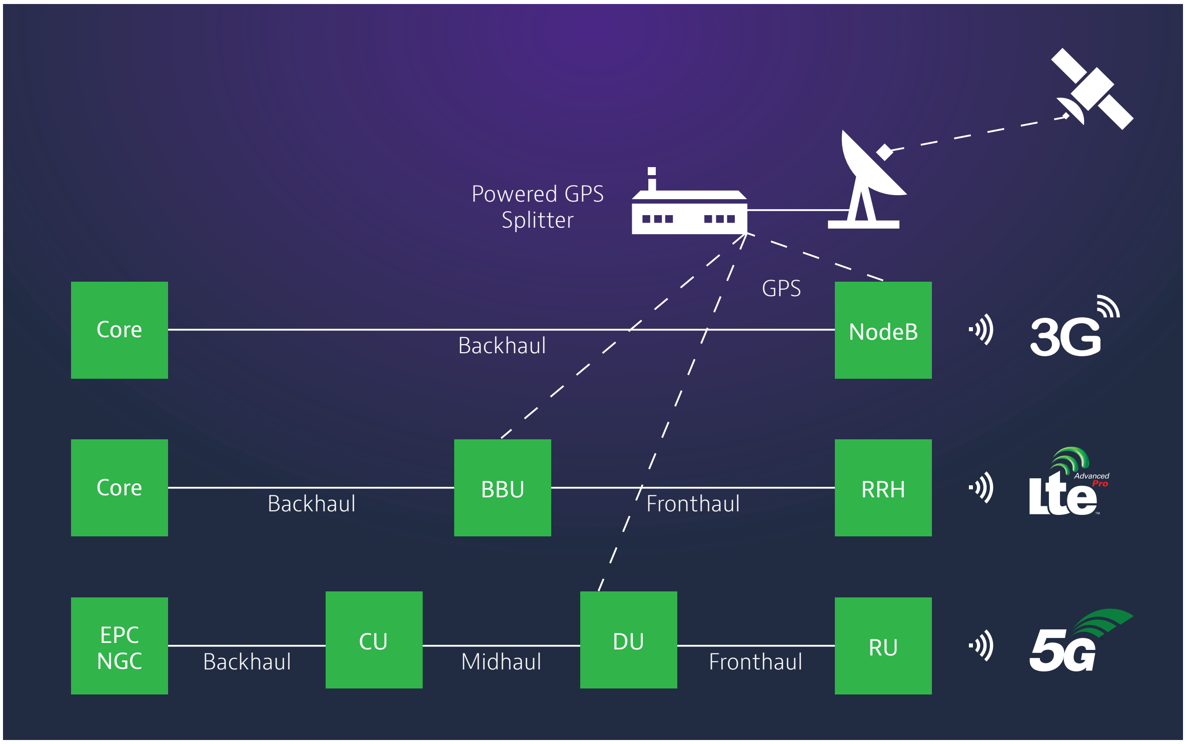

Figure 1

Frequency versus Phase Synchronization: What's the Difference?

Figure 2 below shows two clocks or signals that are frequency aligned but not phase aligned. The amount of time (T1) it takes from the start to the end of the full 360° waveform is identical between both clocks. The waveforms can start at different points in time.

Frequency Syntonization

- Syntonization is the adjustment of two electronic circuits or devices so as to operate at the same frequency
- In this example Clock A is frequency syntonized with Clock B. The time required for of a full 360° cycle to occur is identical.

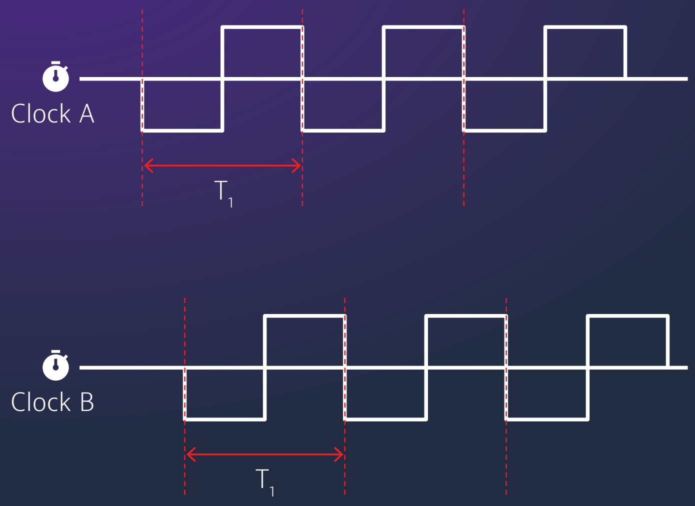

Figure 2

Figure 3 below shows two clocks or signals that are phase aligned as well as frequency aligned. Not only is the amount of time it takes from the start to the end of the full 360° waveform identical between both clocks, but they both start at the same time and end at the same time.

Phase Synchronization

- In the example below Clock A is phase and frequency synchronized with Clock B. The time required for a full 360° cycle occurs is both identical as well as it starts at the same time.

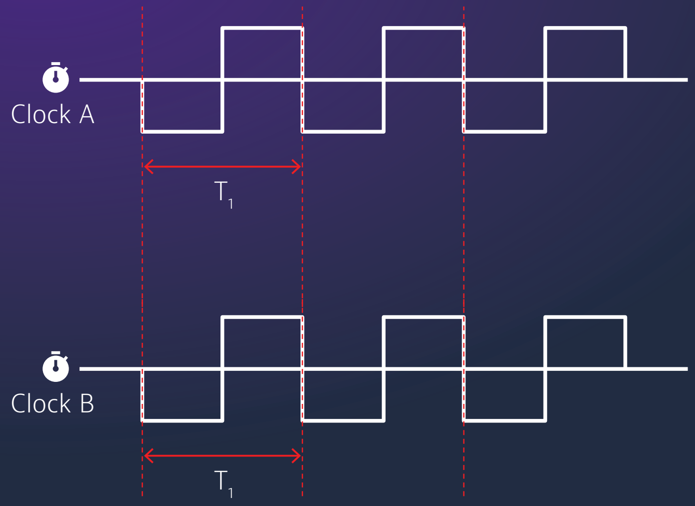

Figure 3

Phase Synchronization is Achieved with Time Synchronization

In the 5G network, if we need to phase synchronize overlapping cells, we need the network equipment to have access to the same time source. The same challenge is also present in a 4G network that uses LTE-TDD technology which also requires phase synchronization. In the United States (US) this time source is the Global Positioning System (GPS) satellite system. This implies all equipment needs to have the same concept of a shared global time. If all equipment knows the accurate and precise time of day then everyone can phase align their transmissions.

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 moving and 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 a mathematical technique called trilateration which is similar in concept to triangulation. Once an accurate position is calculated, in other words once the Survey is complete, then you can compute the delay between the satellites and the satellite receiver to "correct" the time of day that was received.

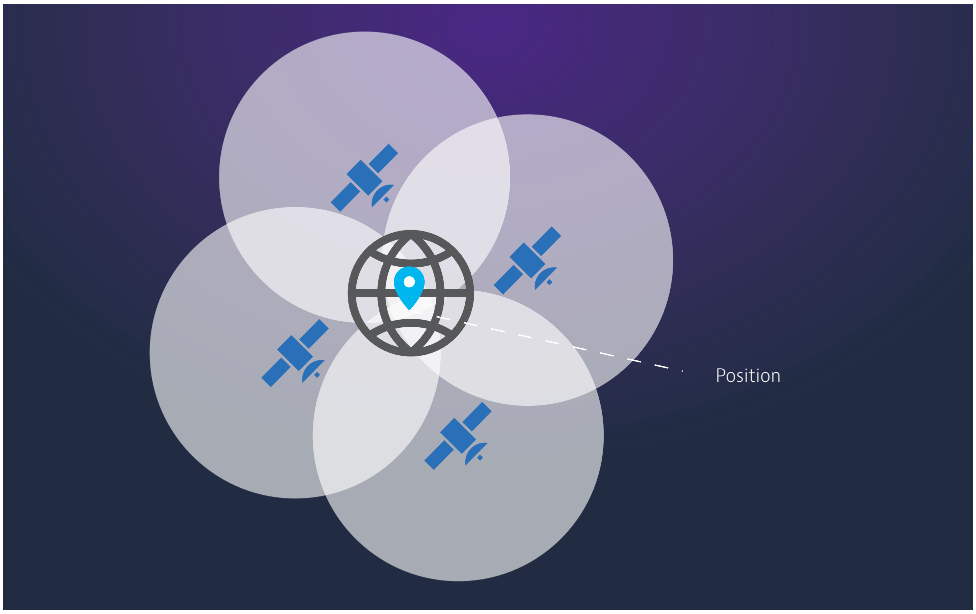

Figure 4

To accurately perform this calculation and establish an accurate position, you need a minimum of four (4) satellites, as shown above in Figure 4. There are four (4) variables to account for – longitude, latitude, altitude and time, hence the need for four (4) 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.

Satellite Assisted Synchronization

There are no specifications that govern the amount of time that four (4) satellites must be visible to a satellite receiver in a 5G network in order to complete a Satellite Survey that is sufficiently accurate for use for synchronization applications. Different equipment vendors will have different requirements based on their hardware and the algorithms they use.

Additionally, the location of the satellite antennas and receivers will vary. This means that in locations where satellite signals could be blocked, reflected and/or distorted such as in the centers of large cities with skyscrapers, the ability to receive a signal from four (4) different satellites will be challenging as shown in Figure 5. Conducting a Survey under these "urban canyon" conditions will require longer Satellite Survey times and/or more relaxed position accuracies if the network topology permits.

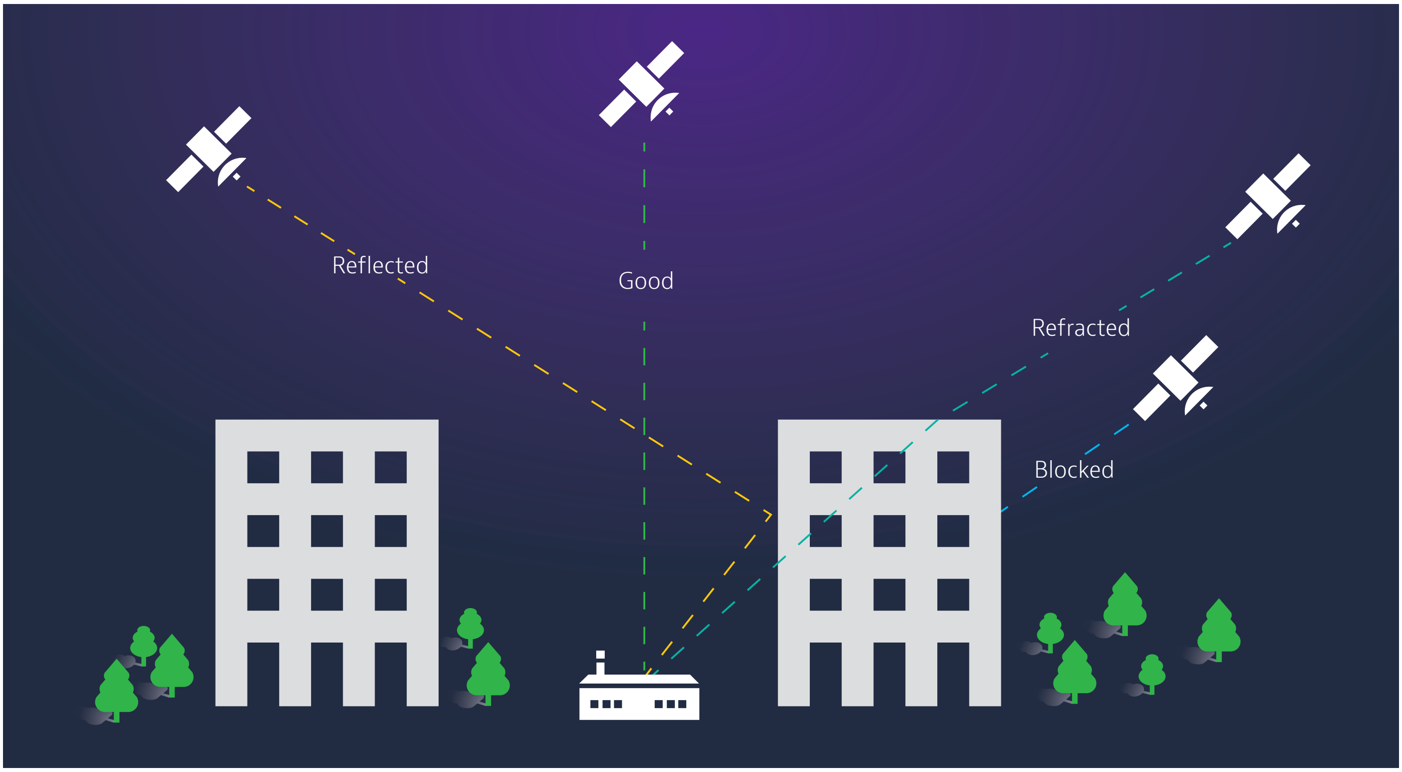

Figure 5

There are however numerous 3GPP and ITU-T specifications for maximum time error at different points of the 5G network as well as how to perform these measurements. These standards can be used to drive the level of position accuracy required at a specific location to ensure that time accuracy is not compromised to a point where synchronization is impossible.

Avoiding Synchronization Related Interference in 5G Networks

If existing 3G and 4G satellite antenna installations are going to be reused and shared by the 5G network, then it makes sense to ensure that at least four (4) satellites are in continuous view over a 12-hour period in order to accommodate for different vendor equipment requirements. Remember that 3G and most 4G networks need only one satellite in order to be able to frequency synchronize while 5G networks need four (4) satellite to phase synchronize. The one exception would be 4G LTE-TDD networks which need to use phase synchronization in order to limit end-to-end time error under 1.5µs.

Why a 12-hour observation period? The typical orbital time of a GPS satellite is a little over 11 hours and 57 minutes. If you can continuously see four (4) satellites for 12 hours, then you know you will be able to see that many all the time. This will guarantee that a satellite receiver embedded in any vendor equipment will be able to run a Satellite Survey however long is needed until it's requirements are met.

Figure 6 below shows a Carrier to Noise Density Ratio (CNO) Map Spectrogram from a T-BERD/MTS-5800. The color of the quadrant in the sky map shows the average CNO Signal Strength measured from a satellite in the quadrant. The higher the number – in this case the greener the quadrant, the stronger the signal that is being received. Since this view is taken from a roof mounted antenna, most of the map is vibrant green. The black on the map is a sign that no satellites at all were measured in these quadrants.

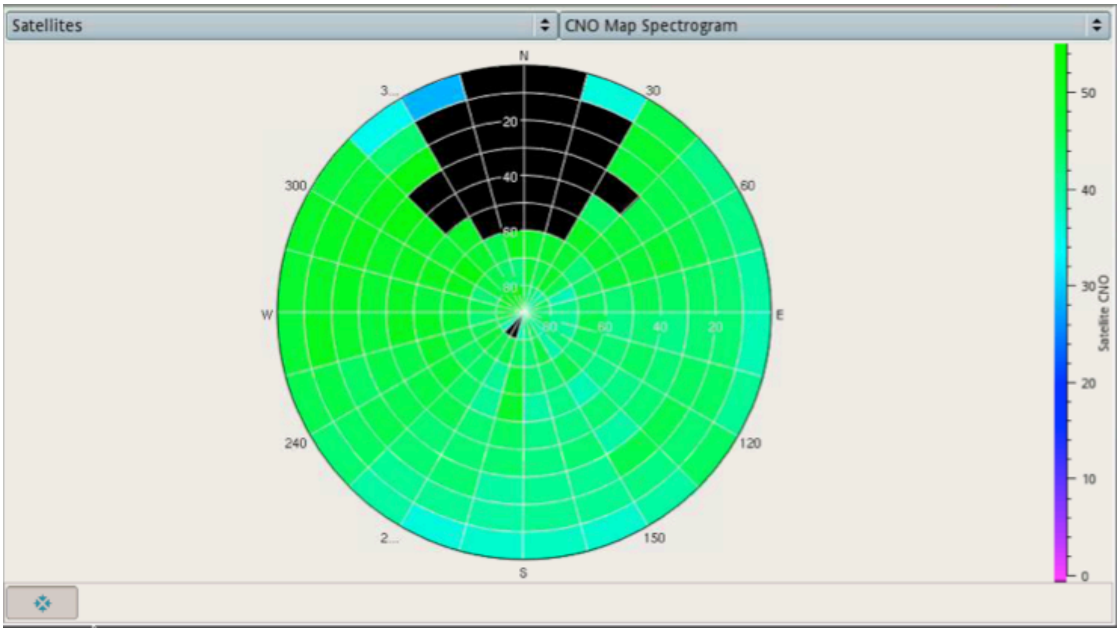

Figure 6

For troubleshooting, the ability to pull up a quick sky plot and ensure that there are no obvious obstructions is ideal. By looking at a sky plot, and separately looking at a CNO signal strength bar graph, anyone can easily establish where an obstruction may reside or where a weak satellite signal is present.

Be mindful that weak satellite signals may be a sign of an obstruction. A weak signal is typically found where the signal received is either being refracted through an object or reflected after bouncing off one or more objects. Both refracted and reflected signals affect the accuracy of the Satellite Survey calculation.

Conclusion

Even though different generations of cellular technology use satellite constellations such as GPS, the way these are used, and the accuracy required by the technology varies by generation. Both 3G and 4G cellular technology mainly require frequency synchronization to prevent interference when cells overlap. As a result, line of sight to one satellite is enough to receive a time of day and 1PPS signal.

However, 5G cellular technology and 4G LTE-TDD require phase synchronization to make the advanced modulations and techniques work without interference when cells overlap. Consequently, time error between different parts of the network is important because time error leads to phase synchronization problems. In turn, to reduce time error, satellite surveys that establish extremely accurate positions are required.

VIAVI Solutions

Contact Us **+1 844 GO VIAVI**
(+1 844 468 4284)

To reach the VIAVI office nearest you,
visit viavisolutions.com/contact

5g-satellite-synchronization-wp-maa-nse-ae
30190924 900 1019