Virtual Primary Reference Timing Clock (vPRTC)

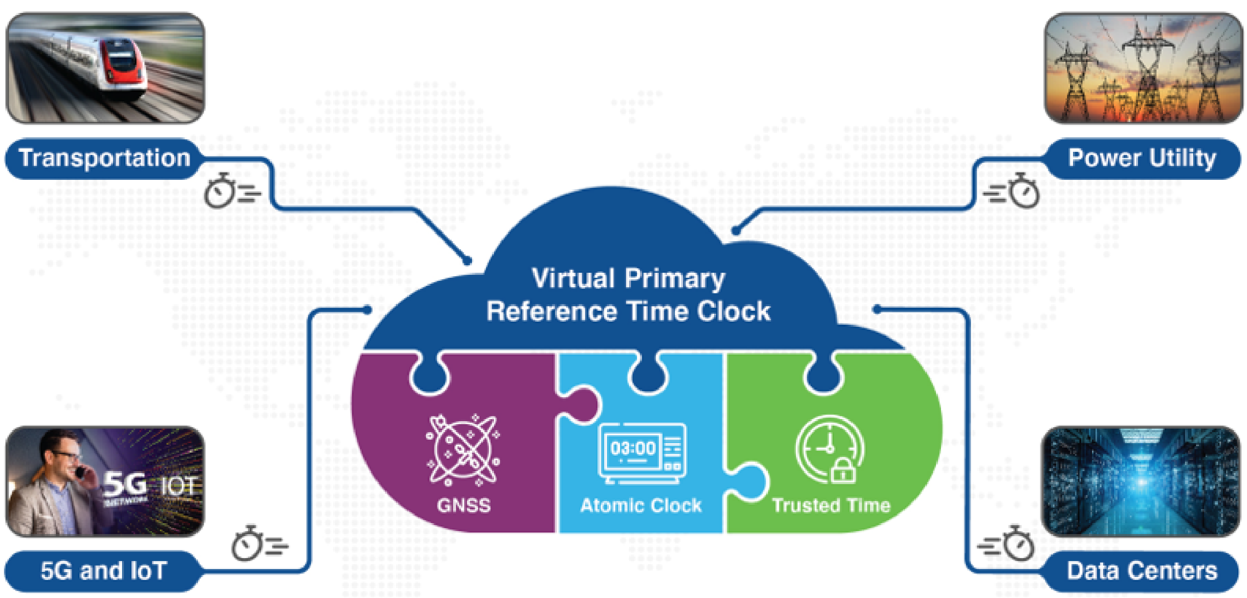
Introduction

Microchip is the world leader in time and synchronization technologies that enable critical services. Microchip's history of innovation continues with the virtual Primary Reference Time Clock (vPRTC), a network architecture that can deliver extremely stable, sub-100 nanosecond time to any point on a DWDM network. Specifically designed to enhance new or existing DWDM networks, the TimeProvider® 4100 High-Performance Boundary Clock can supercharge the optical transport layer to create a "virtual PRTC" that offers deterministic, resilient timing services at unprecedent levels of accuracy, saving operators time, expense, and complexity throughout the network.

The increased need for clock accuracy and precision in critical infrastructures such as communications, transportation, energy, and data centers is well understood. GNSS has been deployed ubiquitously across these industries as the "only way" to deliver local 100 ns timing solutions to growing areas of need, resulting in rapid proliferation of highly accurate point timing solutions in mission-critical applications.

Today, the conversation is shifting from pure accuracy and precision to security and resiliency. It is not enough to simply deliver an accurate timing instance. Critical infrastructure operators must consider their overall timing hygiene and know that their source of timing can be trusted, that it is validated, that they have network wide visibility and monitoring. Most importantly, they must ensure that they have resiliency in the form of backups and protection when something goes wrong.

Figure 1. The Virtual Primary Reference Time Clock Provides Secure and Resilient Timing to Critical Infrastructures



The vPRTC is simple in concept. It blends proven timing technologies into a centralized and protected source location, and utilizes commercial fiberoptic network links with advanced IEEE® 1588 Precision Time Protocol (PTP) high accuracy boundary clocks to distribute PRTC 100 ns level timing to end points hundreds of kilometers away where it is needed. The central locations receive their UTC time traceability from GNSS using highly protected and validated receivers. Threats in the form of GNSS spoofing or jamming attacks are continuously monitored using advanced firewall technologies to assure only valid signals from the sky are passed to the central clock. The central clocking system employs industry proven cesium atomic clocks to establish 30 ns guaranteed accuracy traceable to UTC. If GNSS is detected to be not valid or even completely denied, the vPRTC source maintains 100 ns traceability to UTC for a minimum of 14 days.

With these highly resilient clocks in place, the operator can use their secure fiber optic network to distribute protected timing to all locations that need it. Just as a GNSS satellite based timing system distributes timing to end points using open air transmission, the vPRTC distributes timing using the fiber optic network. The difference is that the fiber optic network is 100% in control of the network operator, and can be secured. The vPRTC architecture can be deployed as the sole source of timing, or can be deployed as a back-up to GNSS based timing solutions.

One of the first industries to adopt the vPRTC architecture is the communications industry. Communications networks have a long history of using centralized cesium atomic clocks and network based clock distribution technologies. With 5G exploding and with increased need for PRTC 100 ns level timing in more and more locations, operators are looking for more protected and resilient ways to deliver timing for their 5G networks. This paper examines engineering considerations for the vPRTC architecture, and presents initial field proven results.

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1. Precise Timing and Network Requirements

The 5G NR architecture imposes the use of PTP as the primary timing protocol for delivery of timing to the Radio Units (RU) (see 5G Changes Network Timing Architectures). From an operator perspective, the biggest question is where to locate the source Primary Reference Time Clock (PRTC). There is not a natural demark point in 5G transport networks such as the BBU in 4G. This challenge can be solved by deploying the vPRTC where every point on the network can be at the equivalent PRTC performance level (100 ns).

Network operators prefer that timing and synchronization, a critical and fundamental function of modern networks, be predictable and stable, but also need flexibility in transport network engineering. The following table contrasts these different requirements.

Table 1-1. Contrasting Network and Timing Requirements

Generic	Synchronization Network
Flexible transport technology	Deterministic
Flexible interface speeds	Resilient
Flexible switch/router capacity	Traceable to primary reference
Flexible networking protocols	Future proof
Flexibility provisioning	Independent from transport layer Independent from traffic

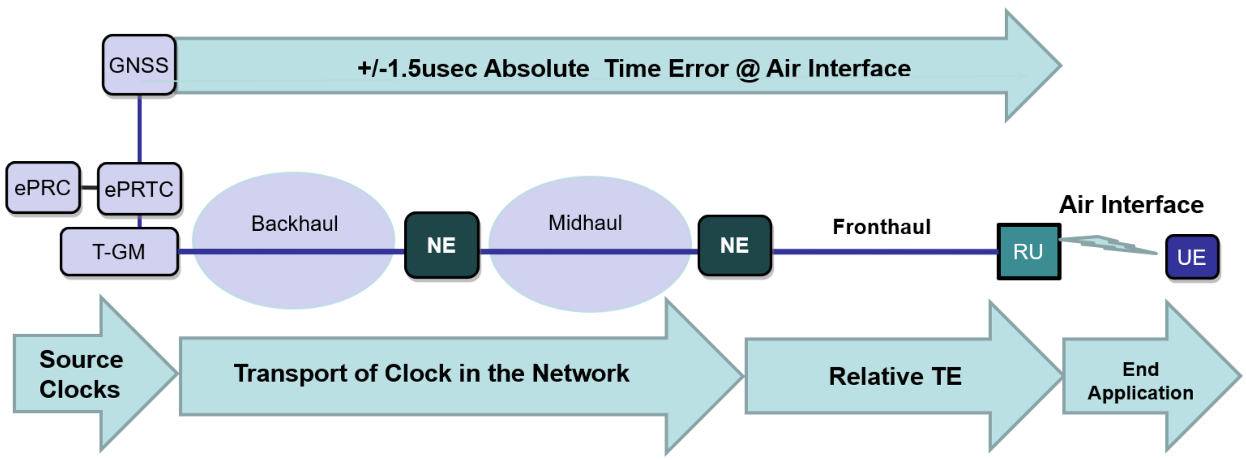
2. End Application Requirements Drive Synchronization Architectures

End application requirements drive network timing architectures. Modern mobile networks require tight frequency and/or time alignment between adjacent RU. Both the transport and synchronization networks must be engineered to guarantee these timing parameters. The synchronization network needs to be designed to support the tightest requirements required with agility to address the continual evolution to tighter end application timing requirements.

2.1 End-to-End Time Error

For the radio elements on a network to meet the time or frequency alignment required, the network must transport the timing signal from the source clock to the radios. Time Error (TE) is with reference to a well-known (traceable) time/clock, usually UTC. LTE and 5G radios must have a maximum TE of ±50 ppb for frequency and ±1.5 μs for phase coordination. The basic end-to-end architecture is shown as follows.

Figure 2-1. Basic Network Timing Architecture



Synchronization architecture is segmented into Source, Transport, and Use. The major challenge for mobile operators is to transport the timing from the source clock to the end application within the stated TE requirements.

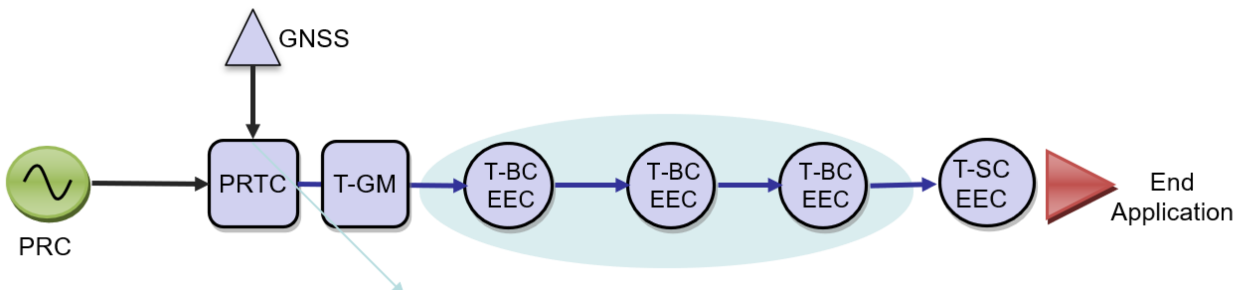
3. Phase Synchronization

LTE amd 5G networks either use GNSS at the base stations or PTP (also known as IEEE 1588).

A Primary Reference Time Clock (PRTC) in conjunction with the PTP Grandmaster supports two-way communications with PTP packets to the PTP clients, which then extract the phase information and use it to synchronize the radio elements.

For phase-based LTE-TDD/LTE-A amd 5G services, operators have a choice of PTP profiles: G.8275.2 uses a UDP unicast over IP layer 3 model. This protocol does not require dedicated clocking hardware in the network elements, G.8275.1 uses multicast PTP on L2 transport. This hop-by-hop model requires a G.8273.2 Time Boundary Clock (T-BC) to control the PTP signal and a G.8262.1 syncE (eEEC) phy to stabilize the element oscillators on every transport node. The G.8275.1 architecture is shown as follows.

Figure 3-1. G.8275.1 Architecture



3.1 Time Boundary Clocks

The time boundary clock T-BC plays a critical role in providing on-path support of the G8275.1 PTP timing service. Although the T-BC function is normally considered as an embedded function in switches and routers along the path, it can also be stand-alone which will be discussed shortly.

To ensure the network can transport PTP within the required TE, the T-BC must meet tight specifications. These have evolved over the past ten years.

The following table shows the time error requirements from Class A through Class D.

Table 3-1. cTe Specifications for T-BC (G.8273.2) and T-TSC (G.8273.3)

Parameter		Class A	Class B	Class C	Class D	Class D+	Unit
maxITEI	Unfiltered	100	70	20–22	10		ns
cTE+dTE$_L$				15	10	5	ns
cTE		50	20	10	5	3	ns
dTE$_L$ (MTIE)	Constant temp up to 1.000 s	40	40	10	5	2	ns
	Variable temp up to 10.000 s	40	40	FFS	5		ns
dTE$_L$ (TDEV)	Constant temp up to 1.000 s	4	4	2	1		ns
dTE$_H$	Variable temp up to 1.000 s	70	70	20	10		ns

3.2 Operational Impacts of T-BC Changes

Operators prefer maximum flexibility in network service engineering, and a very stable synchronization network independent of transport and protocol changes. The constant change in T-BC specifications requires continual hardware changes in the transport elements that can be costly and disruptive.

4. The Virtual Primary Reference Time Clock (vPRTC) Network

The G.8272 PRTC source clock in conjunction with a PTP GM function has the following basic attributes:

- GNSS input (to capture time/phase information relative to UTC)
- PTP output using G.8275.1 or G.8275.2 profiles
- Maximum TE for the PTP output of ≤±100 ns (The PRTC also has MTIE & TDEV requirements, refer to ITU-T recommendation G.8272.)

The ITU considers the PRTC clock function and PTP GM protocol function as separate components. The term PRTC is sometimes used to define a system that supports both functions in an integrated unit although many PRTC units are deployed as standalone clock functions.

Furthermore, these functional components may be standalone or integrated into a Network Element. However, since G.8272 defines functions not an implementation, a network that meets the G.8272 specification end-to-end can be described as a network-based, or “virtual” PRTC.

A virtual PRTC can be defined as a network that meets the following requirements:

- PRTC-A specification ≤±100 ns time accuracy relative to UTC on a PTP output at any point on the network
- G.8272 MTIE mask at the PTP output at any point on the network
- G.8272 TDEV mask at the PTP output at any point on the network
- Can provide SyncE (eEEC) at any point on the network (optional)
- Can provide any PTP output anywhere on the network
- Can provide 1PPS, and Time of Day (ToD) output anywhere on the network (optional)

To do this the vPRTC requires a set of well-defined clocking and transport components:

Network Components

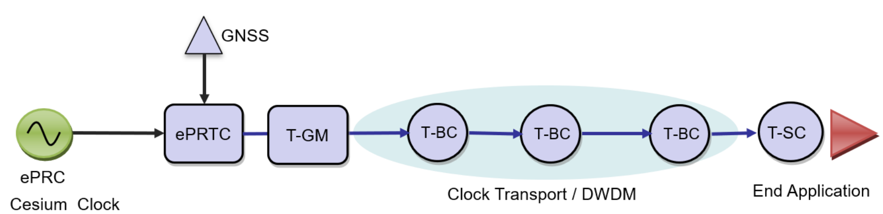
- Source clocks:
  – Enhanced Primary Reference Clock (ePRC) Cesium clock for frequency holdover
  – Enhanced Primary Reference Time Clock (ePRTC) for phase holdover
  – Primary Reference Time Clock class B (PRTC-B) high-performance source clock
- Transport clocks:
  – High-Performance Optical Boundary Clock (HPBC) Class D or better

Network Requirements

- Preferred transport type DWDM pure lambda (recommended)
- Transport directly at Layer 0 (Dark Fiber)
- Uses any appropriate PTP profile
- May optionally use SyncE

The vPRTC uses the ITU transport model for G.8275.1 as follows:

Figure 4-1. vPRTC as an ITU-T G.8275.1 Model



Functions

Timescale:	Enhanced Primary Reference Time Clock	**ePRTC**
Holdover Clock:	Primary Reference Time Clock	**ePRC**
Clock Distribution:	Time GrandMaster	**T-GM**
Clock Transport:	High Performance Boundary Clock	**HPBC (T-BC)**
Clock distribution protocols	**G.8275.1, G.8262.1, G.8275.2,**	

4.1 Virtual PRTC Network Transport

To meet the tight time transfer requirements of the vPRTC, the optimal transport is a DWDM optical network. Separating the PTP flow from higher layer transport and protocols ensures that network timing can meet stringent end-to-end requirements and avoids the complexities and uncertainties inherent when engineering PTP over the OTN, Ethernet, or MPLS layers. It also adds an intrinsic layer of security. In some use cases a vPRTC in an OTN environment with Class C Boundary Clocks in the timing could be engineered with a limited number of hops. The key to this implementation would the ePRTC component of the vPRTC architecture.

5. Optical Transport (DWDM)

Dense Wavelength Division Multiplexing (DWDM) multiplexes signals onto a single optical fiber pair. More than 80 separate wavelengths can share a single optical fiber while maintaining complete separation of the data streams. This allows carriers to add multiple services inside the same fiber/lambda. A dedicated lambda can be used for services such as timing.

As with Ethernet (L2), the native DWDM network is subject to asymmetries caused by separate fibers for transmit and receive, signal regeneration, O-E-O switching, and the frequency differences between lambda. Even small local effects per system can have a significant cumulative impact on phase transport. The most effective management of these local effects would be to use a control mechanism like a T-BC on the DWDM Network Element. But, DWDM systems today do not have embedded clocks comparable to those found on L2/L3 switch/routers.

Microchip has solved this problem with the TimeProvider® 4100 High-Performance Boundary Clock (HPBC).

5.1 The TimeProvider 4100 High Performance Boundary Clock (HPBC)

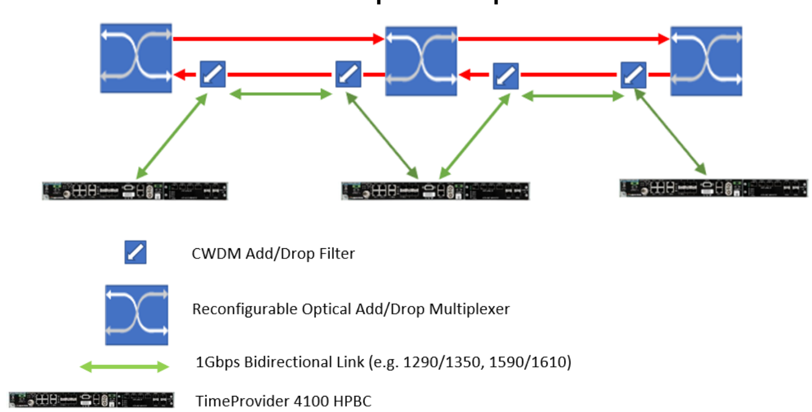
The TimeProvider 4100 is a sophisticated network clocking element with the ability to transfer timing with extraordinary levels of precision, and can be configured in different operational modes: ePRTC, PRTC-A, PRTC-B, Gateway Clock, and as a HPBC designed for the optical layer. In HPBC or “Boundary Clock” mode it meets or exceeds ITU-T G.8273.2 Class D specifications as given above. For more information on operational modes, refer to the TimeProvider 4100 Datasheet.

While the HPBC on the DWDM plays a similar role, it is a quite different to an Ethernet T-BC. The latter are unidirectional, have a single clock domain, and a very basic de-jitter function. The HPBC is a sophisticated clocking element with multiple PTP inputs and clients and dual clock domains per port. With full bi-directional functionality the system accepts PTP input from different directions (“East” and “West”) simultaneously. HPBC monitors the incoming clocks and selects the most stable, highest quality input. HPBC also runs a global Best Master Clock Algorithm (BMCA) function that enables fast switchover between PTP inputs as necessary.

5.2 Deployment on the DWDM System

Modern DWDM Reconfigurable Add/Drop Multiplexer (ROADM) systems can employ add/drop filters to create a hop-by-hop channel over a bidirectional link that is well suited for precise time transfer. In this case, the TimeProvider 4100 PTP output can be directly connected to the DWDM. This method enables transport of timing at the most fundamental frequency layer of the network, provides a non-blocking path independent of user traffic, avoids impact of any congestion in L2 or L3 switches, avoids impact on timing of upper layer network or protocol re-arrangements, and insulates the timing network from extraneous L1/L2/L3 engineering or provisioning. The following figure shows a DWDM transport interconnect example.

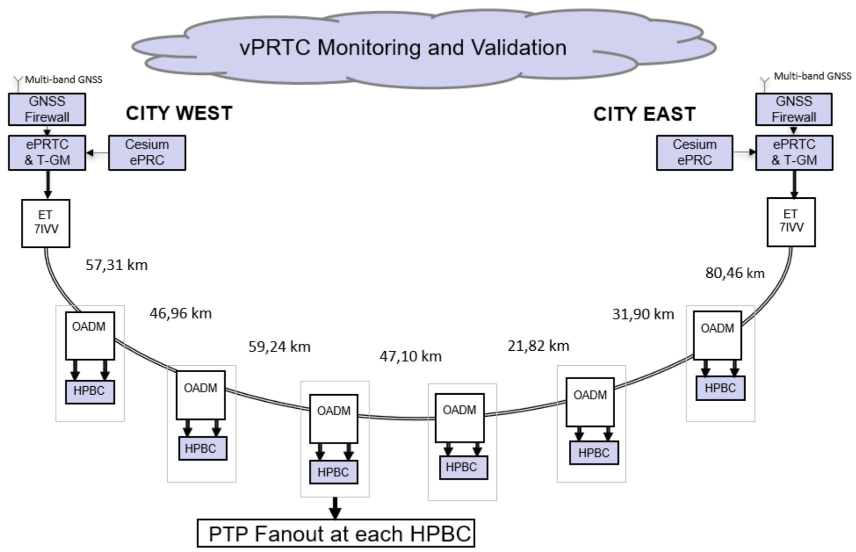
Figure 5-1. TimeProvider® 4100 HPBC DWDM Transport Example



6. Virtual PRTC Reference Architecture

The reference architecture shown in the following figure is typical of several vPRTC deployments. City West and City East represent the “area timing hubs” where core ePRTC clock systems are deployed. These systems include ePRC-compliant cesium clocks, and GNSS firewall validated inputs to the TimeProvider ePRTC system to establish a highly resilient autonomous timescale for the operator network. The TimeProvider 4100 HPBC function bridges the Optical Add/Drop Multiplexer (OADM) transport elements maintaining PTP BC class D <±5 ns time transfer hop-by-hop over the transport network. The entire end to end vPRTC precision time distribution network is under constant monitoring and validation by the TimePictra® management system. Typical time transfer error on this type of network from the source clock (City West, for example) to the clock output is less than 20 ns at any node.

Figure 6-1. TimeProvider® 4100 HPBC Test Bed (Dedicated Bidirectional Lambdas over 345 km)



- **DWDM example:**
  - Optical Splitters in DWDM route for adjacent Wavelengths for Sync (1605/1615 nm)
  - Bi-di Transmission same Fiber
  - One lambda E to W one lambda W to E
  - Bi-di SFPs in HPBC
  - 6 T-BC in chain
- **Sync Performance:**
  - **Typical Time Error < 20 ns**

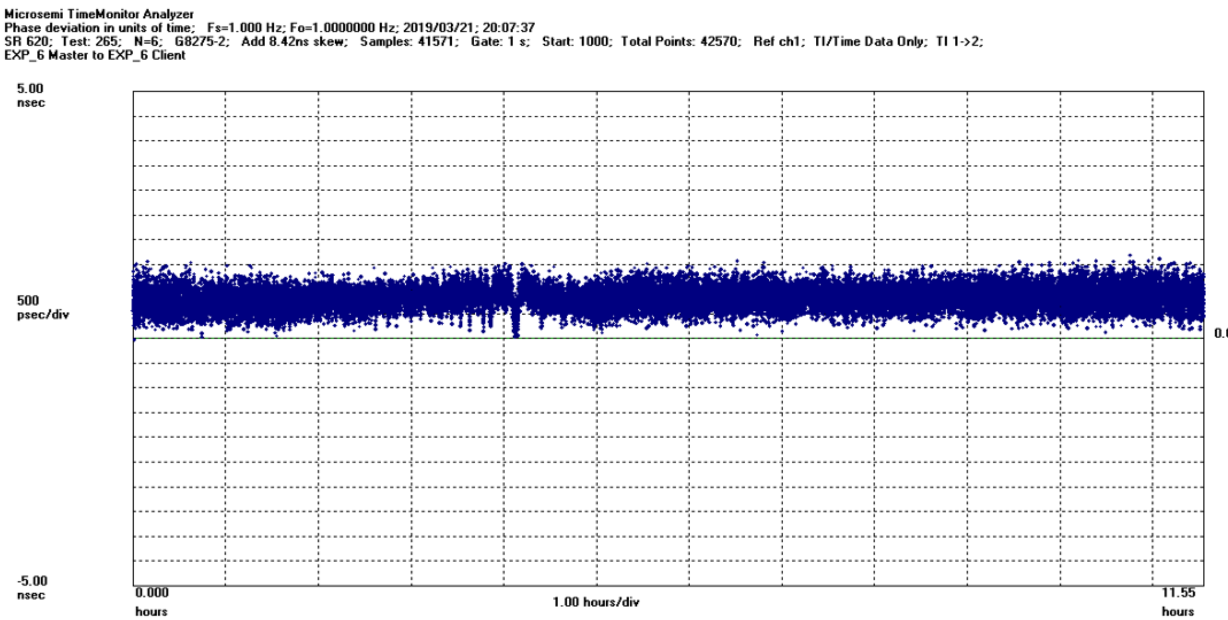
6.1 Performance Results

The above figure summarizes proof of concept trial results. The actual time error results were well below the target values. The HPBC performed at less than ±3 ns time error. This is comfortably below the BC class D budget of ±5 ns. Additional lab test results are shown below demonstrating individual HPBC measurements, and multi-hop scenarios.

The following figure shows the typical performance of a system on a test network.

- Measured MAX|TE| = 1.7 ns
- TE observed was well within nominal Class D (±5 ns)

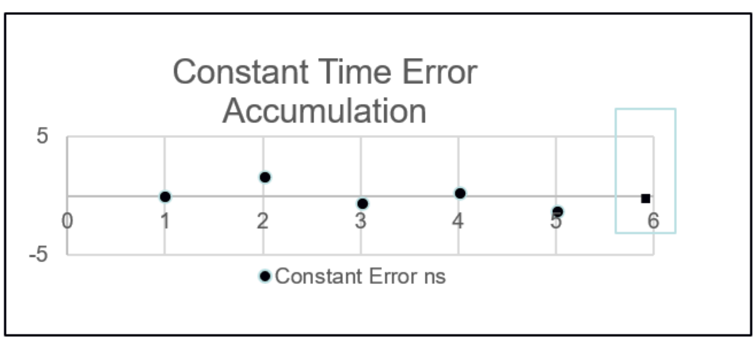
Figure 6-2. 85 km PTP over Dedicated Lambda with cTE Compensation



The following figure shows the accumulated cTE over 6 HPBC on a test network. As can be seen, the TimeProvider 4100 HPBC has demonstrates exceptional accuracy and precision, with unprecedented control of constant time error across the network.

- No appreciable growth in constant time error (cTE)
- Dynamic noise accumulation (dTE) showed modest growth
- Class D performance maintained over 5 nodes

Figure 6-3. Accumulated cTE over 344.5 km and 6 Switches on a Test Network



6.2 vPRTC and Operator Requirements

It is important to evaluate the vPRTC mapped against operator requirements noted above.

Table 6-1. Comparison of Operator Requirements and vPRTC

Operator Requirement	vPRTC Architecture Advantages
Independence	The ePRTC function establishes an autonomous timescale using cesium atomic clocks in core locations that are calibrated to UTC using GNSS, but can operate independent from GNSS. Network architecture can evolve without requiring changes in the timing and synchronization architecture
Security and reliability	Use of a dedicated lambda makes it extremely difficult to hack or spoof the PTP flow. The HPBC would immediately detect any anomaly at the protocol layer. Bidirectional timing flows are an option for ring and linear ring topologies that provides redundancy. Core ePRTC sites can be further protected using Microchip's BlueSky™ GNSS Firewall solution to monitor and protect the system from potential GNSS spoofing or timing anomalies. For more information about the BlueSky GNSS Firewall, see Microchip Synchronization and Timing Systems.
Monitoring and visibility	The entire system is monitored and managed with the Microchip TimePictra® end-to-end synchronization management system.
Reliability/Continuity	Engineer timing at the most fundamental layer (optical DWDM) where it is not subject to continual change as the network upper layers/protocols evolve and must be changed or re-engineered.
Predictable and deterministic	Timing traceable to a source clock and UTC. Well known predictable delay independent of change in any other layer or network function.
Scale	Timing evolves gracefully with the expansion of the optical network.
Flexibility	Use any PTP profile, SyncE optional.
Elasticity	Deliver timing at any level of precision to <100 ns for telecom, power, finance, data center, smart city, and more.

6.3 Comparison of vPRTC with PTN

It is also interesting to compare the Ethernet-based PTN and vPRTC.

Table 6-2. Comparison of L2 PTN and vPRTC with HPBC

Parameter	L2 PTN	vPRTC with HPBC
PTP profile	G.8275.1	G.8275.1, G.8275.2
eEEC (G.8262.1)	Mandatory	Optional
T-BC (cTE)	Class C (±10)	<Class D+ (±3 ns)
Timing flow	Unidirectional	Bidirectional
De-jitter	Basic	Sophisticated de-jitter and clock selection
Management	None	Tightly integrated sync network management
BC monitoring	None/basic	Rich onboard monitoring
Transport	L2	Independent transport layer
PTP flow	In-band with user traffic	Out-of-band/independent from user traffic
Implementation	Embedded in switch	Stand-alone on any DWDM
Brown Field	No	Yes: new or legacy DWDM
Redundancy	Basic A-BMCA	Global (enhanced) A-BMCA

7. Conclusion

As networks evolve through the next phase of advanced smart 5G services, there will be an increasing requirement for even more precise timing to the edge of the network. Operators will require long term stability and predictability of the timing network, while ensuring low cost, flexibility, and adaptability when engineering the service layers.

The virtual Primary Reference Timing Clock is a new concept for a highly secure and protected network-based timing architecture developed to meet the expanding needs of modern critical infrastructures. Please contact your Microchip representative to learn more about how our solutions enable operators to build a vPRTC network delivering ultra-high precision timing services with unmatched stability, security, and reliability.

8. Revision History

Revision	Date	Section	Description
A	08/2020		Initial Revision

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