

5G Synchronization over a Microwave Transport Network

White paper

Time synchronization distribution over the transport network is a commonly used ‘hidden’ tool to support the 5G mobile user experience. The precision required for each transport network element is in the range of a few nanoseconds, which is a very challenging target especially for microwave networks. This white paper describes the deployment scenarios, the challenges, and the solutions available with Nokia Wavence microwave links.

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Synchronization and interoperability

Synchronization is a key topic in transport network deployments; each new generation of mobile networks has driven the need for new synchronization techniques and improved synchronization accuracies. This need requirement is translated by several network operators into a request for synchronization distribution via the transport network. The rationale behind this approach is mainly related to cost optimization, redundancy, or independence from Global Navigation Satellite System (GNSS) infrastructures, such as the Global Positioning System (GPS).

Focusing on mobile backhauling case, synchronization distribution over the transport network has been used since the early days of 2G. At that time, 2G Base Transceiver System (BTS) synchronization needs were met thanks to the frequency reference embedded into time division multiplex (TDM) signals: typically, the same PDH E1/ DS1 is used for the user data connection to the 2G BTS. A lot changed along the development path from 2G to today's 5G. The two most important changes are the shift from PDH/SDH to native Ethernet traffic for the transport network interfaces and the shift from frequency-only synchronization to Time of the Day (ToD) synchronization of the base stations.

This new scenario requires a native-Ethernet protocol, IEEE 1588v2, transported together with the Ethernet user traffic and specifically tuned for time synchronization distribution.

Interoperability between different suppliers and between the transport network and the Radio Access Network (RAN) is recognized as a key requirement by both operators and equipment vendors. Consequently, both groups contributed to a large standardization effort devoted to the development of a comprehensive ecosystem of standards. The most important ones for the transport network are the ITU Telecommunication Standardization Sector (ITU-T) series, G.826x and G.827x. This set of standards provides a solid basis for interoperability and performance targets, covering end-to-end (E2E) behaviors and a single element's behavior within the transport network. In terms of network architecture, the basic idea behind this approach is to have specific functionality (called 'on-path support') embedded in each transport element to control the E2E ToD performance and the ToD performance at each transport element output. This solution – IEEE 1588v2 with the related ITU-T transport profiles and performance targets – is at the leading edge of the technology in terms of protocols, standards complexity, and algorithms.

Figure1. E2E synchronization distribution via a microwave transport network



Radio Access Network Backhauling

Radio Access Network Backhauling (RAN BH) uses and will in the future continue to comprise a mix of fiber and microwave transport, with more than 40% of new macro-cell BH connections in 2026 expected to be covered by wireless links (source: *Dell'Oro Jan'22 "Microwave Transmission & Mobile Backhaul Five Year Forecast Report 2022 – 2026", tables*). The microwave portion of the E2E transport network endures some specific challenges, such as dynamic impairments from atmospheric propagation conditions and on average, smaller bandwidths when compared to the fiber portion of the transport network.

Microwave transport networks are therefore important to analyze in detail. Microwave networks can be deployed using different product categories available from the microwave industry. The two most common ones are split-mount systems and full-outdoor systems. Additionally, considering how microwave links are connected to other network elements, you typically see three cases:

- **Split-mount systems** are composed of a microwave Indoor Unit (IDU), which provides traffic interfaces switching or multiplexing elements and nodal capabilities and an Outdoor Unit (ODU) performing the microwave wireless transmission. Split-mount systems are used in simple point-to-point connections and in nodal configurations, aggregating multiple radio directions. They are also used in more complex topologies, such as rings or meshes.
- **Full-outdoor radios directly connected to a BTS.** A full-outdoor radio is a self-contained system incorporating the traffic interfaces, the radio modem, and the RF transceivers. In this case, the full-outdoor radio is directly connected via an Ethernet connection (very often 10 Gbps) to a 4G/5G BTS. This topology is often used for last-mile hops or for short microwave chains.

Full-outdoor radios connected to a Cell Site Router (CSR). This use case is like the first one, the difference being the IDU is not a “microwave-box” but rather a router, potentially from a different supplier connected to one or multiple full-outdoor radios. It should be noted that the recent market introduction of full-outdoor dual-carrier radios (for example, the Nokia Wavence UBT-Twin) made the deployment of this use case simpler than in the past, because popular configurations, such as 2+0 XPIC and Carrier Aggregation, can now be served with the connection of a single radio unit to the CSR.

The ‘design recipe’ for ITU-T target performance

In the case of a microwave transport network, it is important to note that multiple ingredients are needed in the ‘design recipe’ to comply with ITU-T performance, and more generally, to meet the needs of 5G RAN synchronization. These ‘ingredients’ include:

- The right architectural and design choices.
- Hardware (HW) timestamping with the proper physical components.
- Transparent Clock (TC) and Boundary Clock (BC) algorithms that are specifically tuned for the microwave radio environment and for impairments resulting, among other things, from propagation conditions, adaptive modulation, bandwidth overload, or carrier aggregation.

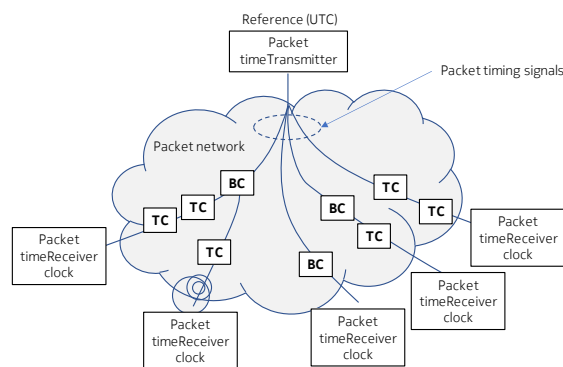
- Proper support – whenever available – from the Ethernet physical layer distribution of the frequency references, that is Synchronous Ethernet.

All the above ingredients have been carefully embedded into Nokia Wavence microwave radios, whether they are split-mount systems or full-outdoor ones, simple point-to-point connections or complex nodal/ring systems. This results in backhauling solutions capable of satisfying the strictest E2E synchronization requirements.

Boundary Clock and Transparent Clock as approaches

Boundary Clock and Transparent Clock are two complementary approaches for the ‘on-path’ support of time synchronization distribution via 1588, as detailed by the three ITU-T standards G.8275, G.8275.1 and G.8275.2.

Figure 2. BC and TC – from ITU-T G.8275



In a nutshell, a **BC** network element regenerates the *time* locally (acting as a timeReceiver¹ with respect to the 1588 timeTransmitter or the upstream BC) and distributes that *time* to the downstream 1588 BC or other 1588 timeReceivers (acting as a 1588 timeTransmitter for them).

Conversely, a **TC** network element only tracks in each 1588 packet the delay (= the noise) experienced by that specific packet to traverse the network element. This allows downstream BCs or timeReceivers to recover the *time*, without being impacted by the noise introduced by the intermediate transport network elements.

The ITU-T Standard G.8275 describes the architecture for time synchronization distribution, while the G.8275.1 and G.8275.2 describe two deployment scenarios:

¹ In accordance with draft IEEE P1588gTM/D1.2 “Draft standard for a precision clock synch (...) Amendment: Master-slave optional alternative terminology” we use in this white paper the term ‘timeTransmitter’ instead of ‘master’ and ‘timeReceiver’ instead of ‘slave’

- **G.8275.1** defines the profile for the so-called ‘full timing support’, a scenario where each transport network element must implement either BC functionality or TC functionality. Ethernet multicast encapsulation is used for 1588 packets.
- **G.8275.2** tackles “well-planned cases where network behavior and performance can be constrained within well-defined limits, including limits on static asymmetry”. Under these assumptions, G.8275.2 defines the profiles for the ‘partial timing support (PTS)’ and the ‘assisted partial timing support (APTS)’. Neither of them requires all intermediate nodes to provide BC or TC support and APTS uses 1588 only for backup with respect to GPS.
IP Unicast is used for 1588 packets.
The usage and performance of TC network elements have been declared ‘for further study’ under the umbrella of the G.8275.2 scenario.

Split-mount links with Boundary Clock. Figure 3 depicts a Nokia Wavence Carrier Aggregation (CA) split-mount radio link with 2 network elements and 2 Boundary Clocks in cascade. Using automated testing, hundreds of tests have been run to identify the worst case with respect to various load conditions, simulated propagation impairments and adaptive modulation. The measured performance complies with ITU-T G.8273.2 Class B limits and so enables multiple applications; 5G synchronization via the BH transport network being one of the most important.

Figure 3. Wavence Split-Mount Boundary Clock (BC)

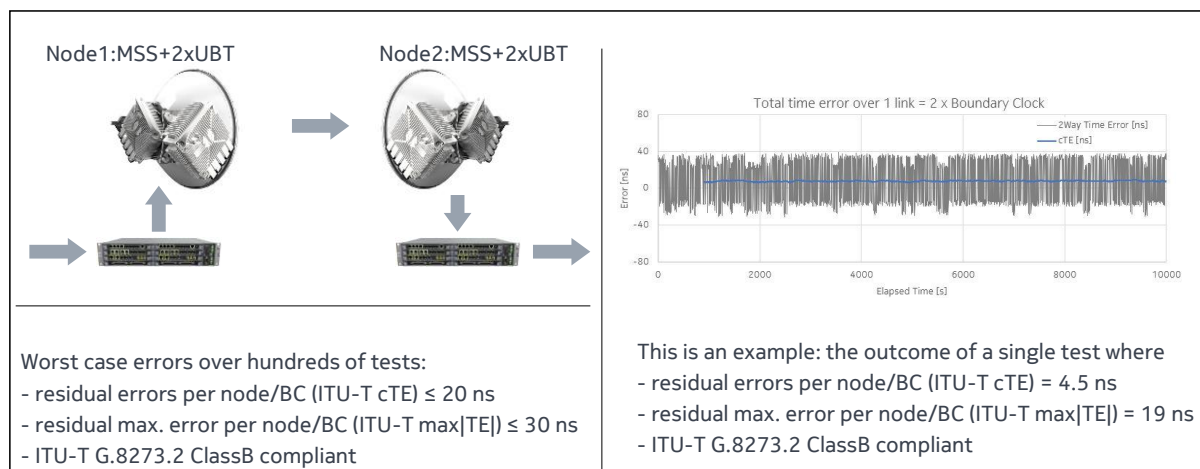
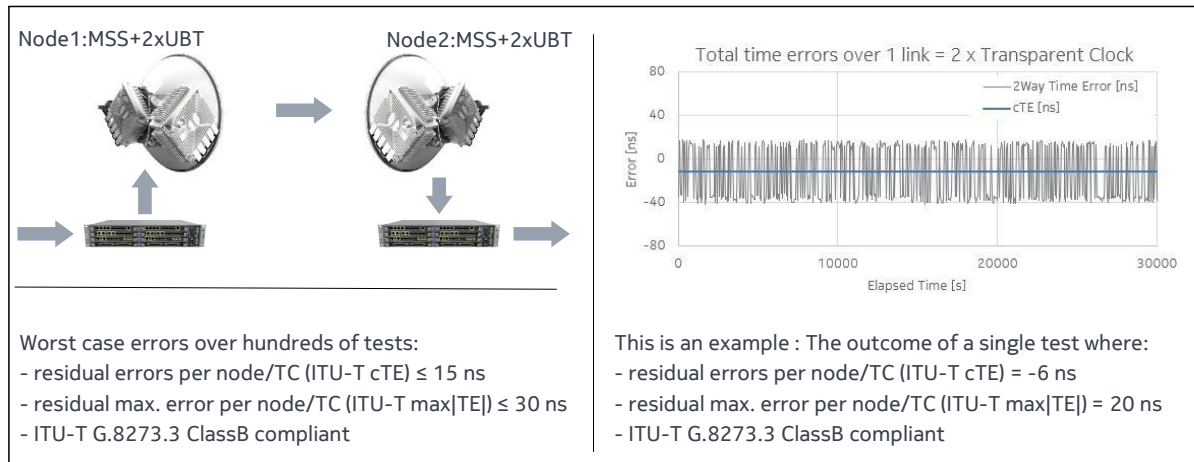


Figure 4. Wavence Split-Mount Transparent Clock (TC)

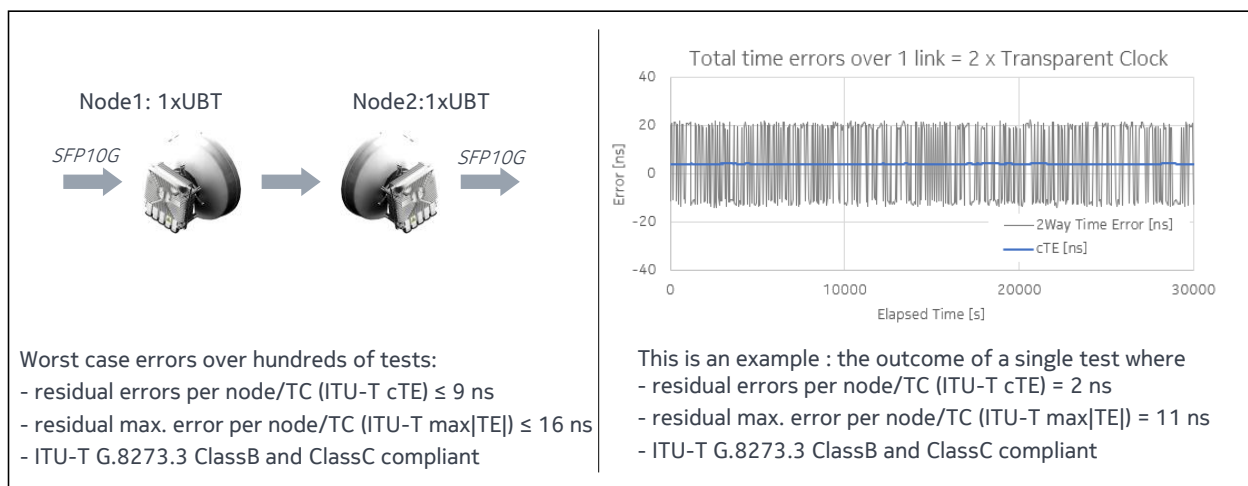


Split-mount links with Transparent Clock. Figure 4 depicts a CA split-mount radio link with 2 Transparent Clock network elements in cascade. In this case as well, an automated test bench allowed multiple tests under various impairments, with a measured performance within ITU-T G.8273.3 Class B limits.

The conclusion is that with Wavence microwave radio links, the Boundary Clock approach and the Transparent Clock approach can be easily mixed, while still maintaining best in class ITU-T Class B compliancy.

Full-Outdoor links with Transparent Clock. Figure 5 depicts a Wavence high throughput full-outdoor point-to-point link, implemented with a 1+0 or 2+0 Wavence ODU box per site. Here the performance is even better than the one in the previous section: in each site ITU-T G.8273.3 Class C limits are respected whatever the impairment conditions (as a reminder: Class C limits are stricter than Class B limits). This is an unprecedented result that paves the way for more radio links in a chain and in fronthauling applications.

Figure 5. Wavence Full-Outdoor Transparent Clock (TC)



Conclusions

Multiple end-user applications require synchronization distribution over the transport network.

5G backhauling and fronthauling is probably the most important example, with target residual errors in the range of a few nanoseconds per network element.

This white paper presents the deployment scenarios, the challenges and the solutions available with Nokia Wavence microwave links. Multiple test results with Nokia Wavence microwave radio links have been detailed in various deployment cases, such as split-mount and full-outdoor, for direct connection to a BTS or a router. Moreover, it introduces the investigation on the performance provided by Nokia Wavence radios when using the Boundary Clock approach with respect to the Transparent Clock approach. The main findings are:

- Nokia Wavence Split-Mount and Full-Outdoor links provide best-in-class performance and in compliance with the strict Class B performance of ITU-T standard series G.8273.x. This compliance was tested on both E-Band and traditional frequencies, with and without Carrier Aggregation (intra-band and/or multi-band) and with and without Adaptive Modulation.
- Two approaches can be used in general in accordance with ITU-T standards: Transparent Clock and Boundary Clock. We showed that with Nokia Wavence links both approaches comply with the strict Class B performance of ITU-T standards. This is an important feature because it means network operators can choose their preferred deployment strategy. The Transparent Clock approach is often chosen by operators in point-to-point links, in leaf links, or in the case of direct connection to a router. The Boundary Clock approach is usually chosen in the case that monitoring points are needed or in large size nodal sites.
- The case of Full-Outdoor point-to-point microwave links is increasingly used for 5G backhauling and fronthauling. Using the Transparent Clock approach, the performance of the Nokia Wavence radio links complies with ITU-T Class C on E-Band and traditional frequencies.

These findings are the basis for the usage of Nokia Wavence radio links. They act as a reliable and a future-proof solution for 5G time synchronization distribution over a microwave transport network.

Abbreviations

APTS	Assisted Partial Timing Support
BC	Boundary Clock
BH	Backhauling
BTS	Base Transceiver System
CA	Carrier Aggregation
C-Band	The frequency range from 4 GHz to 8 GHz, except in the U.S. from 3.7 GHz to 4.2 GHz.
CSR	Cell Site Router
E2E	End-to-end
E-Band	The frequency range from 60 GHz to 90 GHz
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HW	Hardware
IEEE	Institute of Electrical and Electronics Engineers
IDU	Indoor Unit
ITU-T	ITU Telecommunication Standardization Sector
NE	Network Element
ODU	Outdoor Unit
PDH	Plesiochronous Digital Hierarchy
PRTC	Primary Reference Time Clock
PTS	Partial Timing Support
RAN	Radio Access Network
SDH	Synchronous Digital Hierarchy
TC	Transparent Clock
TDM	Time Division Multiplex
ToD	Time of the Day
UBT	Ultra-Broadband Transceiver



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