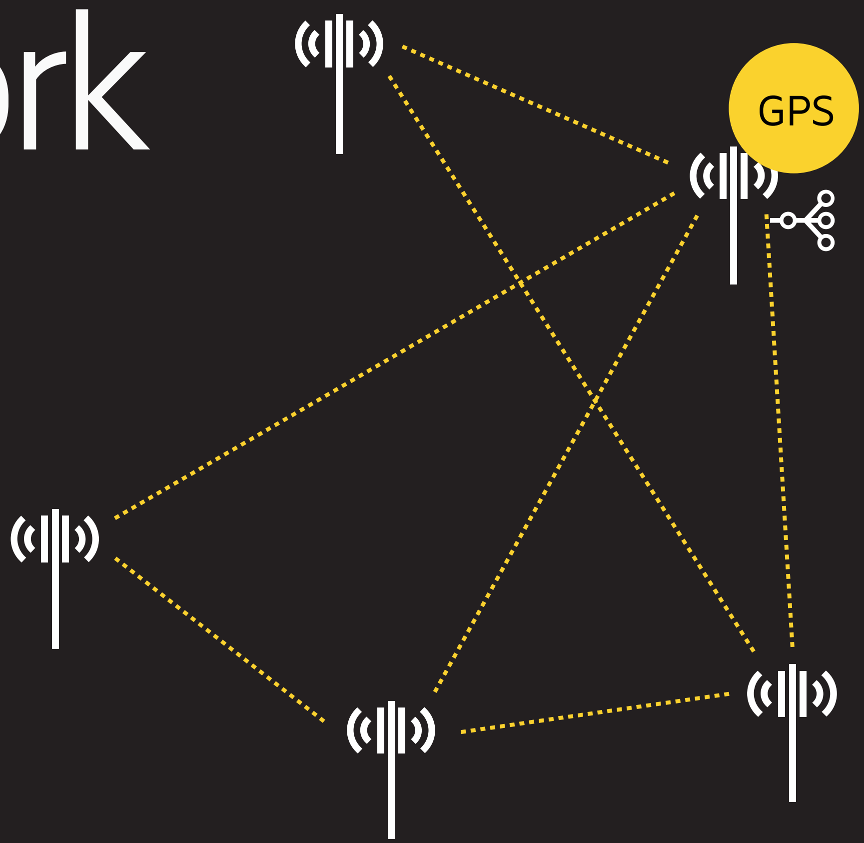
Synchronization solutions in 5G transport network



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Introduction

Accurate and reliable synchronization has long been a fundamental prerequisite for the correct operation of telecommunications networks and it will be so in 5G. All synchronization requirements for 5G networks are driven from the New Radio (NR) interface synchronization requirements defined by 3GPP. These requirements are not more stringent, but are becoming more essential in 5G than in 4G, therefore seamless synchronization operation is fundamental to unlock the full potential of 5G. To efficiently address RAN synchronization requirements, a good understanding of all the technology options for synchronization distribution in transport networks is essential as the most suitable and cost-efficient sync solution may be different from case to case.

The role and importance of synchronization distribution in transport networks has varied during the different mobile generations.

The importance of synchronization distribution in the transport network has grown with 4G, and it will be more important than ever in 5G and future networks due to the need of accurate phase alignment in the RAN. Although the fundamental synchronization requirements have not become more stringent in 5G compared to 4G (and in some cases became more relaxed), the need for time synchronization is critical, as new fronthaul network architectures open new opportunities and new challenges for synchronization distribution.

Finding the right balance between timing accuracy, availability and cost is key to make services successful. To achieve this, a good understanding of all the technology options for synchronization distribution in transport networks is essential, but not enough. It is also important to understand RAN technology drivers for synchronization, and how that translates to transport network requirements in various network scenarios.

The Ericsson Transport portfolio, including the MINI-LINK 6000, Router 6000 and Fronthaul 6000 product families, is developed to address all relevant synchronization requirements of 5G RAN in various transport scenarios. End-to-end solutions are verified across the products providing operators with the benefit of guaranteed performance, ease of use and quick synchronization solution rollouts.

To understand how Ericsson Transport products support synchronization solutions in various positions of the network, this paper gives a comprehensive picture of the 5G transport network synchronization landscape, including:

- an overview of RAN drivers for synchronization,
- the corresponding transport network synchronization requirements,
- the transport technology toolbox for synchronization and
- guidelines on how to find the right solution in various network deployments (both fronthaul and backhaul) using the Ericsson Transport portfolio

to reach a reliable, cost efficient and easy-to-monitor synchronization network in transport.

RAN drivers for 5G synchronization

All synchronization requirements for 5G networks are driven from the New Radio (NR) interface synchronization requirements defined by 3GPP. Such requirements related to communication over the radio interface can be divided into the following categories:

- FDD synchronization requirements
- TDD cell phase synchronization requirements
- Time Alignment Error (TAE) requirements of communication features based on coordinated transmission or reception from multiple Transmission Reception Points (TRxPs).

In the following sections we give a summary of these requirements; for further details read [1].

FDD synchronization requirements

Frequency accuracy requirements on the air interface of FDD networks has not changed in recent generations, being 50 ppb at the radio air interface [2], and corresponding 16 ppb at RBS input interface (according to ITU-T G.8261.1).

A new and important change in 5G is the need for time synchronization of the NR-FDD radio to allow for neighbor cell discovery for the UE for handover. To provide overlap of the 1 ms discovery time gap of neighboring cells, a ±500 µs time alignment requirement has been introduced.

This level of time alignment is a special case for RAN time synchronization that allows for transport synchronization solutions that are far simpler than those required for TDD networks.

TDD cell phase synchronization

TDD cells operating at the same frequency (or adjacent frequencies) in overlapping coverage areas require time domain isolation to prevent base-station-to-base-station and UE-to-UE radio frequency interference. For TDD synchronicity and interference, the critical points are when switching between transmission and reception. Guard periods are used for isolation with a configurable total guard time expressed as an integer number of symbols. To decrease guard time overheads, the emphasis is on striving to keep the guard periods short, while still catering for the desired effects. Allocation of a budget to the different components of the guard period is the result of a trade-off between cost (product and deployment), availability, TDD periodicity and overheads.

In 5G NR-TDD, cell phase synchronization is specified as 3 µs [2] – a requirement that is also applicable for LTE-TDD [3].

The practical interpretation of cell phase synchronization is defined by ITU-T in terms of maximum deviation in relation to a common absolute timing requirement, dividing that requirement by half (i.e. ±1.5 µs). This allows network designs with independent synchronization references across different operators operating at overlapping coverage areas, by creating absolute accuracy requirements that apply to all TDD networks.

ITU-T G.827x recommendations [4] are translating this 3GPP cell phase synchronization requirement to telecommunication network requirements, deriving network limits and device specific functional and performance requirements for transport network equipment, providing a comprehensive set of synchronization requirements that are applicable for backhaul networks.

Communication features based on coordinated transmission or reception

A variety of features that benefit from coordinated transmission or receptions from multiple TRxPs have been standardized over the years, all with different purposes and characteristics:

- some relate to combining spectrum assets, thereby allowing total higher aggregated bandwidth and through-put (carrier aggregation (CA), dual connectivity (DC) and so on)
- others relate to improving link performance at the cell edge (e.g. variants of coordinated multi-point operation).
- still others relate to specific services like Multimedia Broadcast Multicast Service over a Single Frequency Network. Coordination may also occur between NR and LTE.

These features are applicable within a single operator network and cells with overlapping coverage, and as a result, control of relative time error between antennas used by the feature is sufficient within the specific area. The most stringent TAE requirements range between 65 ns to 260 ns, but are only valid for collocated/intra-site deployments, and are therefore not applicable to backhaul scenarios.

With the evolution towards packet switched fronthaul and centralized RAN architecture, however, some of these requirements may become relevant for transport solutions that will support fronthaul scenarios. Such networks will require careful analysis to understand timing requirements – and corresponding network planning to fulfill them.

Inter-node CA and synchronous DC have most of their benefits when 3 µs TAE is achieved (same as for TDD), and while they can operate at a lower level of accuracies, their benefits will decrease.

The synchronization requirements of Ericsson Spectrum Sharing for efficient combination of LTE and NR resources are inherited from the requirements of the combined technologies.

Summary of 5G RAN drivers

The synchronization requirements for 5G RAN are summarized in Figure 1, showing the various synchronization types and performance levels of requirements.

The main novelty in 5G is that NR-FDD has a ±500 µs time alignment requirement, on top of the 50 ppb frequency stability requirement of LTE-FDD. The co-existence of both NR-FDD and LTE-FDD at the same geographical area makes ±500 µs time alignment also required for LTE-FDD.

Cell phase sync requirements impose a strict need for accurate time synchronization for NR-TDD networks. This 3µs requirement is translated to the most often mentioned ±1.5 µs requirement for transport networks, and supported by the G.827x set of recommendations, defined by ITU-T. The same performance level is recommended for inter-node CA or for dual connectivity.

Finally, the most stringent timing requirements are driven by coordinated transmission or reception features imposing relative time error requirements for these features. These are, however, not directly applicable for traditional transport backhaul networks, but may be applicable locally for fronthaul networks or for collocated/intra-site deployments.

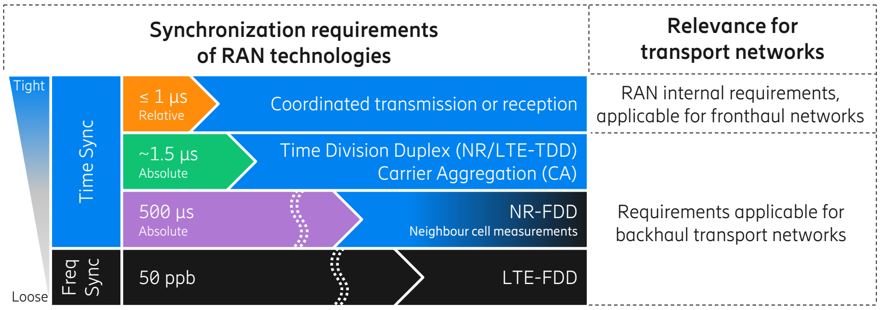

Figure 1: Synchronization requirements of RAN technologies applicable at radio interface

It is important to understand the difference between absolute and relative timing requirements, as explained in Figure 2.

All antenna reference points in NR-TDD networks must be aligned within ±1.5 µs to a common timescale (common time reference traceable to the Coordinated Universal Time (UTC)) to allow networks from multiple operators to operate within the same geographical area.

For coordinated features, however, the time alignment requirements only apply to the antennas that are participating in the coordination, meaning such requirements are relative within these antennas and only apply locally within a coordination area.

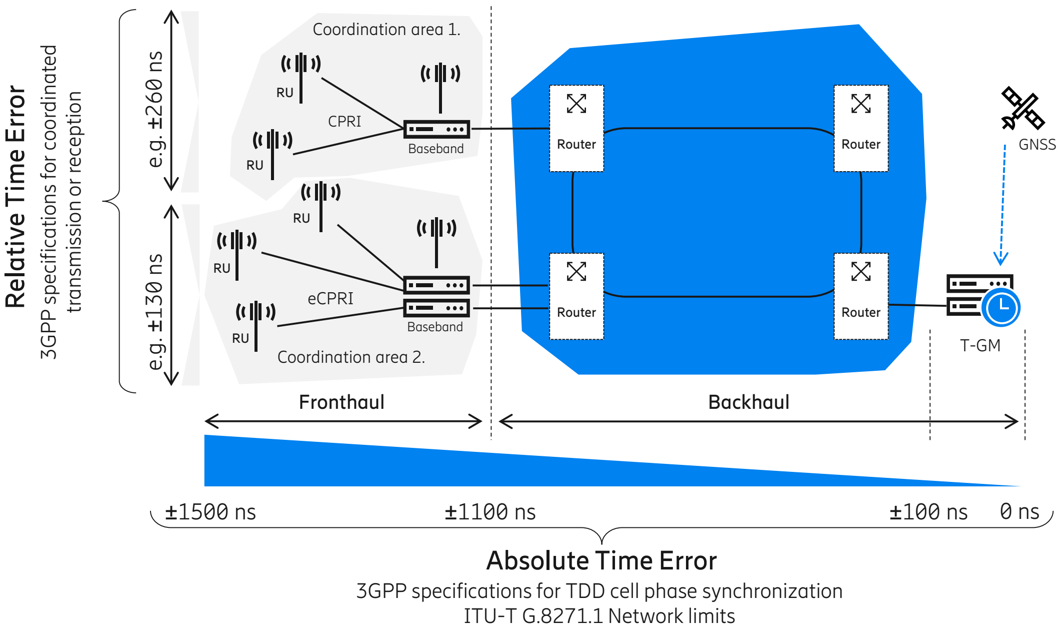

Figure 2: Absolute vs. relative time alignment requirements

Technology options

To efficiently address RAN synchronization requirements, a good understanding of all the technology options for synchronization distribution in transport networks is essential.

Synchronization technologies can be implemented in the physical layer and/or in the packet layer to deliver frequency and/or time synchronization. Synchronization solutions can further be categorized depending on whether they require hardware support from the transport network.

Frequency synchronization technologies

In 5G networks all radio technologies require some level of time synchronization, therefore relevance of frequency synchronization technologies has been declined.
Two main use-cases remain for frequency synchronization:

- to provide hybrid operation for PTP in G.8275.1 profile with Synchronous Ethernet
- to provide prolonged time holdover for TDD networks, using enhanced Synchronous Ethernet

Ethernet technology is – by its original nature – an asynchronous technology, which was subsequentially enhanced to support physical layer synchronization by additional HW circuitry. Therefore, when Ethernet is used for frequency distribution in the physical layer it is required that each node and link in the synchronization path supports synchronous mode, otherwise the synchronization chain is broken.

Standard synchronous Ethernet technology is suitable to distribute stable frequency base for accurate time synchronization in G.8275.1 profile as defined by ITU-T.

The new generation of this technology, defined by ITU-T as Enhanced Synchronous Ethernet (G.8262.1), allows for even more stable distribution synchronization suitable not only for hybrid Synchronous Ethernet and PTP, but also to prolong time holdover.

While microwave technology is fully capable to distribute enhanced synchronous ethernet, leased lines are typically not. A leased line is typically a 3PP-controlled network through multiple hops, not a direct hard line, and therefore is not transparent for the underlying synchronization signals.

Time synchronization technologies

The time synchronization toolbox consists of several options and combinations, including GNSS at all base stations, PTP protocol in different profiles, and various combinations of these.

GNSS at all base stations
Connecting a GNSS receiver to the RBS subsystem at each RBS site by installing a GNSS antenna at rooftop or mast-top is a simple and direct solution to address timing requirements of the RAN network. Installation is usually straightforward, provides excellent accuracy (±100 ns, in case of good sky view), simple troubleshooting and most importantly eliminates the need of timing distribution in the transport network when the network is not yet prepared to support it.

In this way the timing requirements of the RAN network are fulfilled without any involvement from the transport network. Such setup also allows a reasonable TE budget for time holdover in the RBS, as shown in Figure 3.

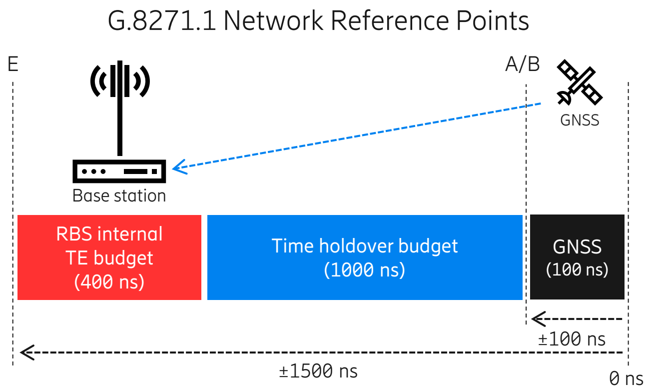

Figure 3: Time Error budget for RBS with GNSS installations

A single reference is never a safe choice, so there is a need for backup in case of loss of the GNSS signal. The main backup options are:

- Assisted Partial Timing Support (APTS) profile of PTP as defined in ITU-T G.8275.2
- Enhanced Synchronous Ethernet assisted time holdover
- Over the Air Synchronization within the RAN

While the G.8275.1 profile of PTP may also be used as GNSS backup, it is more typical to use it as primary source at the RBS with no GNSS reference, as discussed in next section.

The most straightforward backup is the G.8275.2 profile of PTP as an assisted partial timing reference: local GNSS is the primary time source and is used as the active reference at the RBS site, while at any GNSS outages the PTP signal provides stable phase reference for an extended time holdover. Static asymmetry of the PTP is characterized while both GNSS and PTP sessions are active, and therefore G.8275.2 does not require hardware support or awareness in the transport network other than an appropriate quality of service design to minimize PDV (e.g. forwarding messages in the highest priority queue). In Ericsson RBS maximum PDV for G.8275.2 APTS is 42 µs, which needs to be provided for the PTP session through traffic engineering in the transport network.

For PTP unaware networks G.8271.2 provides guidelines and examples for time error budget dimensioning, explained in Figure 4.

Another option to provide backup for GNSS is to use enhanced synchronous ethernet as assisting reference for time holdover periods. In such cases, when GNSS is lost, time holdover stability is provided based on the synchronous ethernet signal. A frequency reference, traceable to a Primary Reference Time Clock (PRTC), distributed over enhanced Synchronous Ethernet capable devices, may extend time holdover as long as the frequency reference signal is uninterrupted.

Another alternative to provide backup for GNSS is time distribution in the RAN network (either as a GNSS assisting backup, or as a synchronization timing channel), called Over the Air Synchronization, a technology that uses the radio air interface communication between base stations to achieve accurate synchronization. This technology can complement timing distribution solutions of the transport.

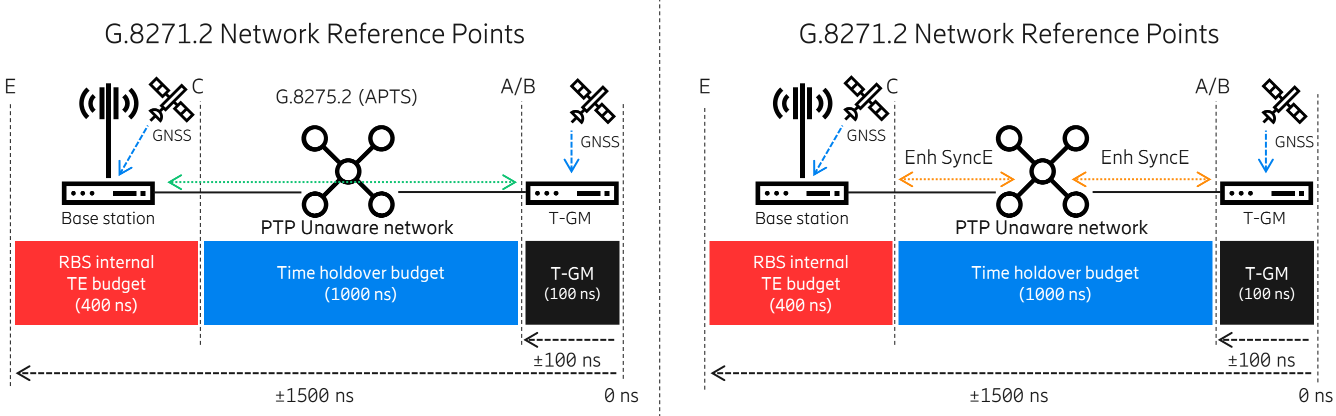

Figure 4: GNSS at base station with assisting references, G.8275.2 (left) and enhanced Synchronous Ethernet (right)

Full timing PTP distribution in the transport network

Concerns regarding relying on GNSS are increasing, as availability of a GNSS timing reference may be impacted by multiple intended or unintended sources (jammers or spoofers by police or military operations or from the grey zone) [5]. Moreover, rooftop installations and in-building cablings can be impractical, costly, or simply not possible at some network sites (especially indoor).

To address this challenge, the evolution towards accurate, reliable, and redundant 5G timing solutions leads to timing distribution in the transport network through the G.8275.1 profile of PTP, that is full timing support (FTS) from the network. It is a very attractive complement to GNSS, with the potential to eliminate exclusive dependence on local GNSS for sync.

The PTP protocol in G.8275.1 profile mandates timing support at each device in the transport network to ensure accurate and robust distribution of the timing signal, otherwise the timing chain is broken. In this profile all nodes implement some type of PTP clock – Telecom Boundary Clock (T-BC) or Telecom Transparent Clock, (T-TC) –, and distribute the PTP messages with hardware assisted timestamping, giving the desired accuracy to the clock recovery.

Microwave as a technology is fully capable of distributing accurate PTP signals, however leased lines are typically problematic since they are not transparent for the PTP protocol. Other lower layer technologies, like OTN and WDM may distribute PTP signals, but require special attention and careful planning to be able to deliver accurate time distribution.

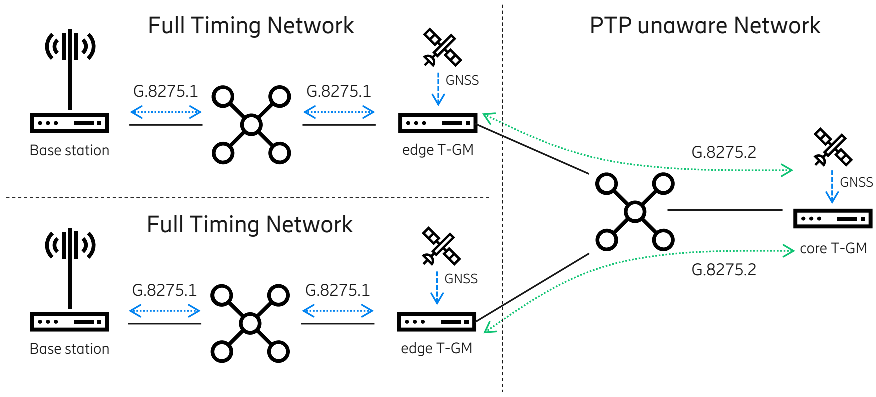

Figure 5: Introducing full timing in the RAN-near transport domain

PTP also supports automatic formation of a loop-free master-slave topology using the Best Master Clock Algorithm (BMCA) and rapidly adapts to any changes in the network topology. This helps to ensure a robust timing solution that provides optimal PTP network topology according to the network situation, influenced by any optionally defined operator priorities. In doing so, the timing solution becomes as redundant as the transport network itself, minimizing the need for time holdover (limited to cover the settling period of network transients), while maximizing the availability and reliability of the 5G network.

Transport timing requirements are driven from the RAN timing needs, so introduction of PTP full timing typically happens at RAN-near part of the network, to an extent where PTP support in the network is provided. This is shown in Figure 5, with the formation of disjoint PTP areas in the RAN-near transport domain. Each area should be installed with redundant time sources, typically a few edge grandmaster devices per area.

While dedicated T-GM equipment with high-end internal oscillators are attractive due to their time holdover capabilities, they also drive cost. Standard transport devices with a GNSS receiver and with built-in T-GM functionality also fulfill 5G timing requirements, while significantly lowering the cost.

When PTP hardware support becomes more widely deployed in the network, PTP full timing distribution can be enabled in larger network segments, potentially ranging from RAN to core leading towards GNSS independent transport solutions.

Time Error budget allocation in G.8275.1 networks
When PTP full timing is expanding in the network, the accumulated time error of the distributed PTP signal becomes important, since each PTP clock in the distribution chain slightly adds PTP error.

G.8271.1 specifies network limits for full timing networks matching the 3GPP requirements for 5G TDD networks, and provides guidelines and examples for time error budget dimensioning, as explained in Figure 6. In these budget calculations the time error of each PTP clock is a significant contributor, though not the only one. As a rule of thumb half of the network budget is allocated for node time errors, while the rest is reserved for other impairment sources such as uncompensated link asymmetries and network transients.

The importance of link asymmetry compensation must be noted. While microwave technology is inherently symmetrical in delays, fiber installations and various optical technologies (OTN, WDM, etc.) may have challenges. Such link asymmetries, if static over time and known, must be addressed by configuring compensation values in the PTP devices, or sufficient budget needs to be reserved in the time error budget planning.

Operators have the flexibility to do TE budget planning for their transport network, allowing more budget to some of these components at the expense of others, but must ensure that the ±1100 ns absolute maximum TE is not exceeded in the transport domain.

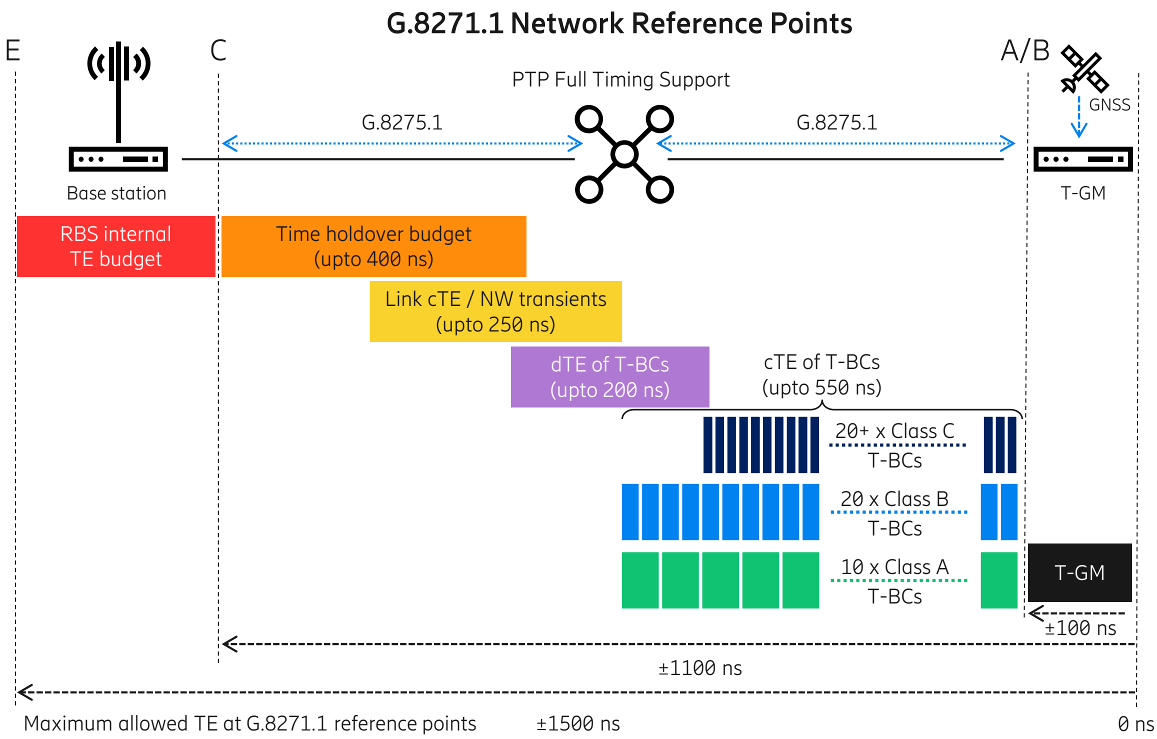

Figure 6: Network Time Error budget planning for full timing PTP networks, according to ITU-T G.8271.1

Derived from these network limits, G.8273.2 specifies the performance characteristic requirements for a network device implementing a Telecom Boundary Clock at various performance levels. Class A and Class B address regular transport network use-cases, with the main difference being the number of T-BCs that are allowed in a chain.

Class C supports enhanced backhaul timing performance to stretch the chain length beyond 20 devices or to leave more budget for uncompensated link asymmetries and time holdover. Class C devices can also address packet fronthaul applications.

Class D is intended for special time distribution solutions to interconnect PRTCs to form a distributed, coherent PRTC clock ensemble. Class D is not yet fully specified and not expected to be a relevant accuracy requirement for standard backhaul or switched fronthaul equipment.

G.8273.2	Maximum Absolute Time Error	Constant Time Error (cTE)	Dynamic TE ow-pass (MTIE)	Dynamic TE low-pass (TDEV)	Dynamic TE high-pass (p2p)
Class A	100 ns	±50 ns	40 ns	4 ns	70 ns
Class B	70 ns	±20 ns	40 ns	4 ns	70 ns
Class C	30 ns	±10 ns	10 ns	2 ns	Not spec.

Table 1: Performance specifications in ITU-T G.8273.2

Multi-profile scenarios
There may be certain network scenarios where the full timing area is small, consisting only of a few transport/radio sites, meaning redundant T-GM installations may become too costly compared to the size of the PTP domain. In this case, a single edge T-GM with GNSS as primary timing source and a combination of G.8275.1 (towards RBSs) and G.8275.2 profile (from a backup T-GM in the network) is a viable option.

Network budget planning becomes challenging in this scenario, since by default both the G.8275.1 and G.8275.2 networks are defined to consume the entire ±1100 ns TE budget up to reference point C resulting in the consumption of twice the available TE budget.

As shown in Figure 7, it is important to make sure that total time error accumulation in the G.8275.1 network and the G.8275.2 clock recovery stability does not exceed the requirements of the end application, even when the synchronization is based on the core T-GM and the combined G.8275.1 and G.8275.2 distribution networks.

This requires careful planning for the G.8275.1 network, complemented by improved stability (lower PDV, reduced TE budget) of the G.8275.2 timing recovery.

The IEEE1588-2019 standard offers a useful extension for such scenarios: using the enhanced accuracy TLV a worst-case estimation of the PTP signal inaccuracy can be added to the PTP protocol messages, allowing the end application to detect if the received PTP signal is exceeding the accuracy limits.

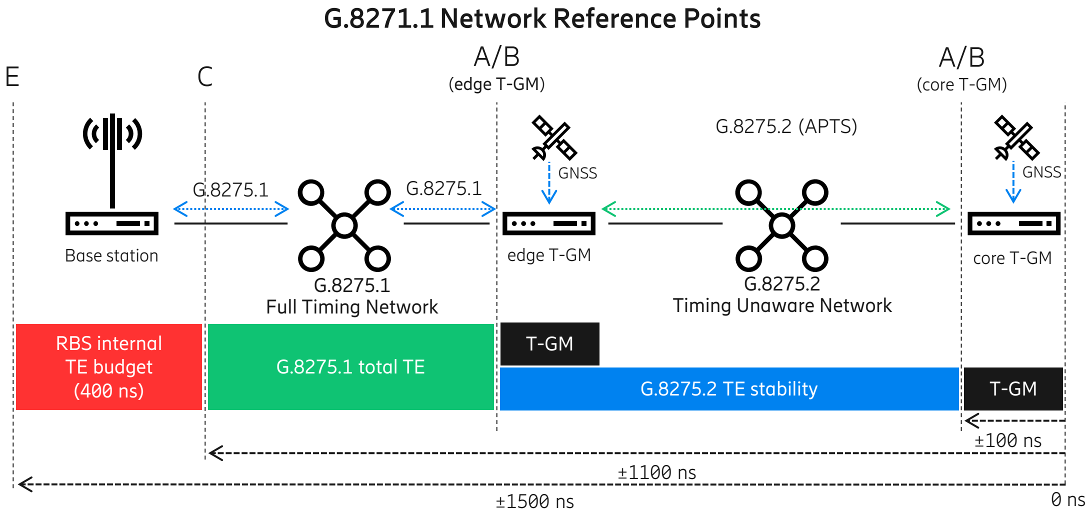

Figure 7: Network Time Error budget planning for combined PTP aware and unaware networks

Partial Timing scenarios
When a PTP signal traverses a PTP unaware device without any timestamping support, it may experience PDV and asymmetrical latencies in the downlink and uplink direction, resulting in time error at the half of the mean asymmetry. Risk of substantial asymmetry is especially high over devices with different port speeds. Asymmetry may also change at recablings or network rearrangements, so asymmetry calibration is not a safe remedy.

While using pure G.8275.2 partial timing solutions without any GNSS at the end application is an attractive option from a cost and simplicity perspective, such solutions have very limited applicability for TDD networks and are generally not recommended. While in some cases TE might be within the ±1.5 µs accuracy requirements, when it is exceeded it is challenging to detect or mitigate. The consequences of time accuracy degradation are usually only observable indirectly, through the degradation of RAN network KPIs (e.g. interfering cells).

On the other hand, G.8275.2 partial timing solution can comfortably meet the ±500 µs requirements of NR-FDD, providing a simple and cost-effective solution for these networks. In such cases the PDV tolerance is also higher, up to 1ms in case or Ericsson Baseband products.

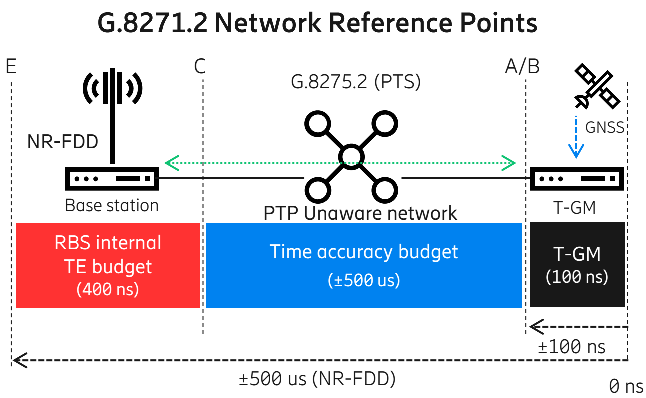

Figure 8: G.8275.2 partial timing for NR-FDD

Ericsson synchronization solution for 5G transport networks

There is no one-size-fits-all solution for time synchronization. Each transport network is unique and the most suitable and cost-efficient sync solution may be different from case to case.

Depending where a network starts from and what the target solution is (influenced by technology preferences, reliability goals, geopolitical situations, or state regulations), the evolution path and the optimal solution could be different. Not all options and combinations are suitable to meet the 5G timing requirements or provide an efficient and cost-effective solution, therefore in the following we list the most typical and viable options.

Timing in backhaul networks

In backhaul network scenarios planning starts with understanding the RAN technology that needs to be provided with synchronization service. Figure 9. summarizes the main combinations of technology alternatives for various RAN technologies.

Since most of the benefits of 5G technology can be achieved in the mid- and high-bands, and those bands are suitable for TDD technology, the most future-proof solution is to plan with NR-TDD requirements, which specify ±1.5 µs at the RAN input.

The next step is to consider the transport network preparedness for full timing support, that is PTP support in network elements and transmission links, as discussed in 3.2.2. If the network is not prepared (no HW support for PTP in equipment or significantly based on leased lines) or the PTP support is scattered and network modernization is not expected in the foreseeable future, then the most viable option is to install GNSS receivers at all RBS sites with some backup reference: primarily PTP in G.8275.2 profile or enhanced Synchronous Ethernet. GNSS may either be connected to the RBS equipment or to the cell site router. The latter has the advantage at large sites, because with a single GNSS receiver, all the RAN boxes can be fed with timing.

Such scenarios are well-supported by the Ericsson Router 6000 portfolio, which provides full support for the G.8275.1 and G.8275.2 profiles of PTP with Class C performance, enhanced EEC clock function and T-GM functionality with GNSS receiver input, and automatic and smooth switchover between available references, maximizing availability of the synchronization signal towards the RBS.

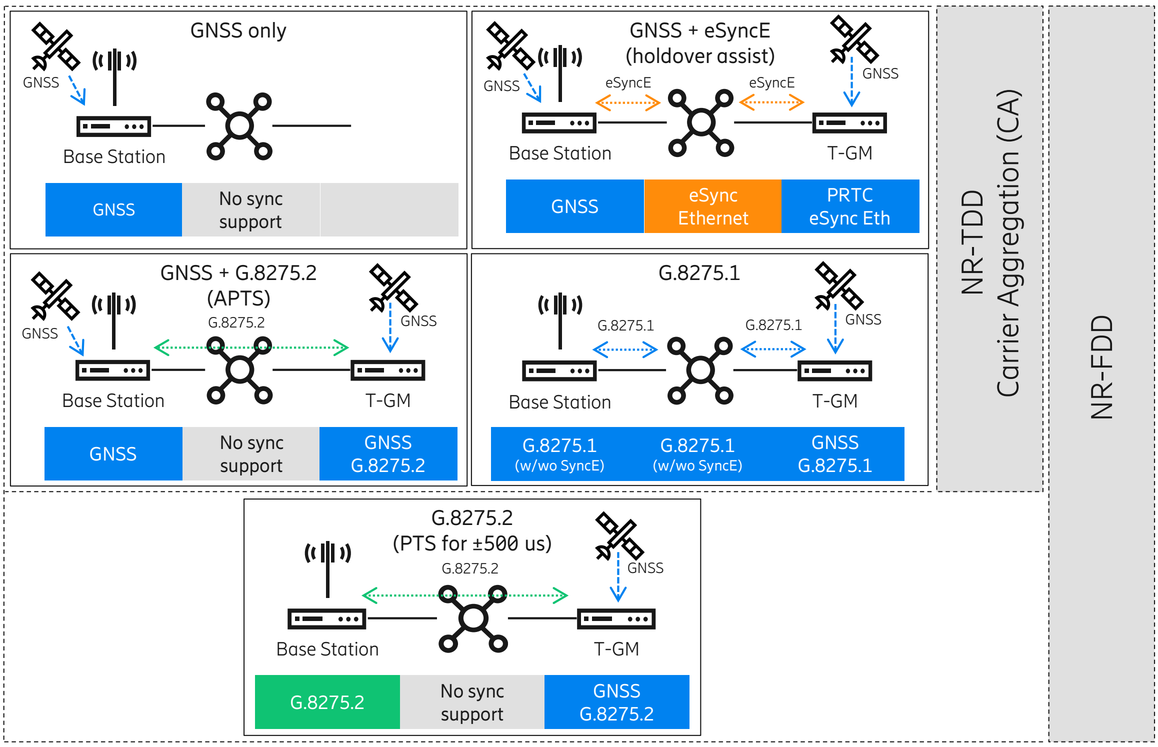

Figure 9: Transport network synchronization toolbox

The natural next step in the evolution is to expand the full timing support in the transport network further to the north and distribute PTP from an edge T-GM, or multiple redundant T-GMs, to all RBSs in a network segment.

This would allow saving GNSS installation cost on most of the sites. Such full timing scenarios can be extended over the microwave transmission network as well.

Ericsson's MINI-LINK product family has proven PTP solutions for G.8275.1 profile, achieving Class B performance or better [6].

In long term strategic plans for synchronization it is advisable to consider a GNSS-independent solution, which means deploying a few high-quality PRTCs in the core network that can operate without GNSS for long period of time (at least two weeks), based on an assisting cesium reference.

By implementing G.8275.1 full timing support all over the network, time can be distributed redundantly and reliably to all end points.

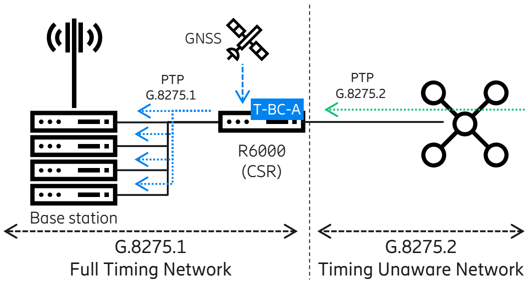

Figure 10: GNSS at RBS site connected to Ericsson R6000 device (CSR)

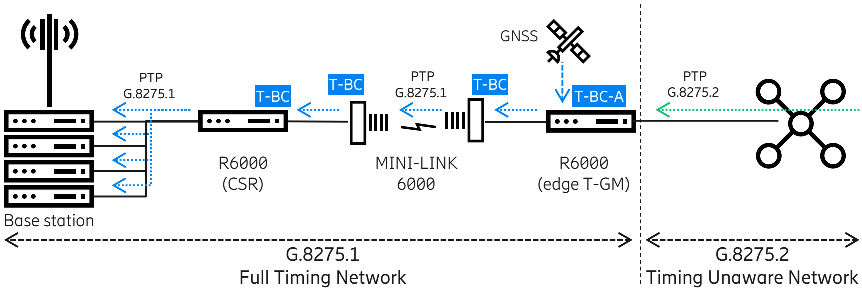

Figure 11: PTP full timing distribution from an Ericsson Router 6000 edge T-GM via MINI-LINK 6000 hop

Timing in fronthaul networks

Fronthaul networks are traditionally point-to-point direct connections between digital baseband units (DU) and remote radio units (RU), where the baseband unit has full control of the timing of its attached radio units. For advanced radio technologies, like various coordination features, tight time alignment of all the radio units are required in the range of 65-260 ns TAE.

This is challenging even in point-to-point topologies, making single fiber installation a preferred choice, as offered in Ericsson's Fronthaul 6000 optical portfolio.

With the advent of switched fronthaul networks, it will be more challenging to meet the timing requirements, driving requirements towards more accurate PTP clocks. Clock performance, however, is not the only challenge in fronthaul synchronization solutions. Another important aspect to consider is the impact of flexible fronthaul topologies on the timing distribution: in redundant switched fronthaul networks the timing topology, and hence the TAE between RUs, may change over time, depending on which potential PTP path becomes active. It requires careful network planning and some advanced PTP capabilities to keep the timing topology – and hence the TAE between RUs – under control, by forming a kind of PTP timing sub-segment from a group of RUs intended for coordination.

By decoupling the tight synchronization control and adding multiple switches between DU and RU, multiple failure points are introduced in the synchronization chain, hence the availability of synchronization becomes an important player in total system availability. Proper handling of synchronization network transients both from the performance and functional perspectives (e.g. clock class signaling in various clock states) is of utmost importance, making consistent network operation and interoperability between RAN and fronthaul transport equipment a critical network quality factor.

These are just a few examples of the challenges that operators need to face, some of which are probably not fully considered by some equipment vendors, making integration of equipment from different vendors in their fronthaul network more difficult for operators.

This is an evolving area, and there are not yet standardized solutions to all possible challenges. Ericsson, with its leading RAN and fronthaul technologies, is pioneering future fronthaul synchronization solutions with the Ericsson Router 6673 fronthaul gateway, offering a flexible and feature-rich synchronization solution for all possible needs.

Towards an ultra-reliable sync solution

As we have seen, synchronization requirements are not more stringent, but are becoming more essential in 5G than in 4G. Seamless synchronization operation is fundamental to unlock the full potential of 5G and to maintain uninterrupted network services. This includes seamless management, easy monitoring and observability, as well as addressing security challenges.

Management

Like for any other features, network-wide operation requires flexible and efficient configuration capabilities. Ericsson transport products offer a wide range of management options including configuration over GUI, command line or various machine-to-machine interfaces (SNMP, YANG) and network topology visualization. Synchronization management models have not yet been standardized but will hopefully be addressed by IEEE and ITU-T in the coming years.

Monitoring, observability

Network-wide monitoring and observability is key for quality assurance and efficient troubleshooting in case something goes wrong. This includes alarm handling, and monitoring synchronization counters and PM data collection including historical 15mins / 24hours counters. Such PTP PM counters have been standardized in IEEE1588-2019 [7] and all Ericsson transport equipment has support for them.

While these counters give a powerful tool for network operators to monitor and troubleshoot their PTP network, the ultimate limitation of all these monitoring options is that they do not reveal any time error that could emerge from link delay asymmetry or other sources. To measure and monitor time error, traditionally an external timing reference (typically GNSS) is required along with a dedicated measurement device that is connected to the network equipment in the field. This is usually cumbersome, costly and does not scale in large networks.

Instead, the transport device could do such in-service measurements in two main approaches, as shown in Figure 12:

- Absolute time error measurement between a GNSS and one or more PTP references (when equipped with GNSS receiver)
- Relative time error measurement between two PTP references

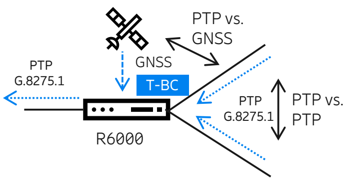

Figure 12: In-service time error monitoring without external measurement equipment

Such measurement functionality is offered by the Ericsson Router 6000 product family, making these products not only feature-rich transport synchronization devices, but also in-service time error monitoring equipment that could report measurements in real-time over the standard management network.

Security

Transport network security is growing in importance. While time is not a secret and therefore encryption is not needed, the reliability and authenticity of the synchronization references are of increasing importance, especially if we understand that radio service can be disturbed by taking the synchronization service down. A comprehensive summary of the security requirements of time protocols can be found in [8].

While there are various approaches addressing security challenges, including new security TLV in IEEE1588-2019, most threats in the G.8275.1 profile can be handled by proper configuration, mainly by disabling sync on all ports that are not used for sync distribution, and forcing master-only mode on ports where PTP reference is not expected (e.g. client facing interface). In G.8275.2 profile encapsulation to IPSec tunnels may address most threats.

It is worth noting that with any security measures, asymmetrically delayed PTP messages through man-in-the-middle attacks may be unnoticeable, though probably difficult to do.

Summary

To efficiently address RAN synchronization requirements, a good understanding of all the technology options for synchronization distribution in transport networks is essential.

Although the fundamental synchronization requirements have not become more stringent in 5G compared to 4G (and in some cases became more relaxed), for many operators 5G will be the very first time they have to meet the tight timing requirements of the TDD networks (±1.5 µs), with its very different needs versus FDD, and with a much smaller holdover window if sync fails. On top of this, NR-FDD also introduces the need for some level of time alignment, though to a much more relaxed level (±500 µs).

Due to the coming wide deployment of TDD in 5G, the concept of "GNSS everywhere" will not be feasible. Instead, adding PTP in G.8275.2 profile in an (assisted) partial timing manner to the network could be the first step and then continuously evolving towards G.8275.1 full timing, taking advantage of the natural transport equipment depreciation/upgrade cycle to build time sync capability through the entire transport network.

Ericsson's transport portfolio has been built specifically to address the timing needs of 5G RAN and is best-in-class for industry sync solutions both in performance and in feature offer.

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Abbreviations

3GPP	3rd Generation Partnership Project
APTS	Assisted Partial Timing Support
BMCA	Best Master Clock Algorithm
CSR	Cell Site Router
DU	Digital Unit
eEEC	Enhanced Ethernet Equipment Clock
FDD	Frequency Division Duplex
FTS	Full Timing support
GNSS	Global Navigation Satellite Systems
IEEE	Institute of Electrical and Electronics Engineers
ITU-T	International Telecommunication Union – Telecommunication Standardization Sector
KPI	Key Performance Indicator
NR	New Radio
NTP	Network Time Protocol
OTN	Optical Transport Network
PRC	Primary Reference Clock
PRTC	Primary Reference Time Clock
PTP	Precision Time Protocol
RAN	Radio Access Network
RBS	Radio Base Station
RU	Radio Unit
SNMP	Simple Network Management Protocol
T-BC	Telecom Boundary Clock
T-GM	Telecom Grandmaster
T-TC	Telecom Transparent Clock
TAE	Time Alignment Error
TDD	Time Division Duplex
TDM	Time Division Multiplexing
UE	User Equipment
UTC	Coordinated Universal Time
WDM	Wavelength Division Multiplexing

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