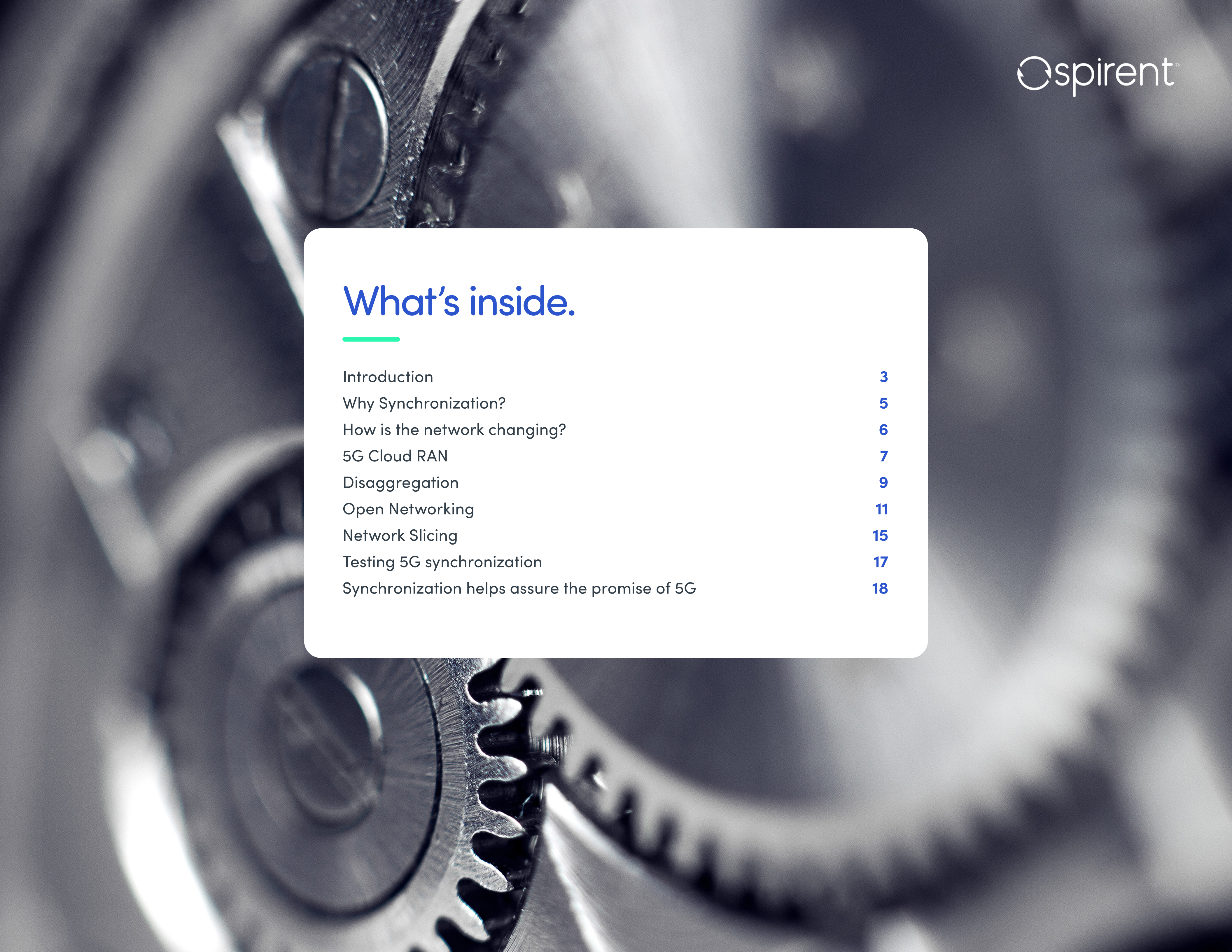
A SPIRENT E-BOOK

The Need for Timing and Synchronization in a 5G World



What's inside.

Introduction

According to the vision laid out by the International Telecommunication Union (ITU), the specialized agency of the United Nations responsible for issues concerning information and communication technologies, "5G is a wireless infrastructure to connect the world."

As always, hype and truth must be separated. However, as 5G devices and systems are moving from development to deployment, it is already apparent that some of the potential benefits will be realized in the next few years.

As highlighted in the [IMT Vision document] (ITU-R M2083.0), the main goal is to leverage new networking technology enhancements from 5G to deliver major advantages to society as a whole.

5G Goals

- Promote a new information and communication technologies (ICT) market to help drive economies around the globe
- Bridge the digital divide by providing affordable, sustainable mobile and wireless communications
- Enable new ways of communication, sharing content anytime, anywhere, through any device
- Enable new forms of education, boosting e-learning, e-health, and e-commerce
- Promote energy efficiency by supporting smart grid, smart logistics, and teleconferencing
- Social changes through shared opinions and information
- New art and culture; virtual group performances, art, and activities

Ultimately, these broader goals are described through the use cases and applications which 5G networks will enable. There are three main types of 5G use:

- Enhanced mobile broadband
- Ultra-reliable and low latency communication (URLLC)
- Massive machine-to-machine (M2M) type communications (i.e. Internet of Things)

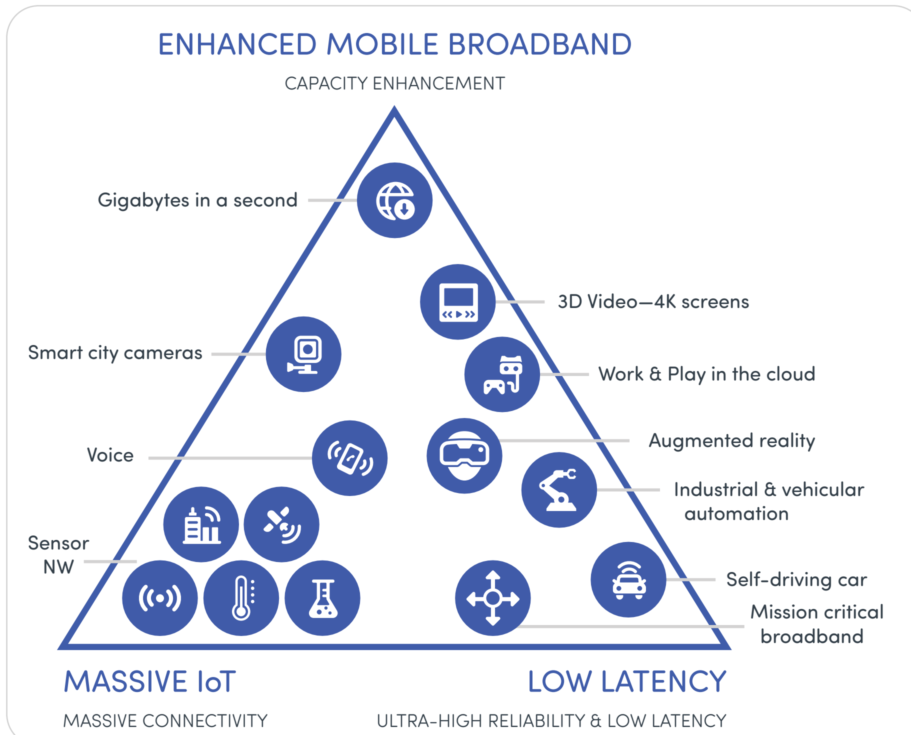


Figure 1. The triangle of 5G applications
Source: ETRI (ITU-R IMT 2020 requirements)

The capabilities required for these new applications, and a comparison to the requirements of pre-5G systems, are listed in the table.

Enabling wireless networks to deliver on these potential applications and providing the required support through the associated fixed networks, poses key challenges in many areas of research and development.

Many of the fundamental techniques involved in 5G not only **require synchronization**, but in fact demand levels of timing alignment beyond anything previously deployed on this scale.

This eBook explores the synchronization challenges for enabling breakthrough 5G experiences and reviews best practices for meeting 5G enhanced time requirements.

Capability	LTE, 4G	5G	Improvement
Peak Data Rate (Gbps)	1	20	20x
User Experienced Data Rate (Mbps)	10	100-1000	10-100x
Spectrum Efficiency	Baseline	2x/3x/5x	2x-5x
Mobility (km/h)	350	500	1.4x
Latency (ms)	10	1	10x
Connection Density (#/km2)	10^5	10^6	10x
Network Energy Efficiency	Baseline	100x	100x
Area Traffic Capacity (Mbps/m2)	0.1	10	100x

Why Synchronization?

5G user experiences that require ultra-fast speeds or ultra-low latency pose significant performance demands on the 5G radio and fronthaul networks. Many of the enhanced radio techniques that contribute to improved user experience in 5G rely on a tightly synchronized network.

The primary spectrum usage technique for 5G is expected to be TDD (Time Division Duplexing) to support high bandwidth 5G connections. Although currently deployed in several commercial 4G networks, the need (and performance requirements) for 5G will be greater.

TDD requires tight time and phase synchronization to protect against interference. For TDD, fronthaul network base stations must be synchronized to within 3μs of each other, or to within 1.5μs of a central time reference.

A range of enhanced radio techniques has been proposed for 5G, many of which involve the inter-operation of cells within a local area. This clustering further tightens the synchronization requirements between local Remote Radio Units (RRUs).

For example, 4G allowed aggregation of two carrier frequencies to provide increased data rates to consumers, with the frequencies transmitted from the same antenna. With 5G, however, frequencies from multiple RRUs in a local cluster can be aggregated. To enable this, the RRUs must be synchronized to within 260ns of each other—a **more than tenfold increase in accuracy** from the base network requirement.

To meet these requirements, the ITU-T has defined a new series of recommendations, building on those already defined for the use of Synchronous Ethernet (SyncE) and Precision Time Protocol (PTP) to deliver synchronization over Ethernet, and intended to deliver an order of magnitude better performance than those defined for 3G and 4G.

New enhanced accuracy classes have been defined for boundary clocks and end points for 5G applications. The time error produced by the highest specification boundary clock (Class D T-BC) must be less than 5ns, and in some cases less than 10ns for Class C T-BC clocks.

How is the network changing, and what does this mean for synchronization?

Beyond the more direct end user applications, there are multiple other transformations taking place in 5G networks. Some, such as **Network Slicing** and **Cloud RAN**, directly assist with achieving the new network performance goals. Some are more indirect, for example the strong industry push toward **open** and **disaggregated** networking. This potentially allows for more competition in the ecosystem and better price/performance, and the capability for network operators to choose the best solutions for each individual capability they need in their network (versus previous single vendor solutions).

All new developments are intended to align with the objectives of 5G, so the need for synchronization remains, and in some cases is even more important. However, the range of available networking options can mean added complexity which makes time transfer challenging.

The following sections provide a closer look at four changes currently happening in 5G, particularly the requirements and challenges for synchronization.

5G CLOUD RAN	SIMPLIFYING 5G DEPLOYMENTS
DISAGGREGATION	LEVERAGING NEW EQUIPMENT TYPES FOR 5G INNOVATION
OPEN NETWORKING	CREATING NEW ECOSYSTEMS FOR 5G
NETWORK SLICING	ENABLING 5G NETWORK TRANSPORT

5G Cloud RAN

5G Cloud RAN (also known as C-RAN), separates the radio elements of the base station from the elements processing the baseband signal. The baseband units, called Centralized Units or CUs, contain the main RAN intelligence and can be centralized in a single location or virtualized into the cloud. This simplifies deployments by decreasing equipment footprints and improving network efficiency by allowing for centralized management of resources. It also reduces the complexity of the radio equipment at the network edge.

As a result, fronthaul can connect a cluster of Remote Radio Units (RRUs) to create ultra-dense 5G macro and small cell networks close to the end user. Distributed Units (DUs) are placed in the architecture to handle processing that must be real-time and therefore cannot be done at the CU.

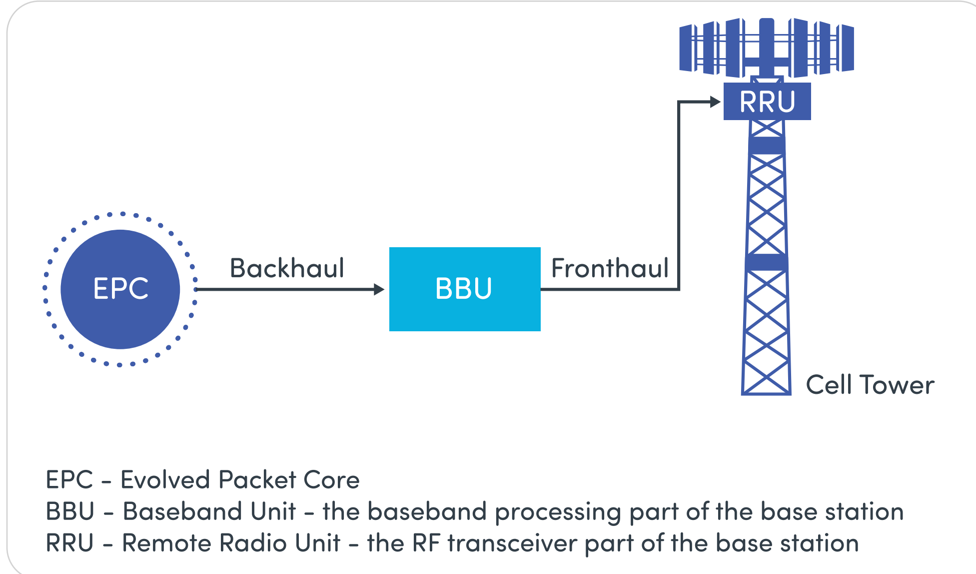


Figure 2. Original fronthaul concept

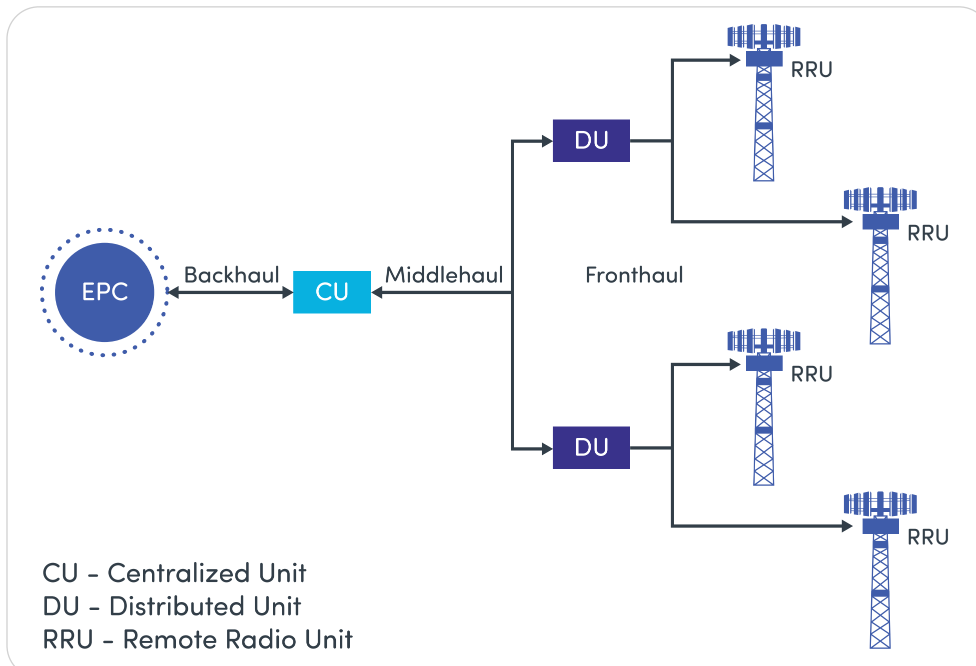


Figure 3. 5G functional split - CU, DU, and RRU

While there are many challenges to meeting 5G C-RAN performance requirements, the evolved architecture provides several technical benefits, including:

- More complex and expensive baseband processing becomes centralized
- Less latency-sensitive functions can be located further back in the network (or even virtualized)
- Support for flexible, standardized Ethernet versus proprietary connections, allowing more equipment choice
- Data and applications can be placed much closer to the end user, enabling edge compute services.

In summary, improved user performance and reduced costs via simpler cell sites, centralized high-power processing, and non-proprietary equipment.

As previously mentioned, one key requirement of a C-RAN network architecture is a very tight alignment of timing between adjacent RRUs, down to 260ns.

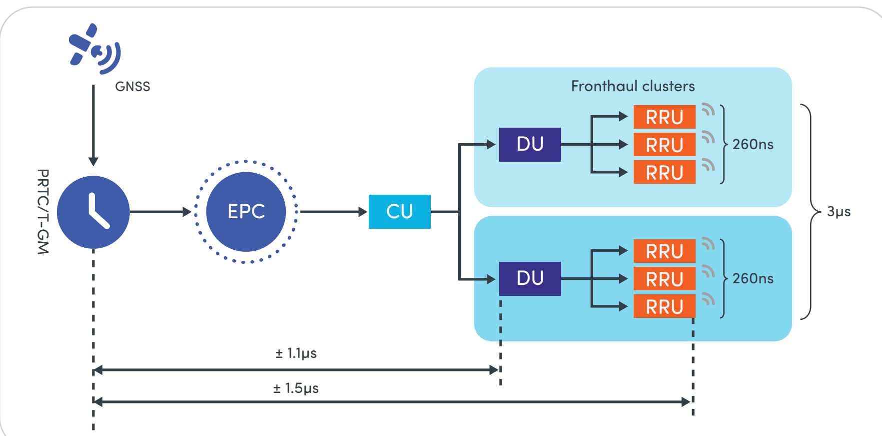


Figure 4. Disaggregated base stations for 5G

In the distributed system, achieving this relies on one or both of:

- Precision timing capability of upstream nodes, e.g. ITU-T G.8273.2 Class C or D Boundary Clock function in the DU
- GNSS timing support in the fronthaul, a potential example is ITU-T G.8273.4 Assisted Partial Timing Support (APTS) clocks.

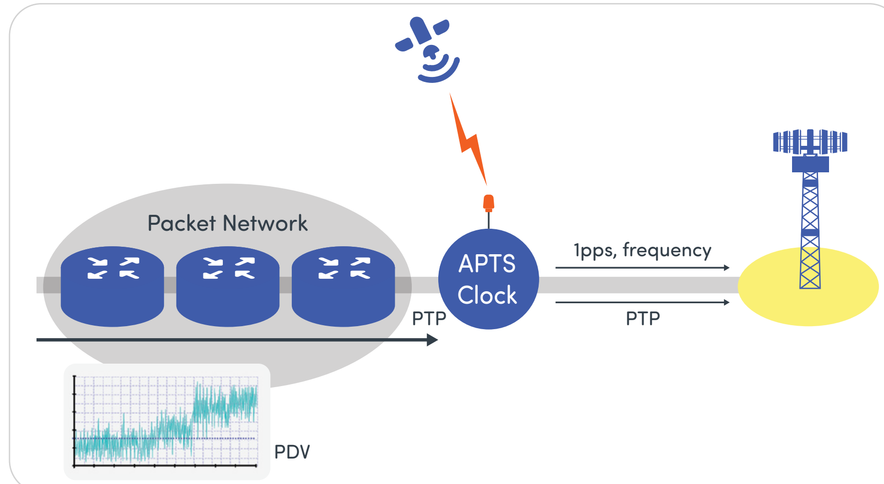


Figure 5. Aligning testbeds with GNSS and PTP stimulus/impairment

5G CLOUD RAN

Key Terms:

C-RAN

Centralized Unit (CU)

Distributed Unit (DU)

Remote Radio Unit (RRU)

Key Standards:

ITU-T G.8273.2 at least to Class C

ITUT G.8273.4

Test Challenges:

- Timing test to sub-nanosecond accuracy for Class C and D devices
- Capturing and Replaying real network timing conditions in the lab

Disaggregation

Leveraging networking transformations that have shown major benefits in the data center space, many major telecoms operators and vendors have joined together to support moves toward disaggregated networks. These networks essentially consist of a split between previously integrated network solutions and platforms into independent and interoperable white box hardware, middleware/operating systems, and software or virtual network functions. Specifications for new equipment types have resulted from the Telecoms Infra Project (TIP), a multi-company community with the stated aims of:

- Increasing the **robustness and flexibility** of telecom supply chains
- Accelerating **innovation in network technology**
- Improving **network economics**

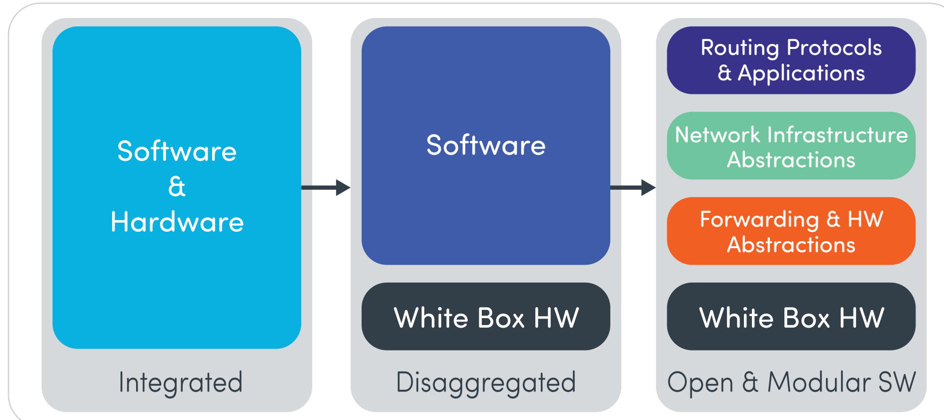


Figure 6. Disaggregation helps drive 5G innovation

One example of a TIP specification is that for the **Disaggregated Cell-Site Gateway (DCSG)** setting communication and performance parameters that should be met by, for example, white box vendors intending to supply the underlying hardware for these systems.

These specifications recognize that the fundamental benefit is also one of the biggest challenges for disaggregated telecoms equipment: To allow the flexibility that is the aim, the capability to support the full range of end applications (including those driven by precise timing) is essential.

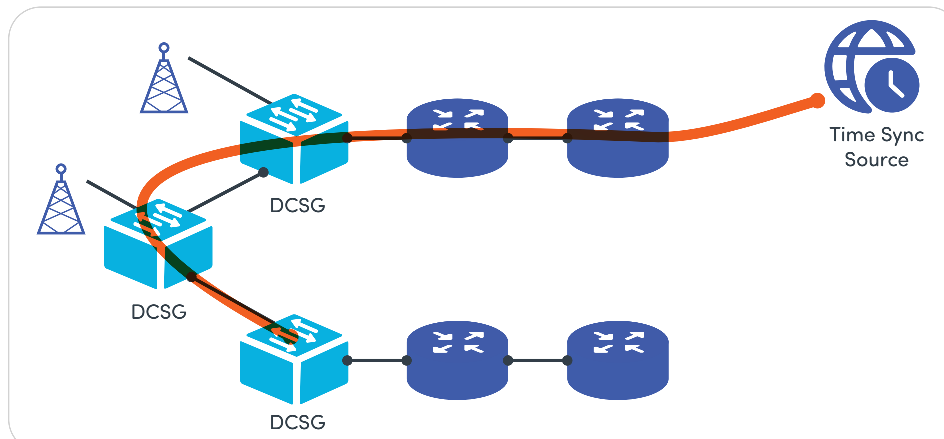


Figure 7. Enabling flexibility at the 5G cell site
Source: Telecom Infra Project

Operators have specified as part of the essential requirement for DCSG that devices must perform to ITU-T G.8273.2 Class C, and white box hardware must therefore have fully proven PTP and SyncE capabilities to the highest levels of accuracy.

Furthermore, the final combination of disaggregated software with base hardware must also be proven.

Because combinations of vendors and functions can be specifically matched to operators' needs, there may be more burden on the operator to plan and validate the system, versus what had become more of a turn-key single vendor approach.

Going forward, the capability to capture and recreate real-network conditions in the lab will allow operators to troubleshoot and improve network timing with confidence.

DISAGGREGATION

Key Terms:

Telecom Infra Project (TIP)

White box

Disaggregated Cell Site Gateway (DCSG)

Key Standards:

ITU-T G.8275.1

ITU-T G.8273.2 at least to Class C

ITUT G.8262/G.8262.1

Test Challenges:

- High number of software/hardware/operating system combinations mean the individual timing contribution of each element must be proven – the margin for error is small
- Systems must be ready for future performance requirements
- Each network environment will be very different, recreating environments is key

Understanding O-RAN Synchronization Architecture

Related to both the industry movement to disaggregated solutions, and the redefined fronthaul network, the Radio Access Network (RAN) has been identified as an area that will particularly benefit from allowing independent combinations of software and hardware.

A particular challenge, especially given the rise in both Cloud RAN architectures and disaggregated systems, is the need to have common communication and interfaces between systems. To that end, the O-RAN Alliance was formed to define these interfaces and help accelerate deployment of multi-vendor Radio Access Networks.

Specific areas of focus have been the functional split between the Open Distributed Unit (O-DU) and Open Radio Unit (O-RU), considering the need for eCPRI (Ethernet) communication to allow for higher data bandwidths. The functional split in O-RAN is referred to as Split Option 7-2x.

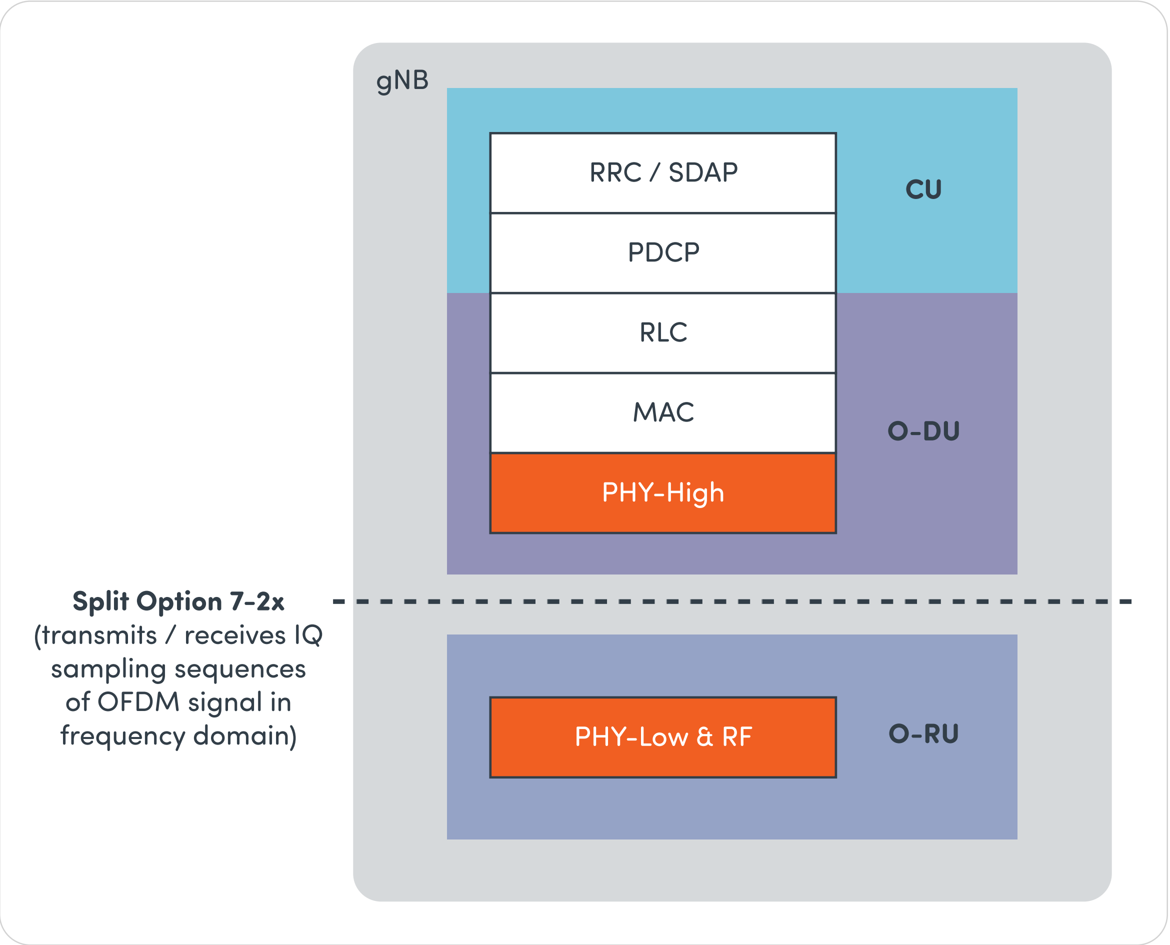


Figure 8. Visualization of the Split Option 7-2x

Further specifications cover Management, User, Control and Synchronization planes.

Regarding accurate synchronization, ORAN-WG4-CUS.0 includes the specification of the O-RAN fronthaul synchronization plane and the basic synchronization requirements.

Four synchronization topologies are defined for O-RAN, as shown in the figure.

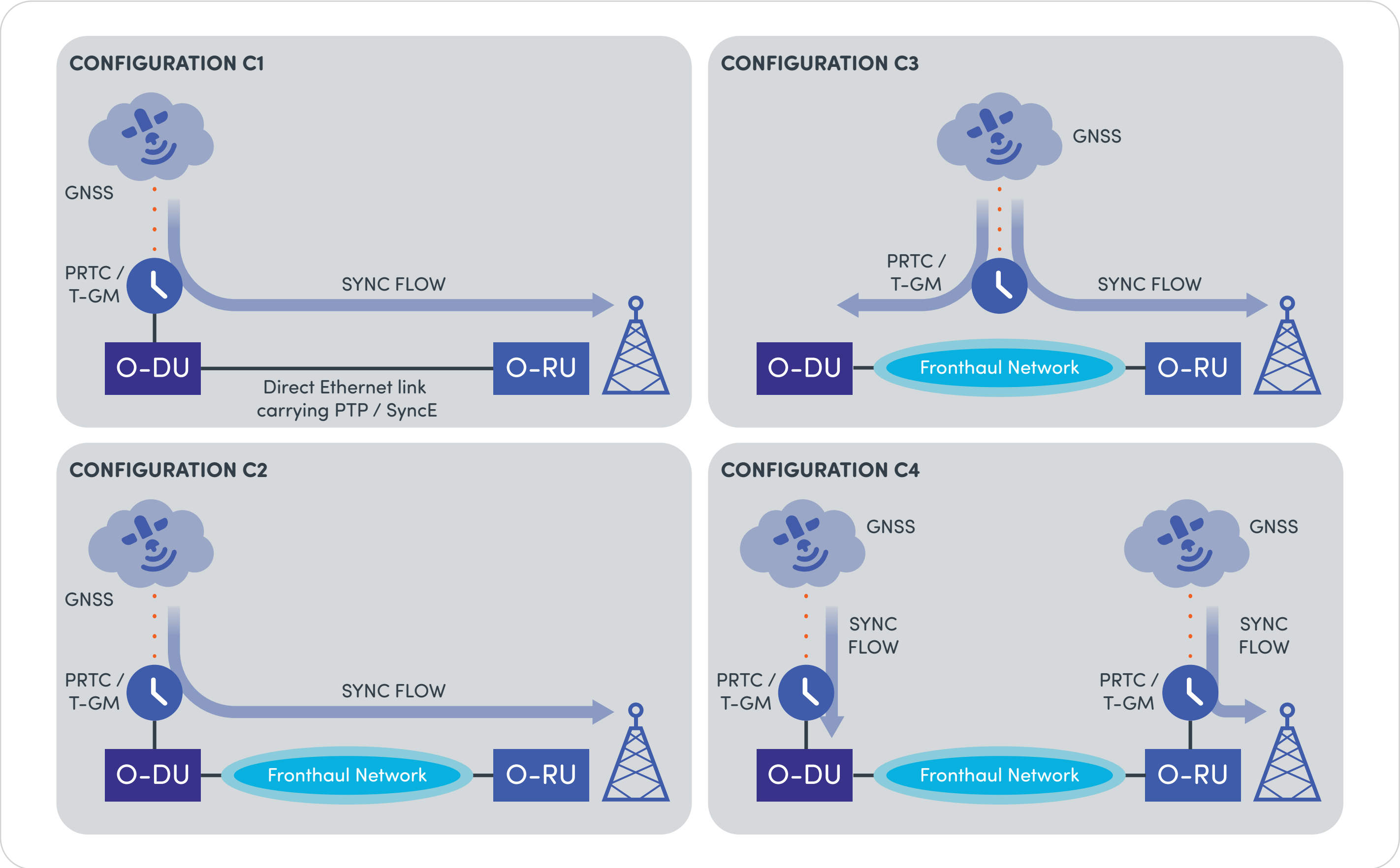


Figure 9. O-RAN LLS* Sync Architectures

Note that the synchronization input to the O-DU can be through a packet network, e.g. mobile backhaul conforming to ITU-T G.8271.1.

At each point in the fronthaul network, the time and frequency performance of the equipment and network is defined. The figure shows an example.

Two types of O-RU are defined: the regular O-RU (containing a Class B T-TSC) and the enhanced O-RU (containing an enhanced T-TSC, roughly equivalent to a Class C).

- With a regular O-RU, the time error budget is 80ns, leaving 95ns for the fronthaul network.
- With an enhanced O-RU, the time error budget is 35ns, leaving 140ns for the fronthaul network.

The O-RAN S-plane conformance test specification also:

> assumes that the vendor's equipment is conformant and has been tested to meet the requirements of G.8275.1 and IEEE1588v2 and other relevant S-Plane standards.

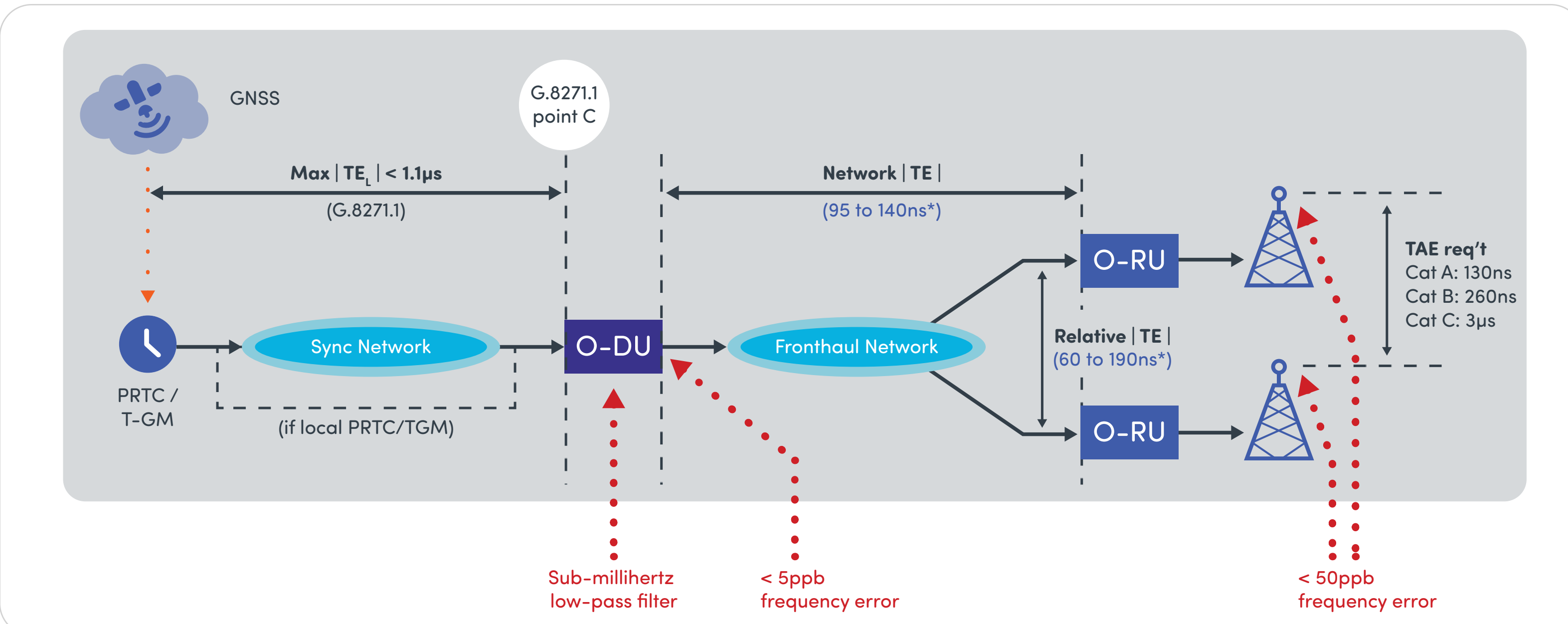


Figure 10. O-RAN C2 Fronthaul configuration example

G.8275.1 is a full on-path timing support profile, and therefore the network nodes (including the O-DU) must perform as e.g. Telecom Boundary Clocks, in line with ITU-T G.8273.2.

The fronthaul budget number is not dependent on the number of switches in the network. The number of switches must be small enough such that the time error and relative time error fits within the budget numbers. If Class B devices are used, that number might be quite small; with Class C (or D), it could be much larger.

Due to the many different potential deployment scenarios, the patterns of time error caused by network chains can vary greatly. The capability to stress test the timing performance of equipment under time error conditions, representing both the defined limits and representative network effects, is essential. This is explicitly referenced in the O-RAN conformance testing specification:

> [test equipment] should be capable of testing S-Plane performance under stress with various noise profiles.

OPEN NETWORKING

Key Terms:

O-RAN Alliance

O-DU

O-RU

Key Standards:

ORAN-WG4-CUS.0

ITU-T G.8275.1

ITU-T G.8273.2 at least to Class-C

ITUT G.8262/G.8262.1

Test Challenges:

- Lab timing test to sub-nanosecond accuracy for Class B O-DU and enhanced O-RU devices
- Replaying standards-defined and real-world time error conditions

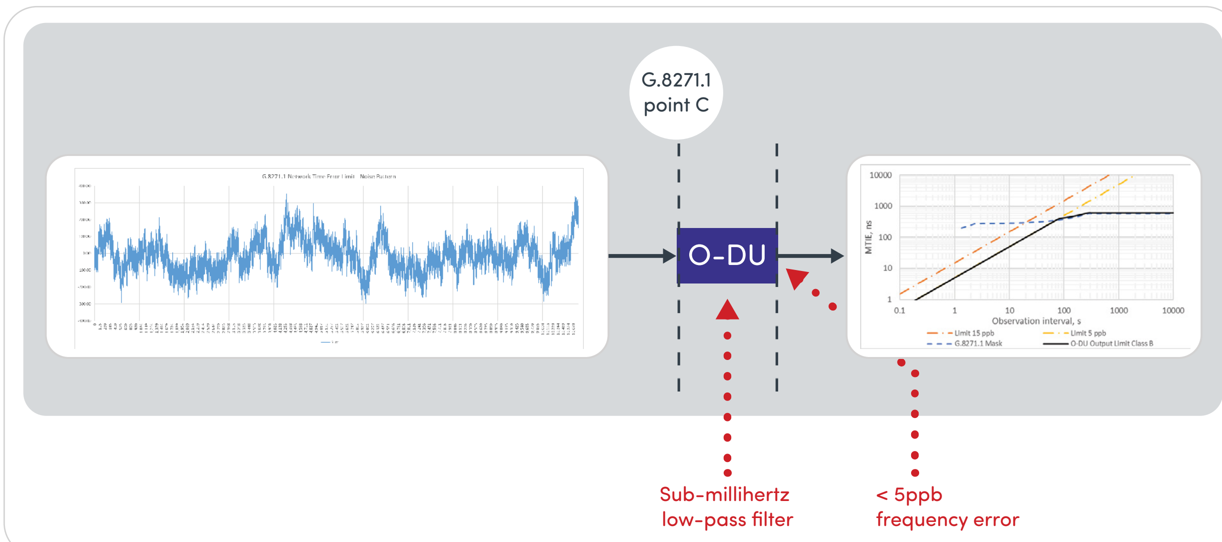


Figure 11. Time and frequency error budget example

Exploring the Role of Network Slicing

5G is intended to cover a very broad range of end applications. AR/VR, massive IoT, autonomous vehicles, and enhanced mobile broadband are just some examples of use cases with vastly different requirements in terms of bandwidth, latency, security, and time synchronization. However, the transport network for 5G must support all of these.

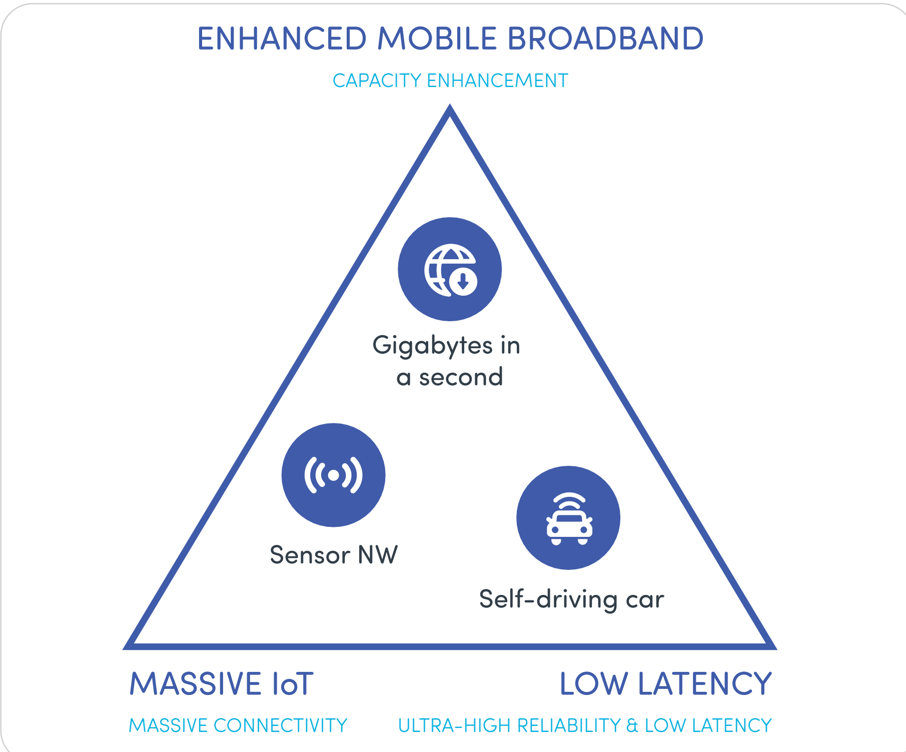


Figure 12. 5G application examples

With standardization efforts underway in ITU-T G.8312, network slicing using Flex Ethernet (FlexE) will play a crucial role in meeting the diverse requirements for the transport network driven by these various applications. This will enable service providers to build end-to-end virtual networks tailored to application requirements - a great value proposition for example, when operators are offering solutions to enterprise customers.

G.8312/FlexE is a Layer 2 (hardware-oriented) approach to network slicing. Similar to ATM mechanisms from previous network generations, small data blocks (5Gb in this case) can be multiplexed across high capacity networks. The three commonly highlighted capabilities of FlexE to assist in Network Slicing are:

- Bonding (providing higher capacity by combining existing links)
- Channelization (using discrete pipes within the overall capacity to allow differentiated capabilities)
- Sub rating (allowing under-filled channels)

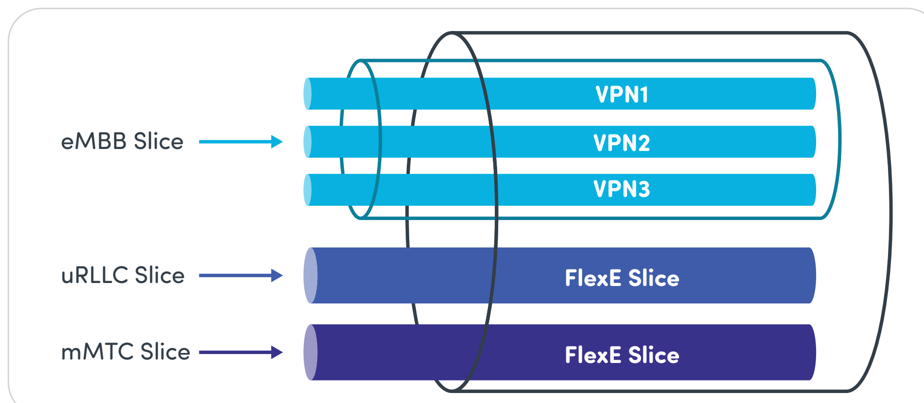


Figure 13. FlexE provides a hard pipe network slicing solution with calendar-based channelization

There are strong use cases for these features, however many of the end applications that network slicing is intended to support also rely on precise synchronization and therefore the transport network must still preserve timing performance.

The benefits provided by technologies such as FlexE are not inherently beneficial to network synchronization, as:

- Framing structures can cause latency changes each time the link is established
- Asymmetry between forward and reverse paths due to these latency changes

Special Treatment for FlexE Synchronization?

For applications such as Class C and Class D PTP devices in G.8275.1 full on-path timing support networks, synchronization cannot be carried in FlexE clients, because framing structure causes variable asymmetry

The Optical Interworking Forum (OIF) Interoperability Agreement FlexE 2.0 (2.1 for 50GbE) approaches this problem by specifying PTP and ESMC (SyncE quality levels) carried in an overhead channel as below:

- Overhead channel is always on the first FlexE instance of the group
- Message timestamp point is the start of the overhead multiframe

These features offer benefits for achieving high timing performance in full-on path timing systems and are also part of the developing ITU-T G.8312 specification for Metro Transport Networks.

For systems being deployed in operator networks using, for example FlexE and full-on-path support over large numbers of hops, timing requirements can be as low as 5ns accuracy for a device, mandating direct testing of single device timing performance over FlexE interfaces. Testing of a Boundary Clock function with a mixture of FlexE and standard Ethernet on the inputs and outputs will also be required as it is a likely network scenario.

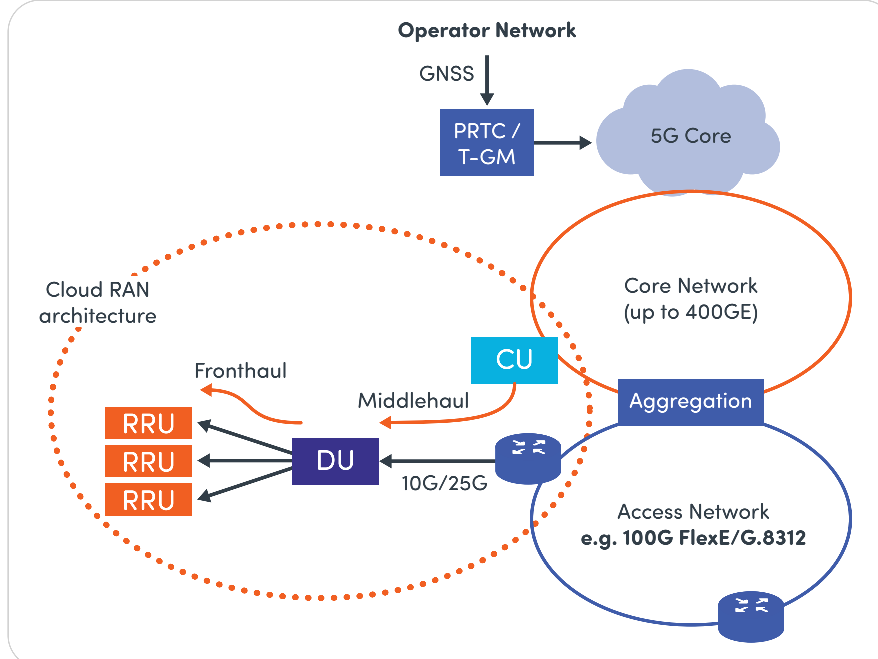


Figure 14. Operator network example

NETWORK SLICING

Key Terms:

Metro Transport Network (MTN)

FlexE Overhead

Multiframe

Key Standards:

ITU-T G.8312

OIF FLEXE-2.0 and 2.1

ITU-T G.8273.2 at least to Class-C (for full on-path timing support systems)

ITU-T G.8262.1

Test Challenges:

- Timing test to sub-nanosecond accuracy over the FlexE overhead channel
- Testing FlexE-to-Ethernet and Ethernet-to-FlexE as per expected Operator network topologies

Testing 5G Synchronization

Accurate synchronization is a fundamental component of 5G systems. Historically, this was a specialized development and test requirement within both equipment manufacturers and service providers.

Currently, the criticality of synchronization and the added complexity in delivering accurate time, due to disaggregated and multi-vendor environments, mean that precise, detailed, and robust synchronization testing is a fundamental requirement for software and hardware vendors, System Integrators and Service Providers alike.

The fundamental nature of synchronization calls for specific testing to be performed. Before conducting pre-deployment proof of concept (PoC) and interoperability testing with multiple pieces of network equipment, it is necessary to verify device timing performance.

The first step in the validation process is to test each device individually to ensure it meets the required specification. In the example case of Class C T-BC and Class D T-BC clocks, an integrated testbed with PTP and SyncE sub-nanosecond test capability is required, as shown in the figure.

Timing performance metrics and limits may vary depending on the target deployment scenario. In addition, stress-testing scenarios which are key to proving that new products and multi-vendor solutions meet the needs of real-world deployments can be very complex. Some of the challenges observed include:

- Accurately applying input synchronization signals over new technologies such as FlexE
- Adding Time Error stress into testbeds both for conformance testing (e.g. ITU-T, O-RAN) and to recreate the varying effects caused in multi-vendor/topology environments
- Precisely testing failover scenarios between discrete timing sources such as PTP and GNSS

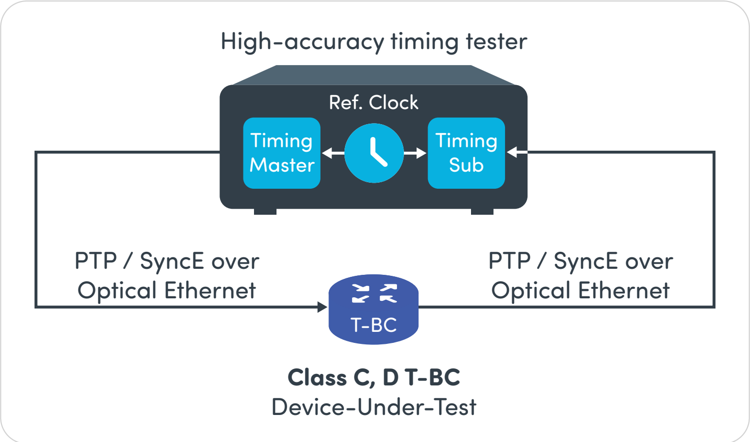


Figure 15. Device testing of Class C, D T-BCs

Below are some typical scenarios for 5G synchronization testing:

Use Case 1

Network equipment manufacturers must validate their chipset implementations of Precision Time Protocol (PTP) for conformance to the latest 5G ITU-T standards. Demonstrating their components' conformance to the latest standards is an essential step for the successful integration into their customers' equipment.

Use Case 2

As Telcos develop solutions for core, cell site, and radio access networks (RAN), they must ensure 5G synchronization capabilities across their R&D sites. These new capabilities will enable them to sell end-to-end solutions to their customers.

Use Case 3

Equipment manufacturers delivering network synchronization capabilities to Tier-1 operators via new intelligent network solutions such as Disaggregated Cell Site Gateways (DCSGs), need to prove that their system has the precision timing capabilities essential to enabling future applications planned for the network. The performance of timing technologies such as PTP are expected to be as low as nanoseconds per device. Demonstrating performance in this area is an essential requirement for their customers and a potential differentiator in the market.

Synchronization helps assure the promise of 5G

In summary, the synchronization requirements of 5G are significantly harder to meet than previous mobile generations. In combination with this, several technology advancements in new networks add complexity to timing transfer and therefore pose additional challenges.

This has been recognized by the industry at large, and many initiatives that are underway pay full attention to the need for defined, precise, and robust timing performance.

As a result, developing and proving synchronization functions in 5G networks can be achieved with confidence by utilizing testbeds that integrate standards-defined test workflows and precision capabilities for generation and measurement of timing signals such as PTP and SyncE. This can be further enhanced by enabling real-world timing conditions to be recreated in the lab environment.

Read ITU-T 5G conformance and 5G network equipment validation case studies.

Learn more about solving the timing challenges of 5G.

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