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Timing: a critical issue for mobile networks

White paper

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For today's mobile networks, everything must be 'right on time' – literally. The issue of synchronisation – aligning the frequency, time of day and phase of network equipment clocks – is becoming increasingly challenging. Radio Access Networks (RANs) are continuing to evolve so that they can support higher data rates, greater coverage and better use of the spectrum. This means that synchronisation information needs to be delivered cost-effectively, reliably and with great precision.

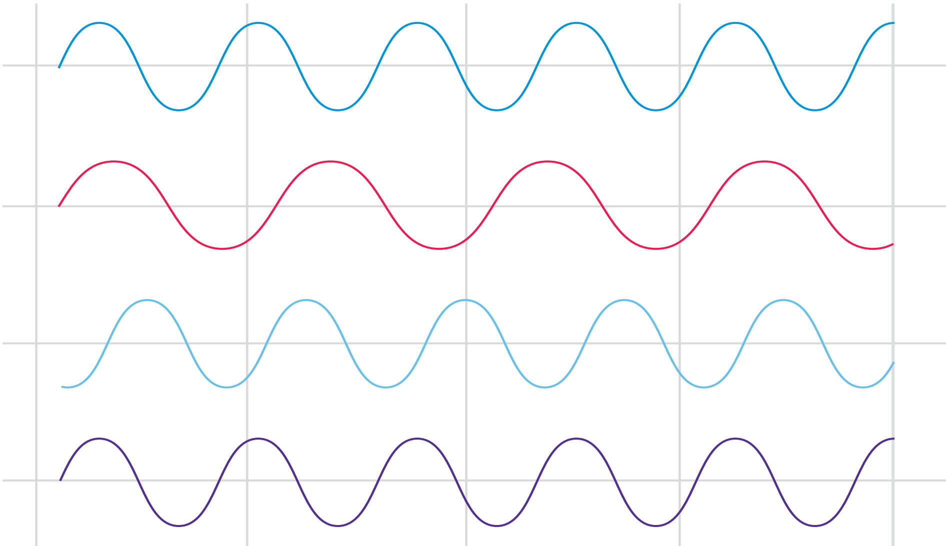
Network synchronisation involves the alignment of network equipment clocks to three parameters:

- **Frequency** – the same repeating interval
- **Time** – the same time of day
- **Phase** – the same phase alignment.

As a simple analogy, if two household clocks tick at exactly the same rate, they're frequency synchronised. The second hands may be out of step with each other but this interval always remains constant. If one runs slower or faster than the other, so that they are sometimes in step and sometimes not, they aren't frequency synchronised. If the second hands are always in step with each other, they're phase-aligned. This is true even if the clocks say completely different times. If they say exactly the same time, they're also time synchronised.

Base stations in mobile networks have always had very strict frequency synchronisation requirements. This is also known as **syntonisation**, and it's ambivalent to both time and phase. Various international standards specify the frequency limits within which mobile technology is allowed to work. If these limits are exceeded, several things could happen:

- Mobile phones might not hand over between cell sites
- The mobile phone might not connect to the network
- In extreme cases, it could cause interference to another provider's radio spectrum.

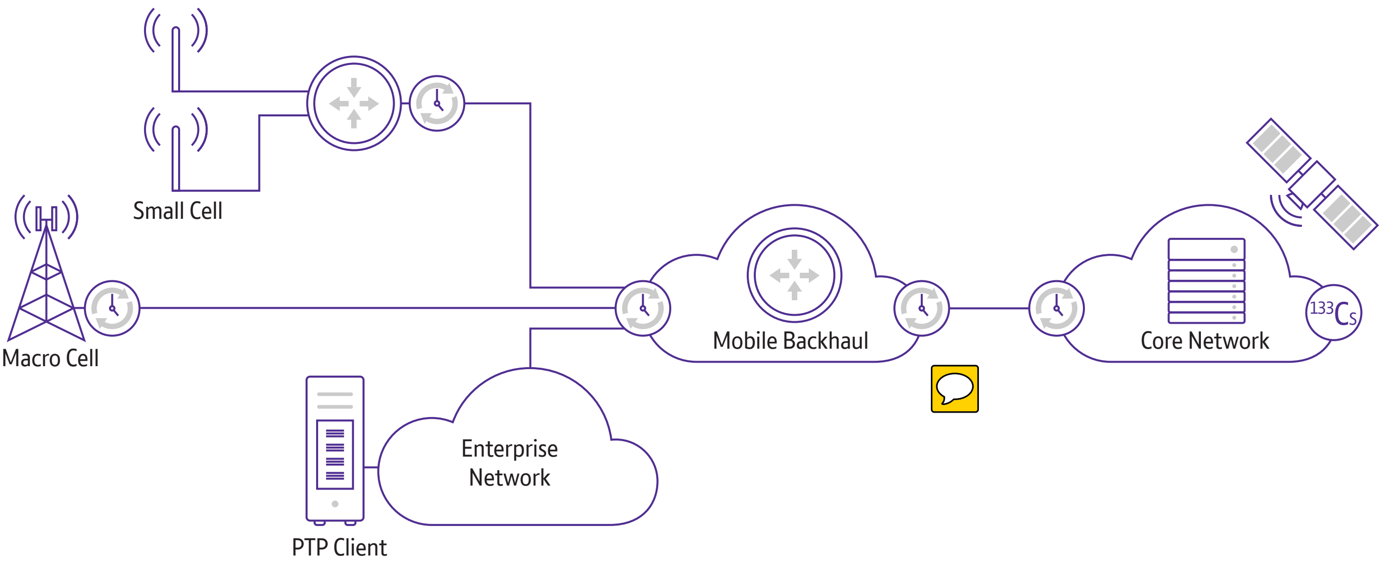


Waveform synchronisation

Previously, network technology based on Time Division Multipexing (TDM) allowed the transportation of frequency synchronisation at the physical layer, which was by its nature synchronous. However, the evolution towards packet and Ethernet-based networks (which are naturally asynchronous) required additional features, including a facility to transport timing information in packets rather than relying on the physical layer itself. Backhaul solutions such as Managed Ethernet Access Service (MEAS) added these capabilities to the network technology.

This type of approach has served the industry well for many years and allowed mass migration to Ethernet backhaul. However, several new features within the mobile standards mean that it's no longer sufficient to meet the needs of MNOs. There's a new requirement for time and phase synchronisation that will enable new advanced networking features and will allow for the use of new spectrum.

In existing frequency synchronisation solutions, signals are aligned so that they have the same repeating interval (frequency). This is needed because eNodeB oscillator accuracy alone can't keep all of the base stations in sync – and mechanisms such as inter-cell handover rely on tight frequency synchronisation in order to work successfully. Each eNodeB clock now needs to be locked to exactly the same Time of Day (ToD) and the signals must be aligned to the same phase angle. As a result, the waveform transitions on the air interface in adjacent cells will happen at the same time and the signals can then, for example, successfully be added together by the receiver without interfering with each other.



Mobile Network Operators (MNOs) therefore need reliable and robust networks that can meet the stringent frequency and phase synchronisation accuracies required by Long Term Evolution – Time Division Duplex (LTE-TDD) and LTE-Advanced (LTE-A) technologies. The networks must also be able to handle any challenges efficiently – such as high packet delay variation and delay asymmetries across the mobile backhaul network. In addition, MNOs need innovative solutions that will minimise the challenges of footprint and power consumption faced by the small cell base stations that are used in the RAN.

In particular, timing for mobile networks is becoming an increasingly critical issue. This is partly because the degree of accuracy needed is changing as new, enhanced services are introduced. Most current networks aren't using the advanced capabilities of the 4G environment yet: just the standard Frequency Division Duplex – LTE (FDD-LTE). To maximise the value of these networks, new services and LTE-TDD and LTE-A are needed. This changes the character of the network synchronisation. Instead of just needing accurate frequency, the network now also needs time accuracy. As mobile networks evolve, with the arrival of 5G and beyond, these requirements will only become more stringent and operationally critical.

There are various ways of meeting the new synchronisation needs, but there are two main methods to choose from. These involve either using individual Global Navigation Satellite System (GNSS) devices at each base station or using a network to provide the timing for the applications.

Some vendors have also introduced proprietary methods for providing synchronisation. These include proprietary algorithms for passing time around small areas; a listening mode for recovering clocks from other sites; and relaying clocks from site to site. Without standardisation, each method would need extensive validation testing before being used.

Application	**Radio Interference**		**Backhaul**	
	Frequency	Phase	Frequency	Phase
LTE (FDD)	±50ppb	n/a	±16ppb	n/a
LTE (FDD) (large cell)	±50ppb	±5µs	±16ppb	±1.1µs
LTE (FDD) (small cell)	±50ppb	±1.5µs	±16ppb	±1.1µs
LTE-A MBSFN	±50ppb	±1 to 5µs	±16ppb	±1.1µs
LTE-A CoMP	±50ppb	±500nsec to 5µs	±16ppb	500nsec - ±1.1µs
LTE-A eICIC	±50ppb	±1 to 5µs	±16ppb	±1.1µs

The current requirements for the new services being introduced, with limits for the Radio Interference on the Air Interface and the Backhaul Limits needed to achieve these.

Global Navigation Satellite Systems (GNSS)

These include various systems that can be accessed in order to recover accurate time signals. The four main options currently used for timing are GPS, GLONASS, BeiDou and Galileo. Primarily designed for navigation, the systems use an accurate time within the transmitted signals that provide the location service. This is then used to provide highly accurate time services. The GNSS uses satellites thousands of miles away. By the time the signals reach the earth, they are low-level, so the right environment is essential for receiving them. GNSS now plays a vital role in providing timing for communications systems worldwide.

GNSS at every cell site

One timing method involves installing an individual GNSS antenna at every cell site. The antenna will receive one or more GNSS services and will pass this time information to the macro or small cell via the manufacturer's receivers and oscillators. Having an operational GNSS at every site gives a traceable feed that can be used to provide the timing for any service that needs it. Most cell site manufacturers will offer this as a timing solution. By adding the installation and connectivity, this can be perceived as a very simple design solution that ensures the necessary time accuracy at the cell sites. However, there are some potential issues (discussed below) that should always be considered in longer-term network architecture designs. GNSS will always be an important part of an overall solution. However, if an MNO is relying on GNSS without any backup, this is a potentially vulnerable single point of failure. Another consideration is that the costs for each site and ongoing maintenance will increase significantly with the introduction of GNSS at every location.

With all GNSS installations, it's important to consider the surrounding environment. The area around mobile base stations has numerous, high-level radio frequency (RF) transmissions, and as more spectrum becomes available, the amount of interference will increase. However, if no other methods of timing are available, this might be the only way to get the timing accuracy required to the edge of the network. The difficulty lies in providing a 'one solution fits all' remedy. In reality, this isn't possible with GNSS, as every site has a different environment. GNSS won't always work at every location, so a backup solution should always be planned.

If GNSS is used at the cell site, the GNSS antenna must be installed correctly and sited so that the impact of any RF interference is minimised. One of the main issues with GNSS at the cell site is poor installation, as it isn't always possible to get a clear view of the satellites.

Therefore planning for each GNSS is important and there should be some form of regular maintenance checks on the GNSS to ensure continued operation to the correct quality levels in the changing environment of a cell site.

There will be some places where the cell sites can't use GNSS. This isn't a big issue for larger tower sites. However, with the move towards denser networks and tighter time requirements, it won't be possible for some small cells to receive GNSS. This issue can be partially resolved by introducing much higher quality oscillators at the edge of the network to support those times when there is poor coverage, although this would also increase the cost of a GNSS installation.

It should be noted that holdover for phase is a major change from holdover for frequency. Oscillators that could previously provide sufficient holdover for tens of days for frequency will only be able to maintain phase for a small number of hours

The 2018 UK government Blackett report, '**Satellite-derived Time and Position: A Study of Critical Dependencies**' suggests that reliance purely on GNSS for network timing could impact network timing resilience within telecommunications networks. The recommendations in the report need careful consideration for network design, deployment and timing resilience for MNOs.

GNSS interference can be caused by many events. These include accidents (e.g. lightning strike destroying a GNSS antenna); a targeted GPS interference attack; or satellite constellation operational problems. The report states that the first line of defence against GNSS interference is a resilient architecture with diverse network routing to high-stability atomic clocks in the core of the network and localised holdover at the edge. In the future, multiple sources of time will be required for 4G/5G services.

Access to various GNSS signals (GPS, GLONASS, GALILEO, BEIDOU etc.) is now possible, giving a better level of service. However, the GNSS products often need to be updated. This is difficult with unmanaged GNSS - because with more than 10,000 cell sites, each site would need to be visited every time an update is needed, driving up costs.

GNSS interference

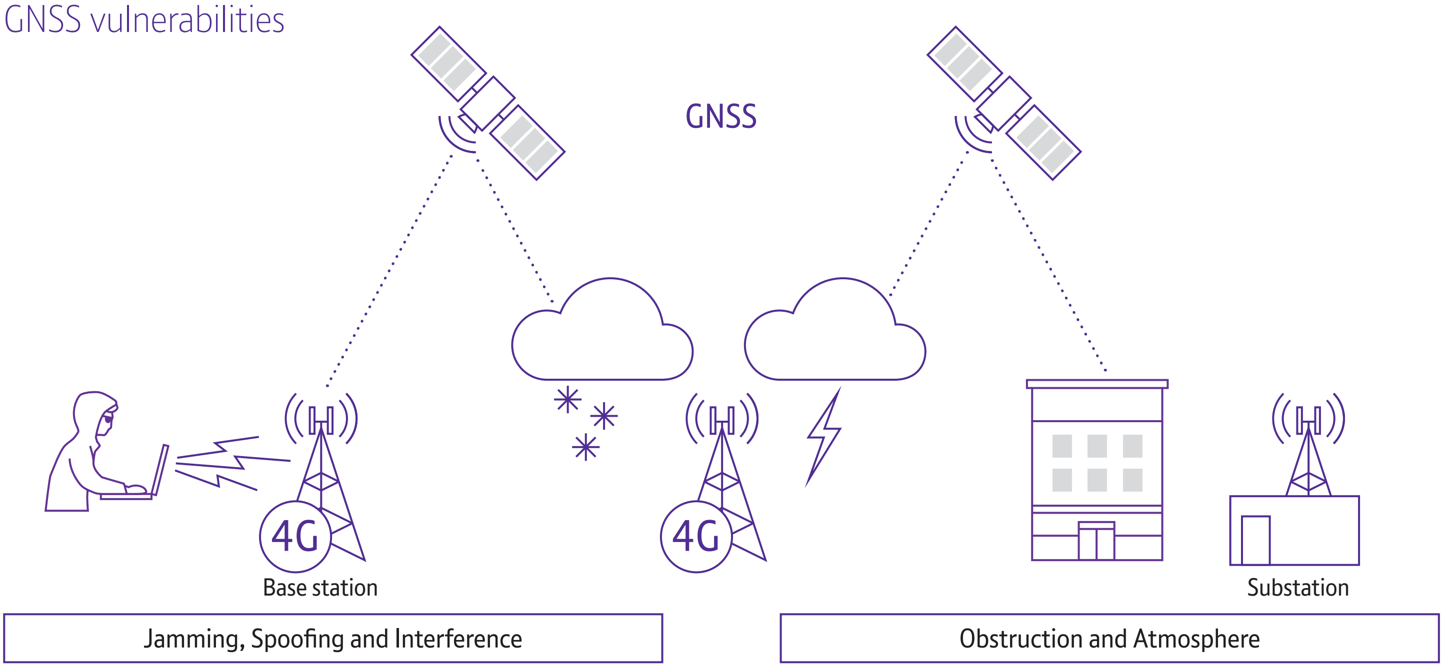
Most current GNSS systems used for timing only use the L1 C/A band. Adding other bands such as L2 can reduce susceptibility to interference. However, these receivers are currently too expensive for large commercial roll-outs.

GNSS interference can be either intentional or accidental. There are two recognised issues for GNSS installations, known as jamming and spoofing.

Jamming is simply a transmitter that produces a strong signal in the L1 band (approximately 1575MHz) that blocks the GNSS signal. This can be intentional (for criminal or security reasons) or accidental (where systems generate L1 band signals through faulty equipment or poor set-ups).

Spoofing is usually intentional and occurs when GNSS data is sent to change the location and/or time of a local area. It can also occur if a specific GNSS constellation has an incorrect time set for a particular sector. Spoofing will usually be noticed if the correct checks are in place - such as monitoring from multiple feeds to see if there's any change in the various times for the different areas. If a clock shows a time discrepancy outside specified levels, it's likely to be incorrect. However, with local GNSS there are often no other sources that can be used for comparison purposes.

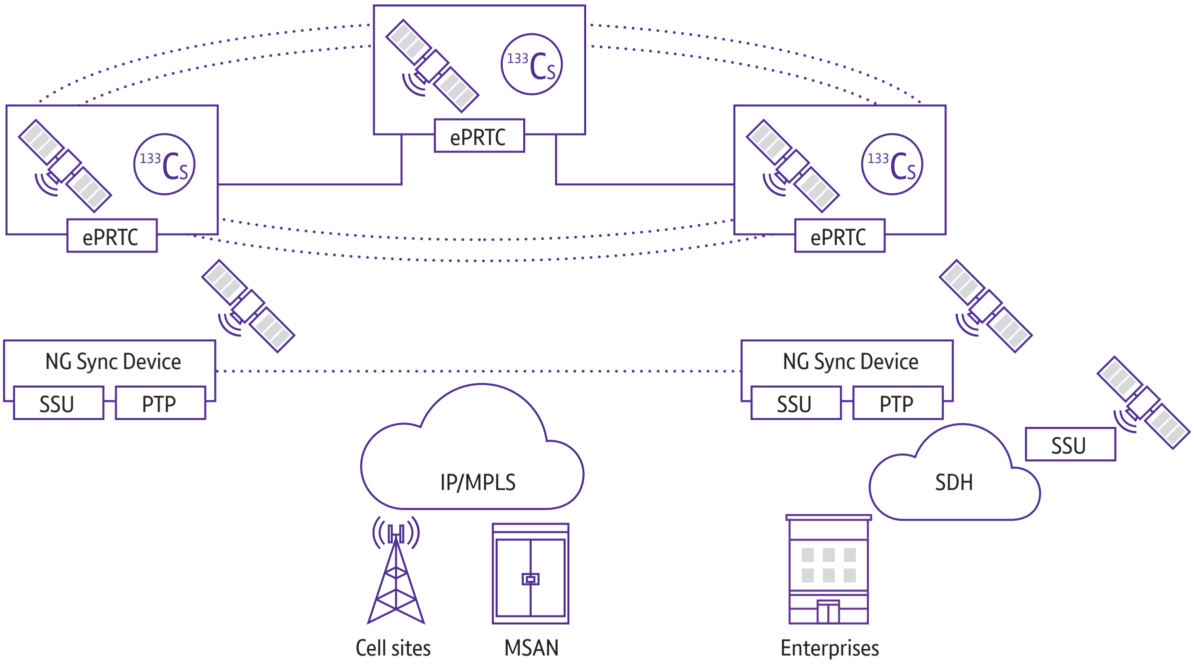
GNSS vulnerabilities



GNSS outages can have catastrophic impact on critical infrastructures

- Jamming can disturb GNSS signal
- Spoofing with faked signal
- No clear sight by weather and obstruction
- GNSS failure

Network-based timing



The standards provide a wide range of solutions that can be used to ensure consistent delivery throughout a network. Core PRTCs (Primary Reference Time Clocks – ITU-T G.8272 – 100nS) and ePRTCs (ITU-T G.8272.1 – 30nS) can provide new levels of accuracy for timing. High-quality caesium clocks can give long holdover times and ensure that time accuracies can be maintained during any outages. The timing solutions in the network core now use multiple sources for time. They need to provide the time as TAI (Atomic Time) for all IEEE1588 solutions. This is often achieved through a combination of caesium, GNSS, network feeds and local, high-quality oscillators.

Network phase time delivery

Over the past few years, there's been a lot of activity in the various standards bodies (supported by technical experts from vendors and operators), which have been trying to find the best way to deliver highly accurate time services. This has resulted in some highly evolved standard delivery mechanisms for transferring time across the network. Time delivery begins with a number of key sites in the core that generate time to an enhanced level, with ePRTC clocks being allowed a maximum drift of 30nS from the Co-Ordinated Universal Time (UTC). This is achieved through a combination of GNSS, caesium and network back-up feeds to ensure the time integrity of the network.

With these core nodes in place, time needs to be transferred across the network to the delivery points with the minimum impact. Core optical transmission techniques enable the time to be delivered over long distances with minimal errors.

ITU-T Standards for Network Timing

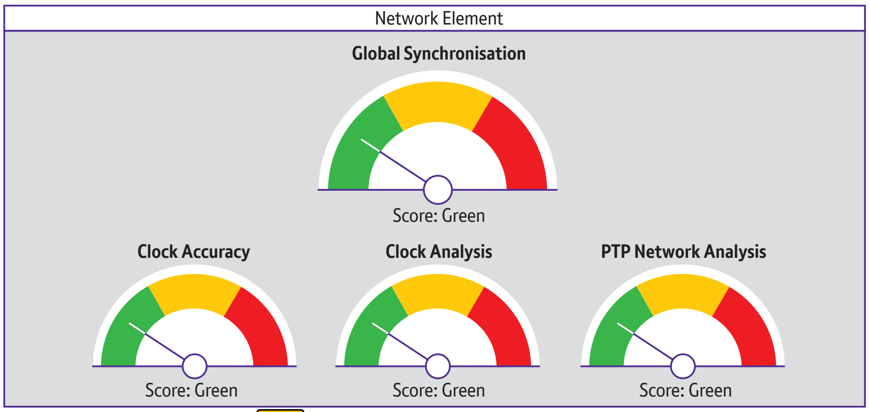
The International Telecommunication Union has developed several recommendations for the best way to transport time and frequency over current networks. These include ones for Precision Time Protocol (PTP) and Synchronous Ethernet (SyncE). The main recommendations are within ITU-T G.826x for frequency and ITU-T G.827x for Time/Phase.

Final timing deliveries are then passed over a synchronisation-aware network in the local access layer. These networks can provide minimal time errors per element by using boundary clocks or transparent clocks. A correct network design gives a very robust and repeatable solution for all delivery points across the network.

The key is to manage the error budget through the network to ensure the delivery of the required services. Designing networks to provide a minimal Time Error allows successful delivery to the cell sites.

Continuous Monitoring

The introduction of a solution that provides continuous monitoring of the network feeds will also give a network-wide view of the synchronisation at all times. There can be some variations in the transmission of time through the IP network, especially if traffic loads increase or there is an issue with the equipment. Monitoring strategic points in the network enables potential errors to be identified before they occur, so that any network changes or equipment issues can be sorted out proactively.



Summary

In summary, phase time will become increasingly critical for MNOs as they seek to offer the enhanced services of 4G and the severer requirements of 5G. There are currently two main ways of providing sufficiently accurate timing to cell sites: either a local GNSS at each site or network-based timing. However, another useful alternative could be a hybrid of these two solutions, depending on network availability and location.

The advantages of using GNSS at the cell site are that it's a simple and quick solution that can prove very effective in consistent installations and environments. However, MNOs will need to address various potential vulnerabilities in the network operation.

In comparison, network-based timing is consistent (as the same solution is used for all of the network) resilient (as it uses multiple locations and sources to provide synchronisation) and scalable (and smaller sites can benefit from the higher levels of security in the network). As new features become available or when fixes are needed as networks change, these can be rolled out easily across the simplified network.

Another advantage is that only one design is needed for different locations or environments. Also, by using the shared high-level caesium units in the core, the edge networks can enjoy better holdover capabilities. In addition, network-based timing gets rid of the site security issues that can affect individual GNSS solutions in certain locations. However, MNOs using this method also need to consider the delivery of full end-to-end synchronisation. In particular, that well-known phrase 'time is of the essence' has never been so applicable.

Glossary of terms

CoMP Coordinated Multi-Point

eICIC enhanced Inter-Cell Interference Coordination

FDD Frequency Division Duplex

GLONASS Russian Navigation System

GNSS Global Navigation Satellite System includes:
- **BeiDou** Chinese Navigation System
- **Galileo** European Navigation System
- **GLONASS** Russian Navigation System
- **GPS** Global Positioning System (USA System)

IEEE Institute of Electrical and Electronic Engineers
- **1588** a range of standards of Precision Clock Synchronization Protocol for Networked Measurement and Control Systems

ITU-T International Telecommunication Union – Telecoms Standardisation Sector

LTE-A Long Term Evolution - Advanced

MBSFN Multicast Broadcast Single-Frequency Network

MEAS Managed Ethernet Access Service

MNO Mobile Network Operator

MTIE Maximum Time Interval Error

NGMN Next Generation Mobile Networks Alliance

PRTC Primary Reference Time Clock

RAN Radio Access Network

SyncE Synchronous Ethernet

TAI Atomic Time

TDD Time Division Duplex

TDM Time Division Multiplexing

PTP Packet Timing Protocol

UTC Coordinated Universal Time

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