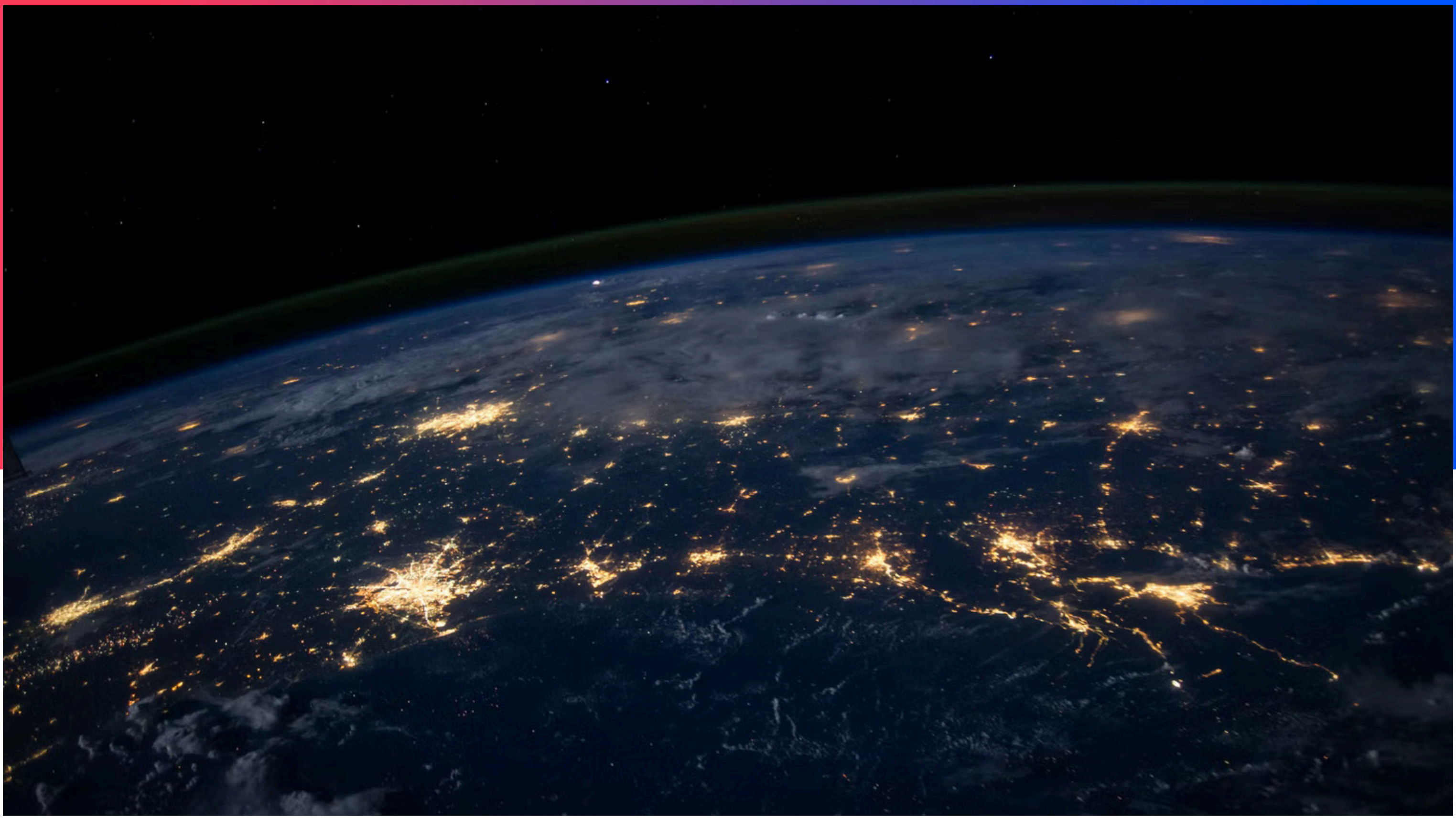
GNSS/GPS Independent 5G Synchronization

Reducing cost and complexity for 5G mobile network rollouts



5G mobile networks require high accuracy time synchronization

Time synchronization, i.e. to provide accurate time and phase synchronization to the cell tower, is the new heartbeat of the 5G mobile network and is a critical function in all 5G networks.

The time accuracy requirements are much higher in 5G networks compared to 4G because of the increased use of TDD and massive MIMO, but also due to requirements from new services such as eMBB, mMTC and uRLLC. This results in an increase in cost and complexity of time synchronization in mobile networks and puts high demands on underlying infrastructure.

GNSS/GPS solutions are often used to provide accurate time synchronization in mobile networks, but recent years' conflicts and tense geopolitical situation have made operators aware of the vulnerability of GNSS solutions and that satellite signals are easily jammed or spoofed. Several countries have mandated that all 5G deployments need to be GNSS-independent for the operator to receive a license.

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Network-based time synchronization solutions based on the IEEE1588 (PTP) standard have therefore become the primary synchronization solution for 5G networks, often complemented with GNSS for resiliency and performance improvements. However, to achieve the accuracy requirements, PTP installations require full on-path support, i.e., every network node from the master clock needs to support FTS (Full Timing Support) of the Precision Time Protocol (IEEE1588 PTP). This forces mobile operators to replace or upgrade a large part of their existing IP and optical infrastructure, which will significantly increase the cost of deployments, especially in regional and rural areas.

This document elaborates on the requirements and challenges with time synchronization in 5G network and outlines a more cost-effective and flexible overlay synchronization solution that can be used with existing network infrastructure and still provide the required accuracy. Overlay synchronization solutions are inherently open and disaggregated from underlying network technology or vendor choice.

RAN drivers of timing and sync in 5G networks

The specific requirements for RAN timing and synchronization are dependent on the radio technology deployed and the spectrum used. In frequency divided (FDD) systems, pure frequency synchronization is needed. FDD-based 5G and LTE networks can survive lengthy (> 1 hour) loss of sync. However, time division duplex (TDD) systems used in most 5G systems, will require much tighter time and phase synchronization, down to below 1,5 µs to avoid interference between the uplink (UL) and downlink (DL).

Secondly, certain uplink and downlink TDD patterns have been regulated as well e.g. across Europe in order to avoid interference between both mobile phones and mobile systems. The MNOs networks have to be synchronized within a nation as well as between nations.

TDD (Time Division Duplex)

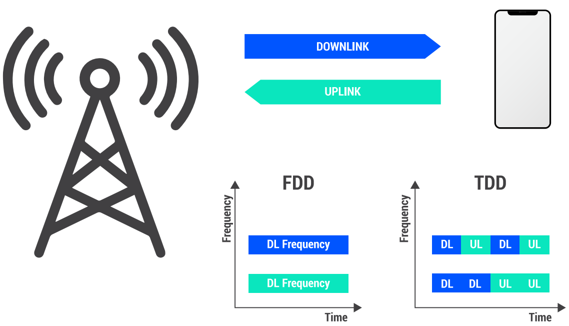


Figure 1. TDD (Source: R&S)

Massive MIMO

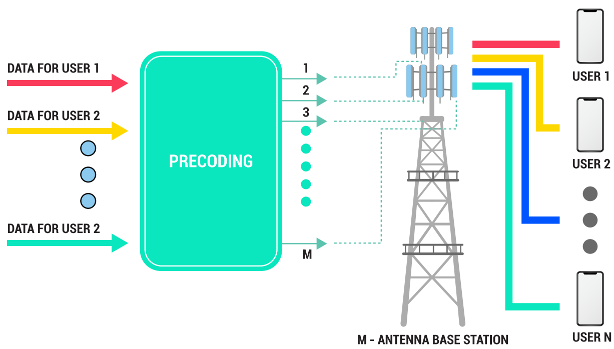


Figure 2. M-MIMO (Source: R&S)

In dense urban areas 64T64R and 32T32R Massive MIMO (M-MIMO) will be deployed, using TDD for optimized capacity enhancement (in the order of 5-10x). In general, a mix of absolute (network wide) and relative (between neighboring radios) criteria require a time sync of ~1.5 µs or less to support a network’s new spectrum and RAN features.

Depending on RAN architecture, such as e.g., C-RAN, CloudRAN, vRAN, Open RAN or Cloud Baseband, the fronthaul (whether using CPRI or eCPRI) will require better timing accuracy. RAN features such as Carrier Aggregation (CA), Dynamic Spectrum Sharing (DSS), License Assisted Access (LAA), and Coordinated Multi-Point (CoMP) transmission and reception technologies require further enhancements in synchronization, especially in more dense areas and shorter inter-site distances (ISD).

Thus, in addition to the TDD spectrum arrangement requirements and RAN architectures, different RAN technologies and features have different requirements as indicated in Figure 3.

Currently with 5G Non-Stand-Alone (NSA) using EPC/4G Core the main benefit of 5G is the fast development of new ecosystem of 5G devices and the enhanced capacity of Mobile Broadband (eMBB), mainly in dense areas.

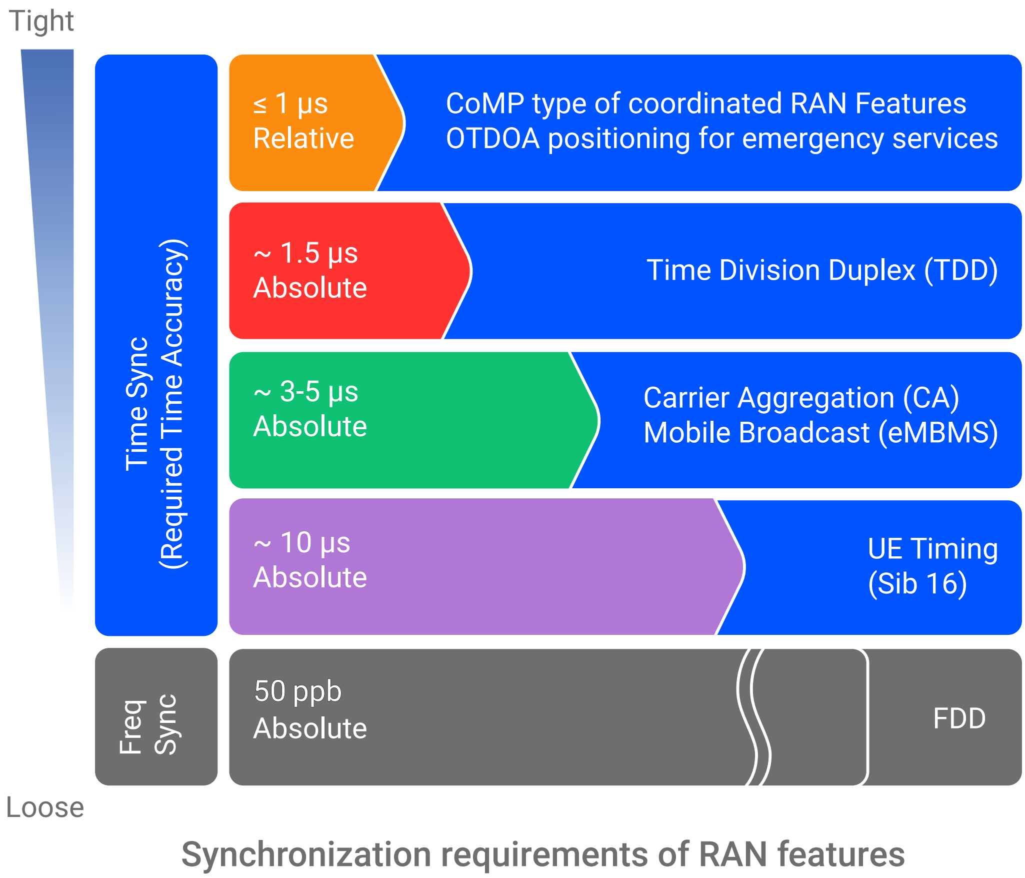


Figure 3. Synchronization requirements of RAN features (Source: Ericsson)

But, 5G Infrastructure deployment is ongoing at a tremendous speed, even compared to the fast deployment of 4G/LTE about 10 years ago. With a common 5G SA - all the new 5G services, such as e.g. uRLLC and 5G vertical applications, are being able to deploy globally and everywhere, not only in dense areas but also rural areas, at the Edge (MEC) and in Enterprise MPN (Mobile Private Networks). Thus, 5G synchronization is needed everywhere in the network. Synchronization over large distances (and many router hops) or in rural areas can be a major challenge and a costly operation for the mobile operators (both CAPEX and OPEX).

As a conclusion - Cost efficient synchronization solutions are needed for 5G.

GNSS independent timing is becoming a mandatory requirement

GNSS encompasses four main satellite systems: GPS (the USA), GLONASS (Russia), BeiDou (China), and Galileo (Europe). GNSS is based on satellites having a known time and orbit position, transmitting messages whose arrival are measured by the GNSS receiver. It provides a convenient way for mobile networks to get a very precise time. Due to the weak nature of the signals, any form of RF interference can cause severe disruptions to the GNSS service.

All forms of GNSS/GPS disruptions are on the rise.

In 2019, the European Organization for the Safety of Air Navigation, (Eurocontrol) reported that outages rose massively by well over 2,000%, between 2017 and 2018, and continued to rise in 2019 with more than "3,500 reports of outages". An American study 2019 initiated by National Institute of Standards and Technology (NIST) estimated the economic consequences of 30-day GPS outages overall as a combined loss to the U. S. economy with more than one billion USD per day, with up to half of that in the telecommunications sector.

The current geopolitical situation, with the Russian invasion of Ukraine, the awareness of GNSS jamming and/or possible spoofing has become even more obvious. The European Union Aviation Safety Agency (EASA) issued a safety information bulletin on March 17 2022 warning of a GNSS outages leading to navigation / surveillance degradation have intensified in geographical areas surrounding the conflict zone as well as in other areas.

The Swedish regulator, Swedish Post and Telecom Authority (PTS), are explicit that a GNSS independent solution to transport synchronization is a mandatory requirement for operating the 5G network

- Time synchronization in 5G networks is considered a system-critical function.
- If the primary source of common time reference is the reception of signals from satellite (GNSS) or if the source is otherwise located outside Sweden; a redundant source located in Sweden shall be functionally tested and ready to enter service, if necessary, by 1 January 2025.

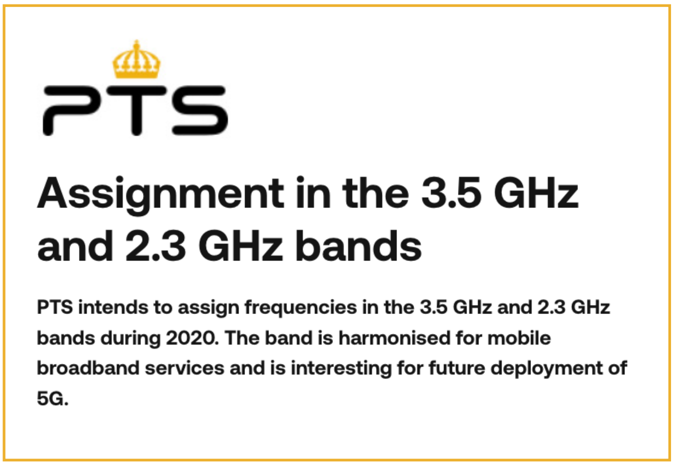


Figure 4. The PTS conditions in the auction of 3.5 GHz and 2.3 GHz frequency bands

It's been increasingly obvious to Service providers that GNSS timing cannot any longer be the only source of timing to the critical infrastructure that a Mobile Network constitute. Most Service providers are looking to introduce GNSS independent timing in the networks or at least introduce GNSS independent timing as backup in the networks when the GNSS timing is jammed, spoofed or otherwise unavailable.

Legacy timing solutions require costly infrastructure upgrades

IEEE 1588v2/PTPv2 is the current standard for providing precise time over IP networks. Many vendors offer solutions based on the standard, and different applications standardize different profiles. The most common use of PTP in telecom networks has been to provide a frequency reference to the network. This will change when moving to 5G TDD networks where time and phase is the critical feature required. This will pose new challenges since:

- The PTP Frequency profile, ITU-T G.8265.1, is significantly easier to implement and does not require any support in intermediate nodes.
- Frequency synchronization does not suffer from asymmetries. This means that there will be hidden asymmetries in the network until phase and time are enabled.

- Frequency synchronization is magnitudes more forgiving. Normal FDD requires an accuracy of 16 ppb in the backhaul, meaning that the phase could drift 60 µs in an hour compared to a TDD requirements on 1,5 µs maximum absolute time error.

Operators sometimes mistake a network to work with PTP just because they are able to use Frequency synchronization with PTP Frequency profile. This is definitely NOT the case, time and phase synchronization and the new 5G requirements on accuracy put completely new requirements on the readiness for PTP in the network.

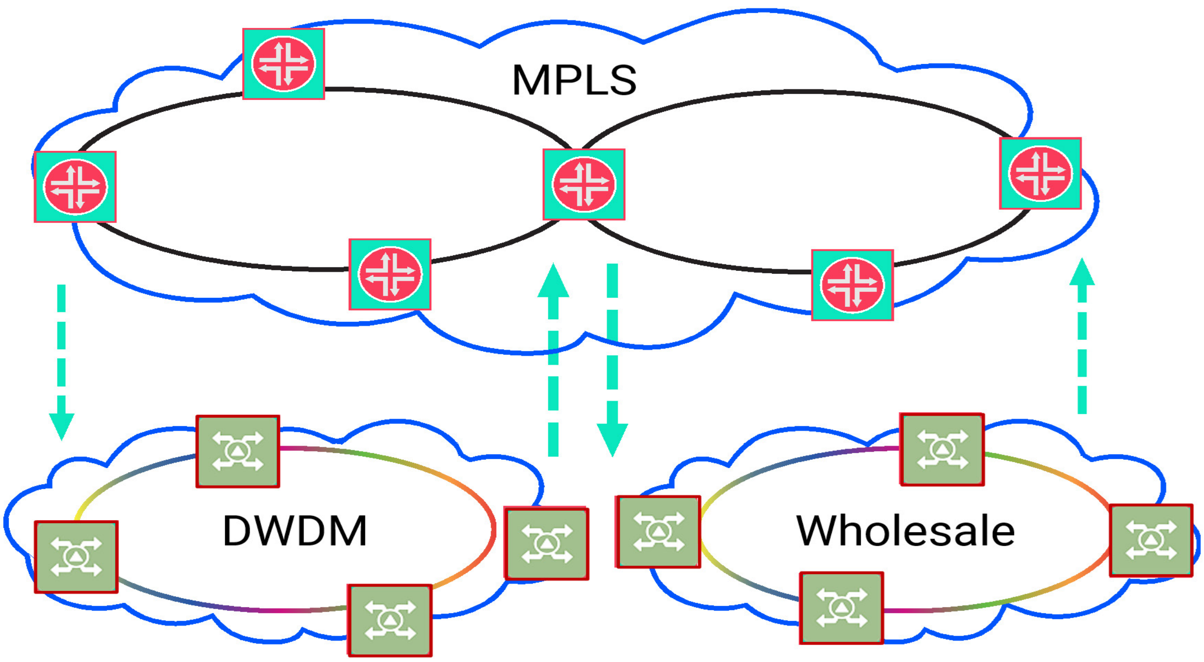


*Figure 5. Full Timing Support means that *all* network elements in the network are part of the timing chain.*

To handle the more demanding time and phase synchronization a new profile was developed in ITU-T. The "Precision Time Protocol Profile For Phase Time Synchronization With Full Timing Support From the Network." - G.8275.1. It mandates that ALL of the switches and routers are PTP aware. What also have happened is that the networks have become DWDM enabled and using DWDM coherent technologies have placed even more electronics in the data path. So, not only all switches and routers need to be PTP aware, also all transport equipment needs to be adapted and PTP aware in some shape or form.

DWDM optics operating at 100 Gb/s and above use coherent optics that contain digital signal processor (DSP). This creates a random cTE per device/interface of ±20 to 130 ns on restart. DWDM transponders and muxponders based on OTN mapping have a latency that varies on initial startup and restarts. These add a random cTE per device/interface of ±20 to 1,000 ns on restart. All this creates a need to upgrade the optical transport layer and the line system to be timing aware or even to use an Optical Timing channel added to all transport equipment which adds the transport equipment to the PTP Boundary Clock chain.

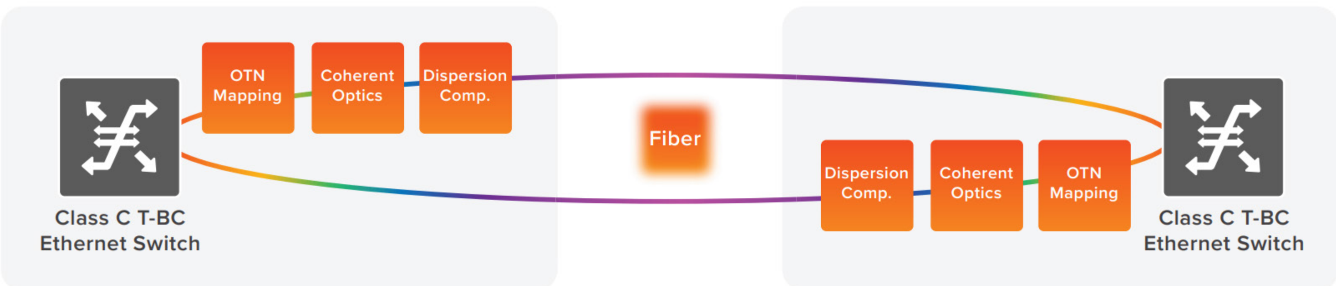


Figure 6. Random cTE added by transport layer (Source: Infinera)

And not all operators own all parts of the mobile backhaul network themselves, often parts are leased lines from various wholesale operators. These services must also be fully PTP enabled for the PTP Full timing Support architecture to work.

In the ideal case;

- All routers and switches are PTP enabled and configured to handle G.8275.1 FTS
- All transport equipment and line system are assured and PTP enabled, for example using Optical Timing channel (OTC)
- All leased lines are PTP enabled and provide a timing SLA

The mobile operators are then faced with an exceptional operational challenge. Previously, if there where an issue with the synchronization service, it was provided by one or possibly two synchronization vendor equipment providers. Troubleshooting was relatively straight forward using the tools from the synchronization experts. Now however, the synchronization service is built up by equipment from a mix of synchronization vendors, various router vendors in the network and the transport system vendors. And on top of that, the wholesale providers various equipment. Troubleshooting suddenly involves several systems from several NOCs, often blaming other systems for not conforming to standards and methods.

Advantages of overlay time synchronization

Dis-aggregation is a strong trend in Telco and ICT Industry. Future 5G is not simply a connectivity network for voice, video, or data (eMBB) but will also address new business opportunities for Enterprise and the digital transformation in society. By separating network functions, using open Interfaces and APIs etc. future 3rd party developers and service providers will be able to design future innovative solutions and enable modern DevOps methods. An open overlay synchronization solution is cost efficient and superior in many aspects and brings unique advantages. It is independent of network architecture and can be combined with current FTS PTP solutions. An overlay solution also makes it possible to be deployed in parts areas of the network (e.g. MPN, Mobile Private Networks or MCS, Mission Critical Systems). This helps operators to a smooth roll out and deployment over time and in pace with the overall 5G evolution.

The table below outlines the pros and cons of the three synchronization solutions on the market; GNSS, Full time support (FTS) PTP and an Overlay synchronization. While GNSS and FTS are commonly used, the Overlay solutions are superior in terms of flexibility, security, reliability and cost for a complete network.

Option	Description	Pros	Cons
GNSS	GNtSS/GPS at all RAN sites	Accurate local timing and sync at all sites High accuracy	Increased risk of deployment delays due to GNSS signal unavailability
FTS	GNSS at some RAN or Transport sites with full timing support (FTS) from transport network	Accurate and redundant time distribution High overall reliability and performance if all nodes already timing-aware	Every node in transport network must have a boundary or transparent clock Careful placement of GNSS and reference clocks required to cover network within time error budget Large operational cost when upgrading parts of the networks or enabling ne w5G sites.
Overlay Sync	VPN based “Sync overlay mechanism”	Do not require each transport net-work node to be timing aware Independent or working together with GNSS Fully redundant architecture Fast rollout in existing networks Low overall cost Asymmetric link compensation	Calibration needed initially at installa-tion for highest accuracy

Overlay time synchronization using existing infrastructure

Net Insight offers a new GNSS independent timing solution called Precision TimeNet that meets the timing requirements of 5G TDD over existing IP/MPLS and DWDM networks, thus avoiding expensive network upgrades. The solution creates an overlay synchronization network that scales to thousands of time nodes. It includes built-in mechanisms to handle link, node and clock failures as well as changes in asymmetries in underlying networks.

Precision TimeNet significantly reduces overall rollout costs and network operations compared to previous approaches and since existing infrastructure can be used, the rollouts can be much faster.

Net Insight's Precision TimeNet was originally developed for digital terrestrial TV, DVB-T2 and ATSC3.0, networks requiring Single Frequency (SFN) transmission. These networks have similar requirements of a maximum time error of 1.0-1.5 μs as in 5G mobile networks. The Time Transfer solution has been in use in large national DVB-T networks for over 10 years. The ability to use standard MPLS L3VPNs or L2VPNs is a huge advantage and makes it very easy to introduce time transfer in existing network without upgrading the technology in neither the MPLS nor the optical layer.

The biggest challenge delivering time and phase in a mobile backhaul network is handling the asymmetries that occur in the network. As described earlier, asymmetries originate from both the optical OTN/DWDM layer due to the behavior with large and random changes in unidirectional delay and from the IP/MPLS layer e.g., due to unidirectional MPLS protection switching. The Time Transfer technology has inbuild capacity to detect asymmetry changes and then react and compensate for them.

Another challenge in overlay synchronization networks is the varying packet delay variation (PDV) that the timing information experiences when switched over a L2VPN or L3VPN. Where PTP with Full Timing Support goes to a very large effort to remove the PDV, the Net Insight Time Transfer technology instead uses methods to manage and mitigate the effects of PDV and therefore is able to transfer time over multiple network nodes without PTP FTS support.

The solution includes an intelligent synchronization routing protocol and inherent redundancy and holdover support in case of link or node failures. Net Insight's Time Transfer solution can handle many different synchronization sources in the network and can act both as a transparent clock and PTP Grand Master.

Feature	Functionality	Characteristics
High Accuracy	Multilink Collaborative Clocks Dynamic adaption of timestamp streaming. Advanced filtering with intelligent min delay algorithms,	The solution is very resilient to the PDV of the underlying network. High accuracy over underlying infrastructure with many IP/MPLS hops
High Resiliency	Intelligent Synchronization Routing supporting Redundant masters, GNSS Backup and extended ePRC Holdover Network resiliency instead of expensive oscillator options.	Network resiliency to provide maximum uptime
Handle Asymmetries	Asymmetry autocalibration	Handles asymmetry changes and asymmetric delays in underlying infra-structure
Operational efficiency	Extensive Sync Telemetry and Visualization. Full support for 3rd party analytics and interac-tive visualization such as Grafana.	One stop shop when it comes to operating the entire synchronization network.
Interoperability	Full PTP stack with Telecom, Media and Utility PTP profiles. Proven over 10+ years. Supports 2,048 and 10 MHz frequency input and output signals	Applicable through all industry appli-cations. Wholesale enabled. Reliable.

Successful validation from real-world networks

Overlay synchronization solutions are inherently disaggregated from the network transport and have strong advantages when it comes to openness, both in terms of infrastructure technology and vendor independence. However, the largest advantage is that it does not require a full network upgrade to support full on-path synchronization support in each node but works seamlessly also over heterogenous and leased network infrastructures. The functionality has been used and proven in other industries but has now been optimized for 5G networks and verified in commercial 5G rollouts.

Network Trial with Türk Telekom

Türk Telekom performed an extensive network trial over their IP/MPLS and DWDM network. The solution was setup as a pure overlay solution where time information was transported between Time Nodes in normal enterprise VPN connections without any PTP support in any intermediary nodes. In the below measurements, time and phase was transported from a central master clock in Adana to a Time Node deployed at an actual base station in Istanbul, a route over 1200 km. The underlying network used a diverse set of equipment from multiple vendors, and the route traversed 14/11 MPLS and optical hops.

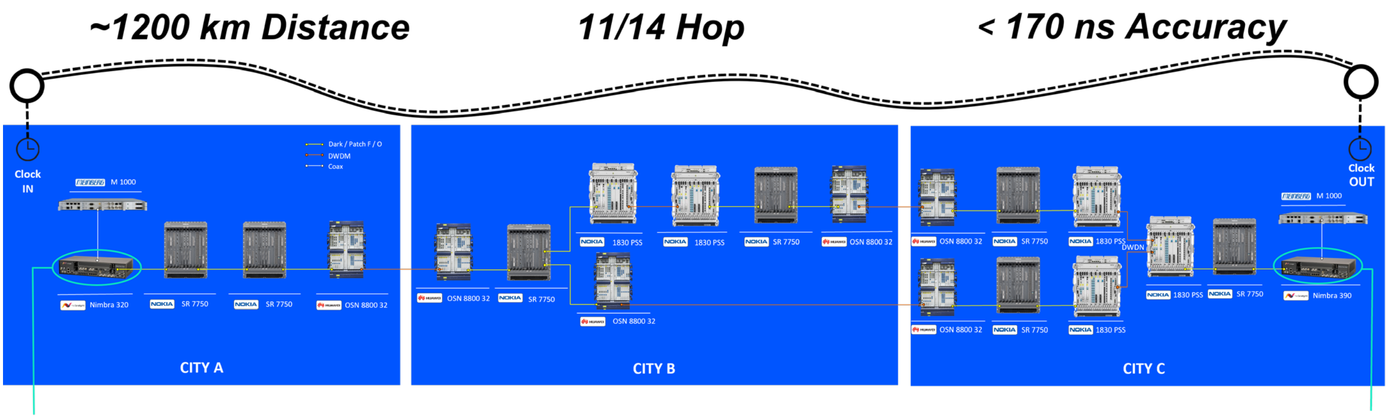


Figure 7. The FTS challenge as illustrated by Türk Telecom

The results show a very high accuracy of +/- 170 ns MTIE, as can be seen in Figure 2, which is well below the 5G absolute phase requirements of 1,1 us. Effects from traffic load were not significantly present, and effects from protection switching and underlying varying asymmetries were efficiently handled.

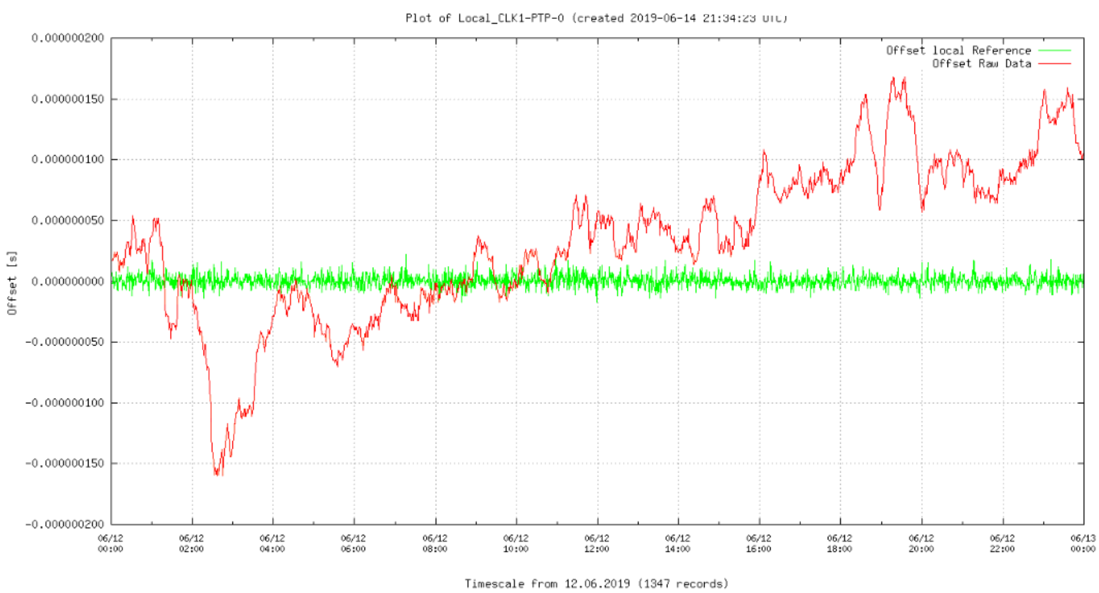


Figure 8. Measure of time-offset of a 1200 km 11 to 14 nodes network traversal after calibration. Green trace is reference variations. Red trace is produced timing variations, during 24h.

Network Trial with a Nordic Operator

A Nordic Operator which is not yet announced has performed a Network Trial Testing with Net Insight's Precision TimeNet technology. The Network Trial has been focused if it is possible to use the Net Insight's Precision TimeNet technology in the varying network scenarios.

The source of the time in the network is an enhanced primary reference time clock (ePRTC) located in a core datacenter. The ePRTC provides reference time and phase synchronization signal to a Master Time Node in that location.

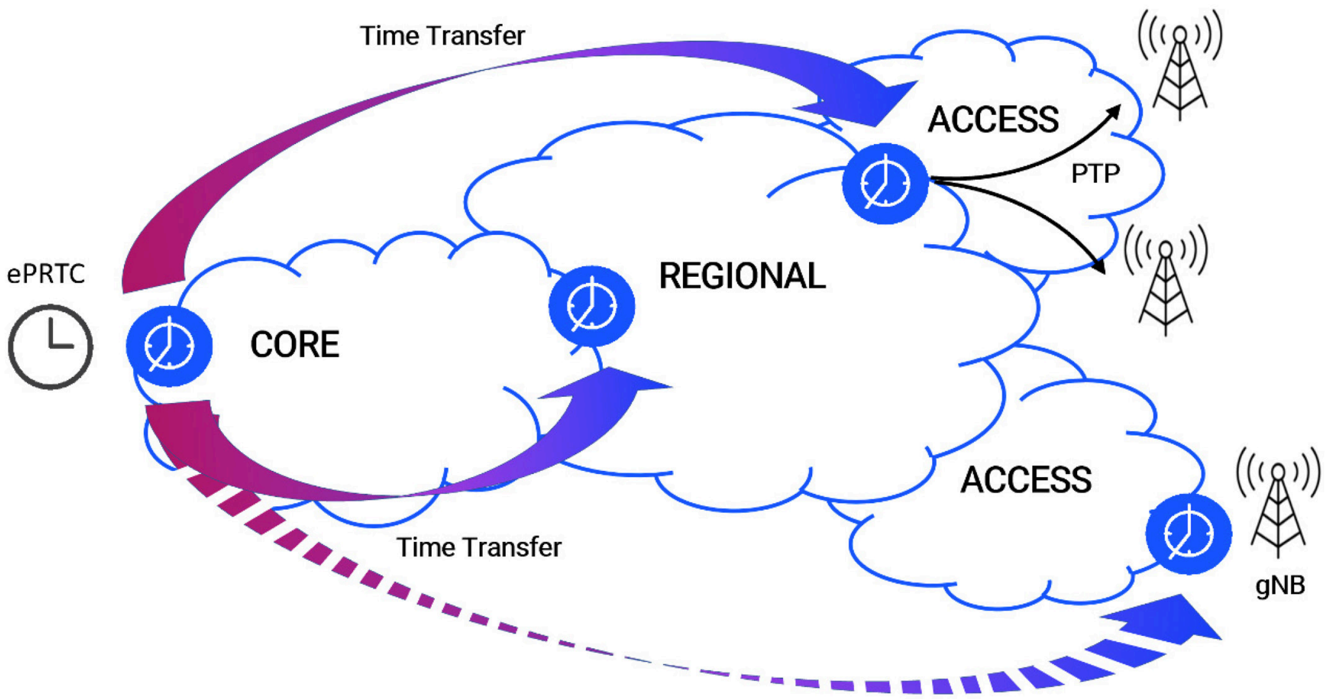
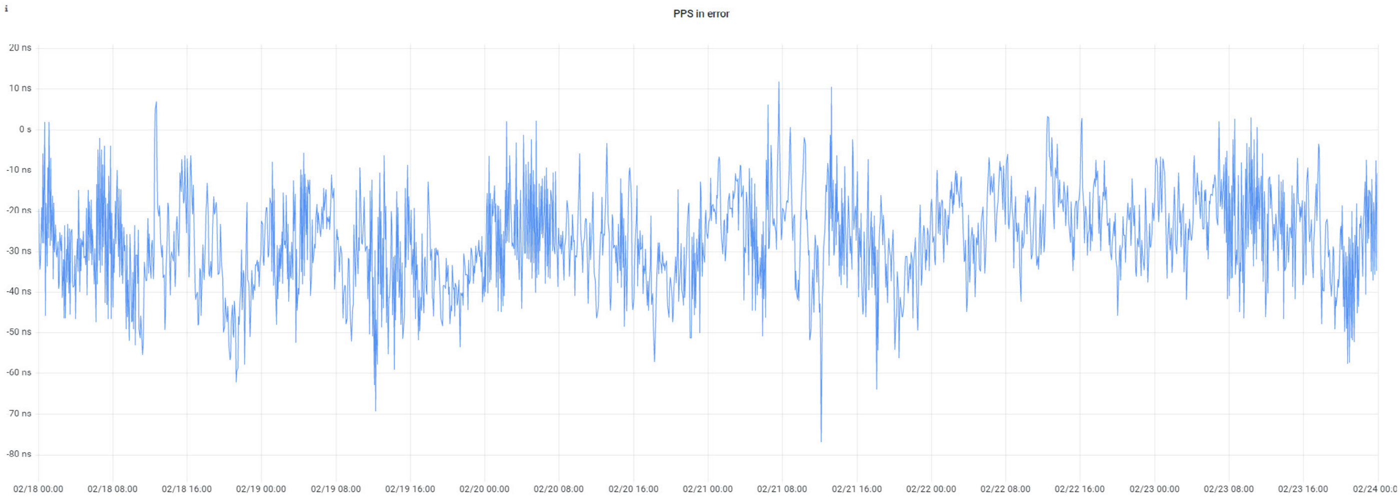


Figure 9. Two sites in the network, edge of core and edge of regional

Three positions in the network were selected as test nodes. The test nodes were equipped with local GNSS receiver, and the absolute time calculated from the time transfer at these three sites was compared with the local reference GNSS time. The Time Transfer was run in a Virtual private wire service (VPWS) Layer 2 VPN over the core MPLS. The Traffic Class for the time VPWS was AF41 (DSCP 34) which normally is used for Multimedia and below voice and signaling data, but above normal bulk mobile traffic.

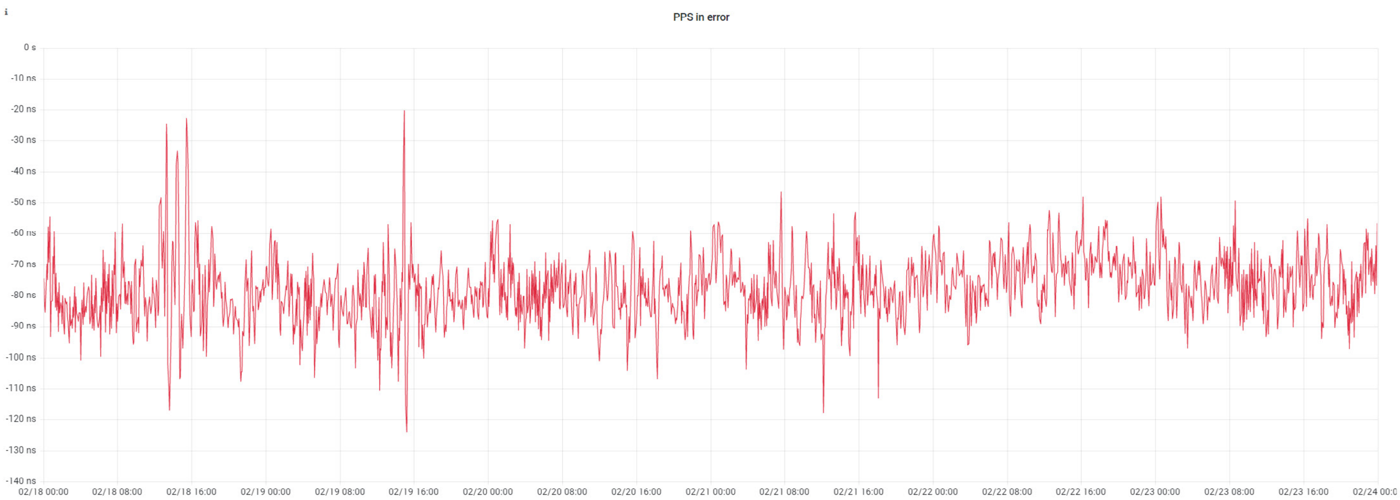
The test has been run over a month, the test results below are reported only on one consecutive week (6 days). Two sites were chosen to represent different reference points in the network and are described below:

1. A node on the edge of the core network. The core network consists of DWDM (100G and above) and core routers that are fully owned by the mobile operator. The distance was about 200 km.



The maximum absolute time error max|TE| measured over one week was about 80ns for the edge node.

2. A regional node on the edge of the regional network. The regional network consists of wavelength service and the regional routers that are fully managed by the mobile operator. The distance was about 120 km from the edge of the core network.



The maximum absolute time error max|TE| measured over one week was about 120 ns for the regional network node.

As can be concluded, an overlay synchronization solution can easily handle the accuracy requirements of 5G networks but needs to include features to manage the network delay variations and detect and compensate for network asymmetries.

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CONCLUSION

This solution paper describes the inherent challenges with providing accurate phase and time for 5G mobile networks. Analyst firm Kearney has estimated that the CAPEX cost of time synchronization in mobile rollouts will increase from 0.2-1% in 4G/LTE rollouts to 3-5% for 5G. A potentially even bigger cost lies in that full on-path PTP requires every node to be PTP enabled (FTS) which can lead to costly upgrades and even replacement of existing network equipment, including both IP/MPLS routers and underlying DWDM transport equipment. This results in high costs and often lock the operator into a single vendor. That the sync is tied to the transport and requires support in every node and line card increases operational complexity, both for network planning, installation, trouble shooting and upgrades, leading to significantly increased OPEX for the operators,

GNSS can offer the time accuracy required by 5G networks, but the vulnerability of GNSS/GPS solutions to jamming and spoofing is increasing, which has made both operators and governments look for GNSS/GPS independent solutions.

Net Insight's Time Transfer solution provides an alternative synchronization solution which is based on an open overlay architecture disaggregating the synchronization functionality from the transport. It is GNSS/GPS independent and meets the tough time synchronization requirements from 5G deployments including TDD and Massive MIMO.

Overlay synchronization solutions have the benefit of being open and working over existing infrastructure without requiring a full network upgrade or replacement of nodes. Net Insight's Precision TimeNet solution uses unique asymmetry detection and compensation in combination with jitter smoothing mechanisms to enhance synchronization performance. The solution has been verified in 5G networks to be well within the timing accuracies required, even over long distances and many hops. The solution technology is well proven and stems from the media industry which has had strict reliability and time synchronization requirements for their single frequency digital TV networks for over fifteen years.

The solution promises to significantly reduce the CAPEX and OPEX in new 5G rollouts, especially for incumbent operators (i.e., brown-field operators) and can significantly reduce rollout times since it can bring time synchronization to 5G RANs over existing transport network infrastructure.

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