OPNT
Optical Positioning, Navigation and Timing

Feeding Local PTPv2 and NTP Branches with Accurate Time from a Wide-Area White Rabbit Core Network

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A Network-Based Back Up for GNSS Timing?

- Strategies exist to mitigate vulnerabilities of GNSS timing, but there are limits to:
  - Failover/holdover performance (local atomic clocks, PTPv2, APTS, …)
  - Willingness to invest in back-up solutions (atomic clocks, PTPv2, APTS, …)
  - The range of GNSS anomalies which can be detected (sophisticated meaconing of GNSS signals might go unnoticed)
- GNSS timing is often used in networks, so network-based back-up systems may be preferable
- In networks, GNSS timing is often converted to PTPv2 or NTP format to sync servers, base stations, PMUs, …
- Yet, no fully GNSS equivalent network-based back-up system exists:
  - PTPv2 typically deployed in 'local area' networks (data centers, plants, mobile backhaul)
  - PTPv2 over long distances may in principle be done*, but achieving same accuracy and up-time as GPS will be challenging

*M. Weiss and L. Cosart, PTTI, Monterey, CA (2017)

White Rabbit for Long-Distance Time Transfer

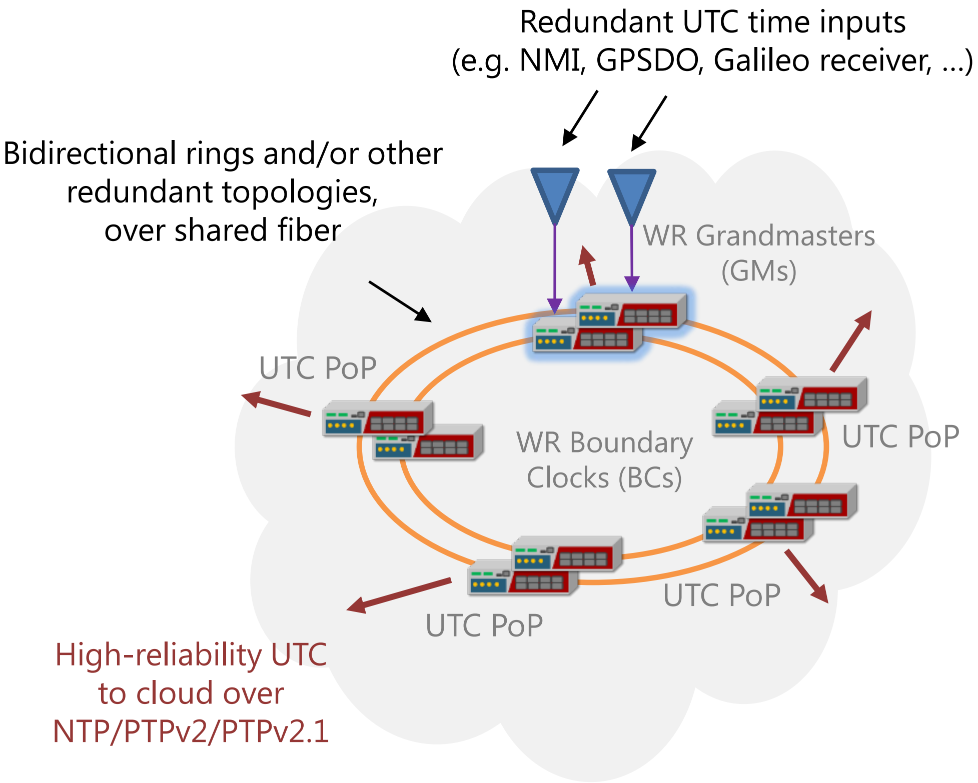
- White Rabbit: "PTPv2/SyncE upgrade" developed at CERN for < 1 ns time sync over ~10 km of optical fiber, will be included in the updated PTPv2.1 as a "High accuracy option."
- Sub-nanosecond accuracy achieved after initial calibration of delay asymmetry of the link
- Long-distance WR demonstrated* and nowadays commercially available
  - Example: 260 km cross-border link between timescales UTC(ESTEC) (Netherlands) and UTC(SMD) (Belgium), operated by ESA, VSL, SMD, CGI, and OPNT
- WR pros (*specifically in the context of 'assured timing'*)
  - Can be deployed using custom wavelength division multiplexing schemes
  - High accuracy (sub-ns), high stability ($< 1\times10^{-11}$ @ 1s) $\Rightarrow$ *Superior back-up to GNSS timing*
  - Picosecond resolution $\Rightarrow$ *Enables rapid detection of reference clock anomalies possible*
  - Redundant networks possible $\Rightarrow$ *Enables assured timing*
- WR cons
  - End-to-end control of physical layer required (technically feasible, but not always operationally possible)
  - Network equipment needs hardware upgrade $\Rightarrow$ can be expensive for networks with many clients (mobile base stations, data centers, …)

*E.F. Dierikx *et al.*, IEEE TUFFC **63,** 945 (2016)

A Possible Solution: Integrated WR/PTPv2 Networks

Proposal:

- WR wide-area core network
  - 1 ns offset from UTC(k) thanks to access to physical layer (L1) and WR
  - Long distances (cross continent)
  - Minimize cost:
    - Fibers prepared for shared use (data + WR time)
    - 'Sparse network': low equipment volumes
  - Redundant paths and equipment
- Each WR Boundary Clock represents a "UTC Point of Presence"
- From UTC PoPs, use flexible, low-cost L2/L3 protocols towards edges, e.g. NTP, PTPv2 (or WR, of course)



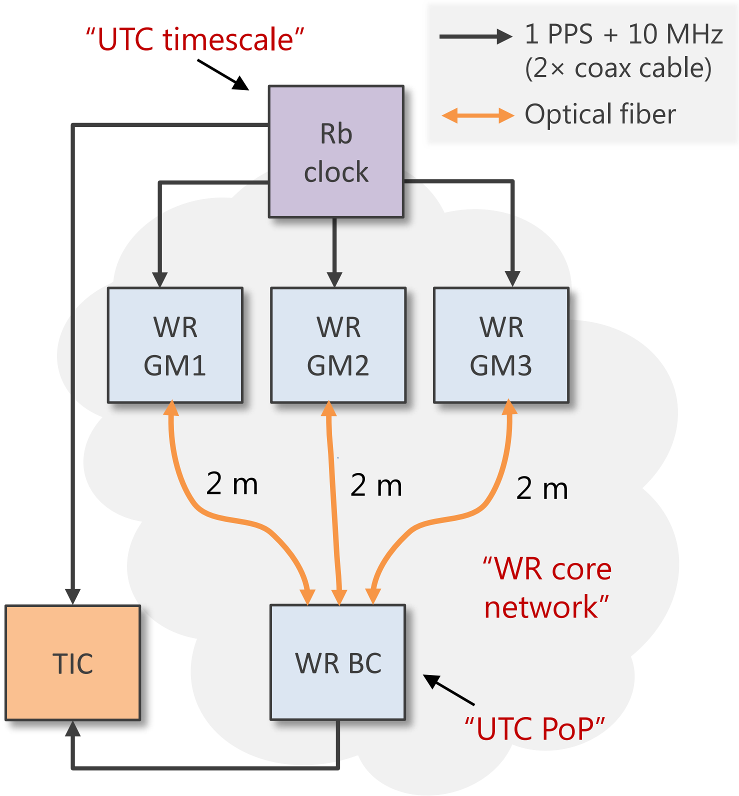
Requirements for Secure WR/PTPv2 Networks

- (Some) prerequisites for a high-reliability WR core network are:
  - Path redundancy: additional paths/WR links to the reference clock
  - Clock redundancy: having other reference clocks available in the network
  - Rapid (automated) link failure detection and failover mechanisms
- Work towards redundancy has been done by the WR community, but not (yet) available in open-source WR, and not fully tested $\Rightarrow$ critical aspects of high-reliability timing through WR still need to be demonstrated and we report here on our progress
- Note that in WR, there can be only one Grandmaster, i.e. only one reference clock
  - Failover to a back-up reference clock could therefore lead to phase jumps, as two reference clocks are never perfectly synchronized

Feasibility: Results of Lab Tests at OPNT

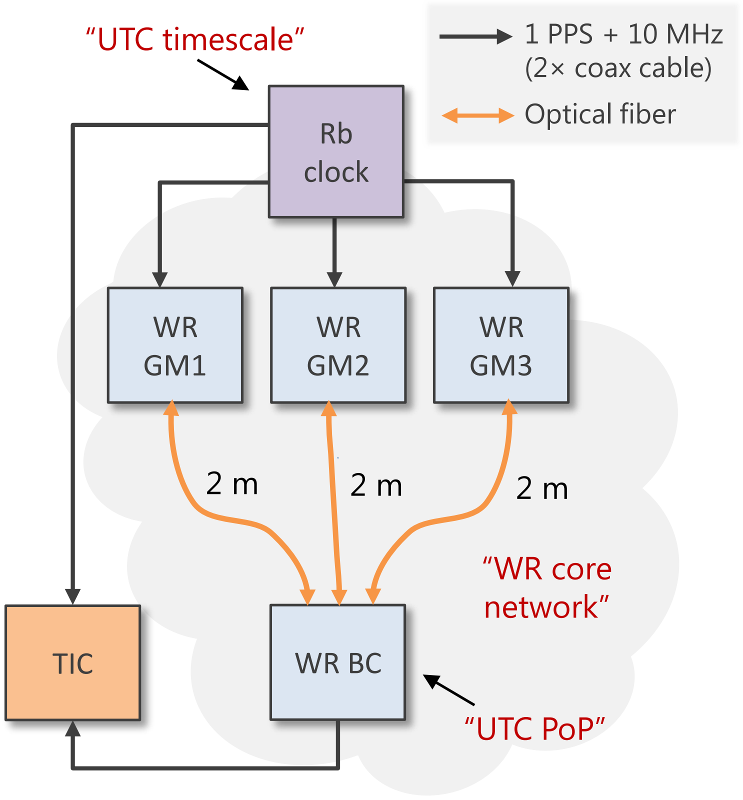
- Build and test redundant paths, redundant clocks, and automated failover
- Tests performed in OPNT labs using spooled fiber

Redundant GMs and Failover



- Manually disconnect/reconnect optical fiber between BC and GM*i*
- Automated link failure detection and failover to back-up GM
- If link to previous GM comes back up for >60 s, switch back
- Monitor response of 1 PPS and 10 MHz outputs of WR BC

Redundant GMs and Failover



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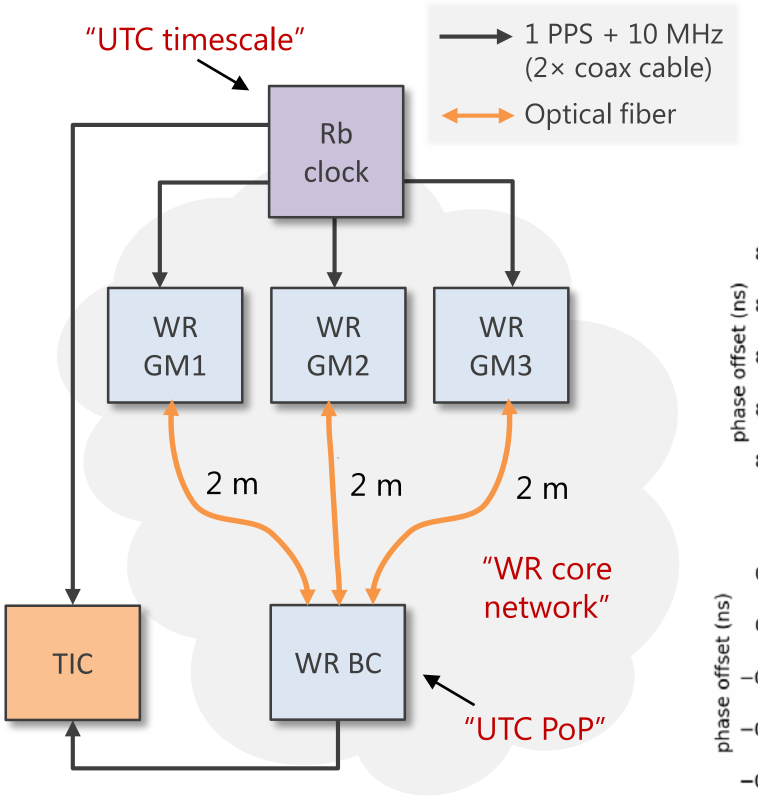
NOTE:

For the measurements presented here, several-nanosecond offsets were deliberately added to the 1 PPS output of the WR BCs, to facilitate unambiguous TIC measurements "away from 0 ns"

However, under normal operating conditions, residual PPS offsets are well below 1 ns

Redundant GMs and Failover



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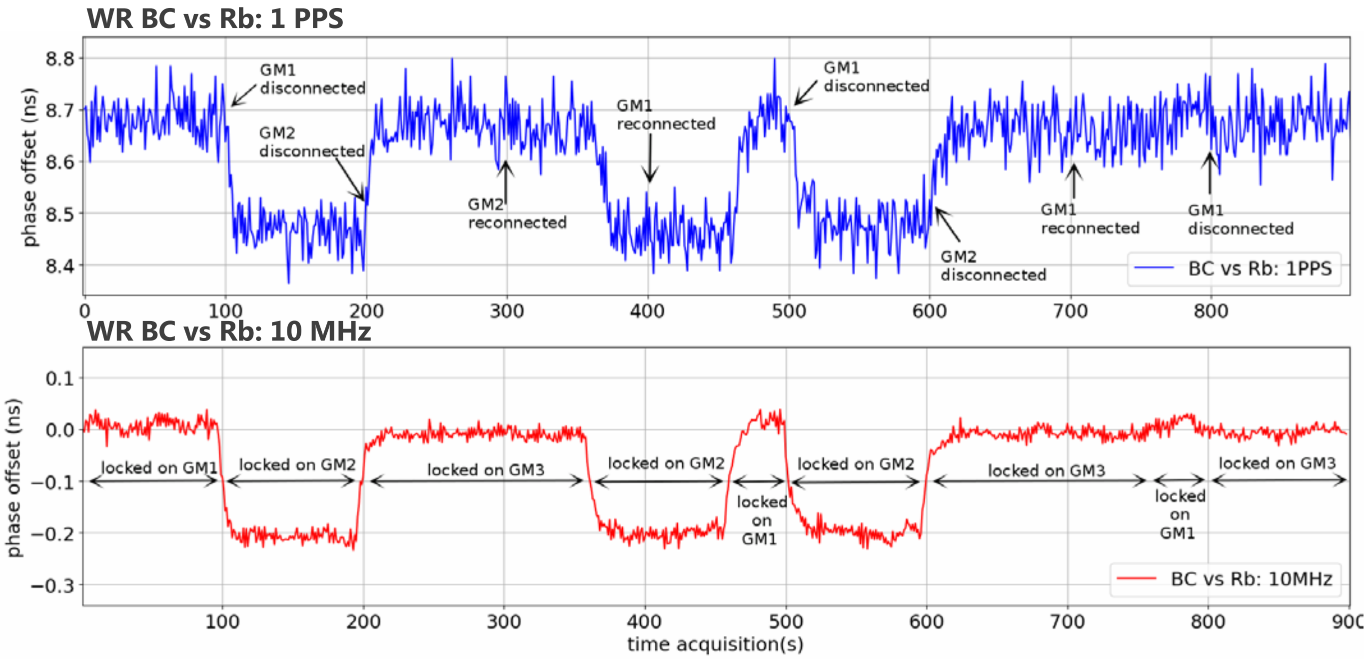
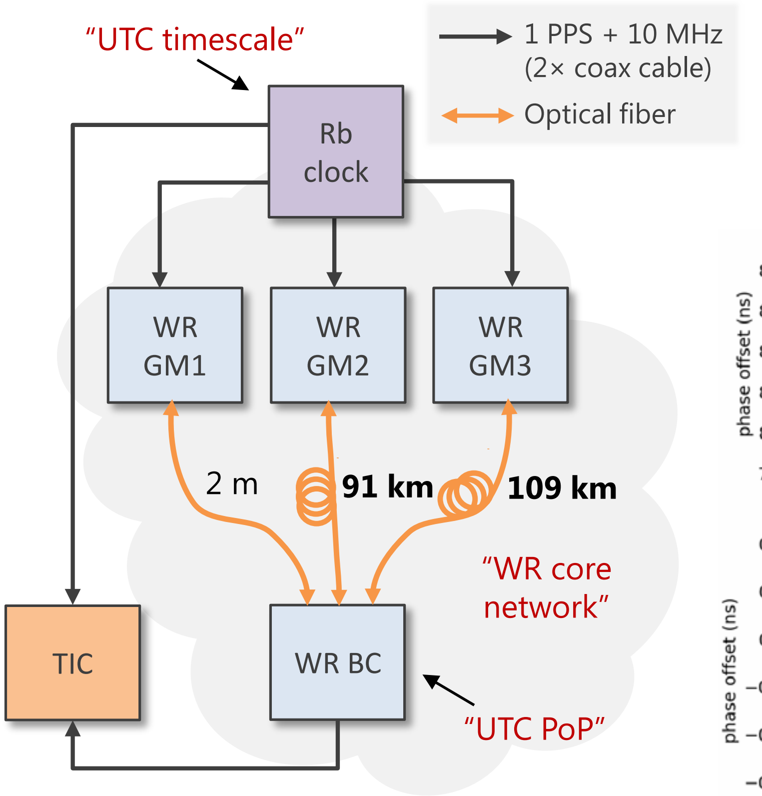


Redundancy over Long Links (Fiber Spools)



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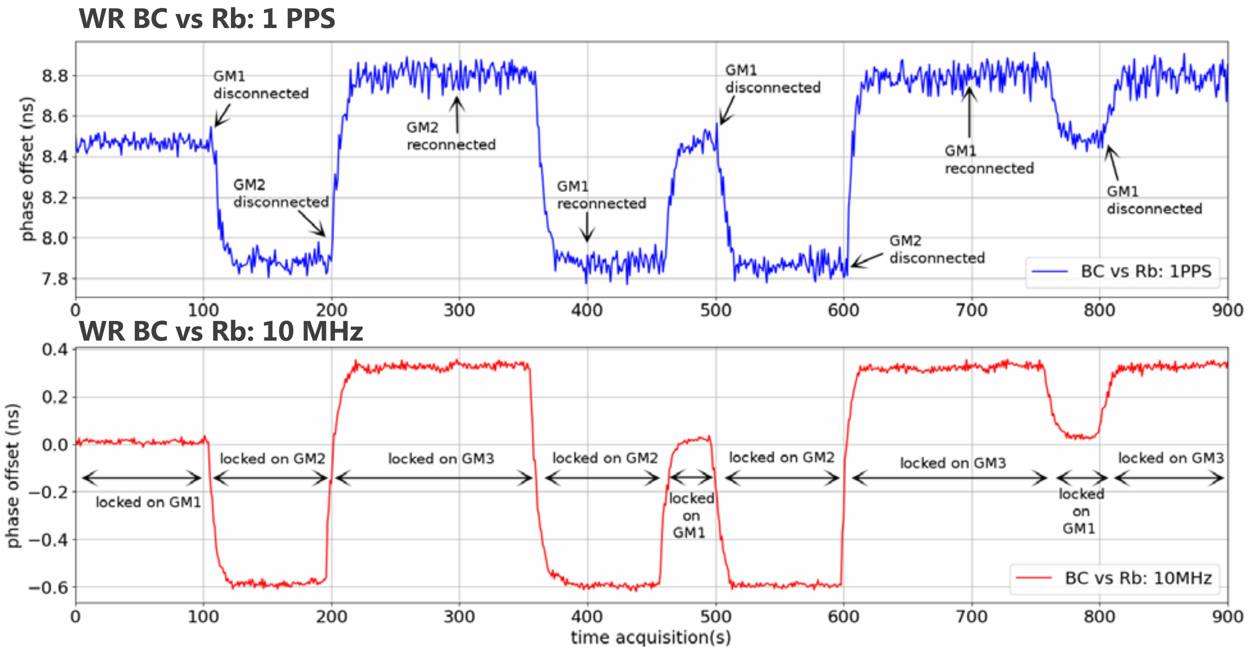

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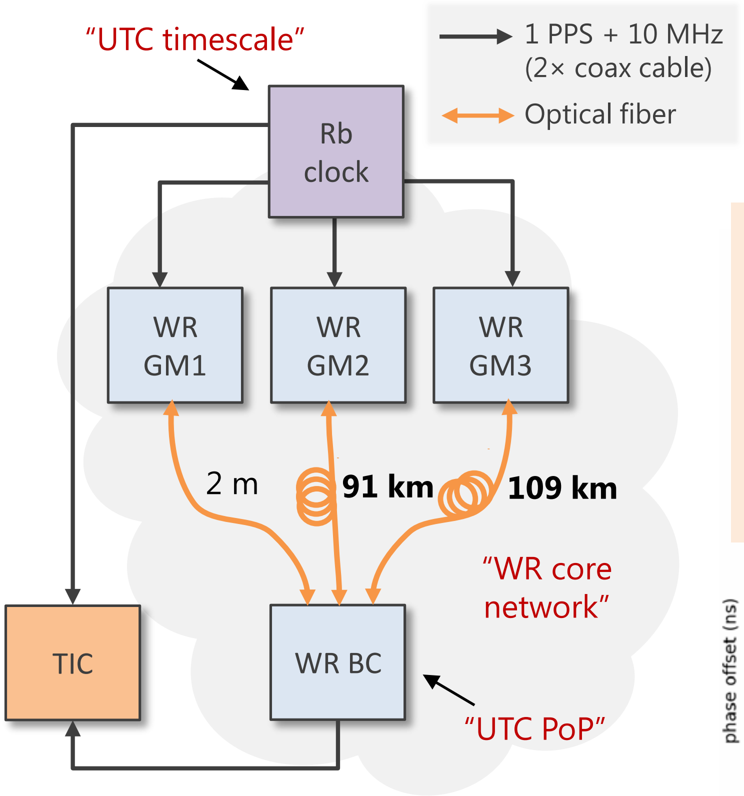

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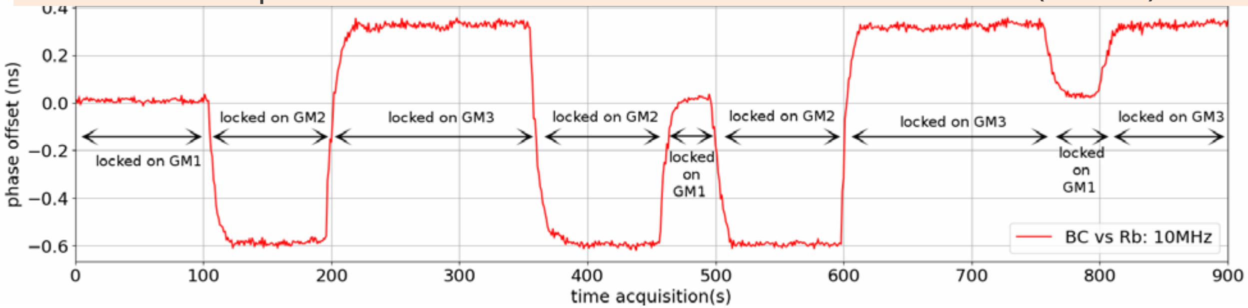
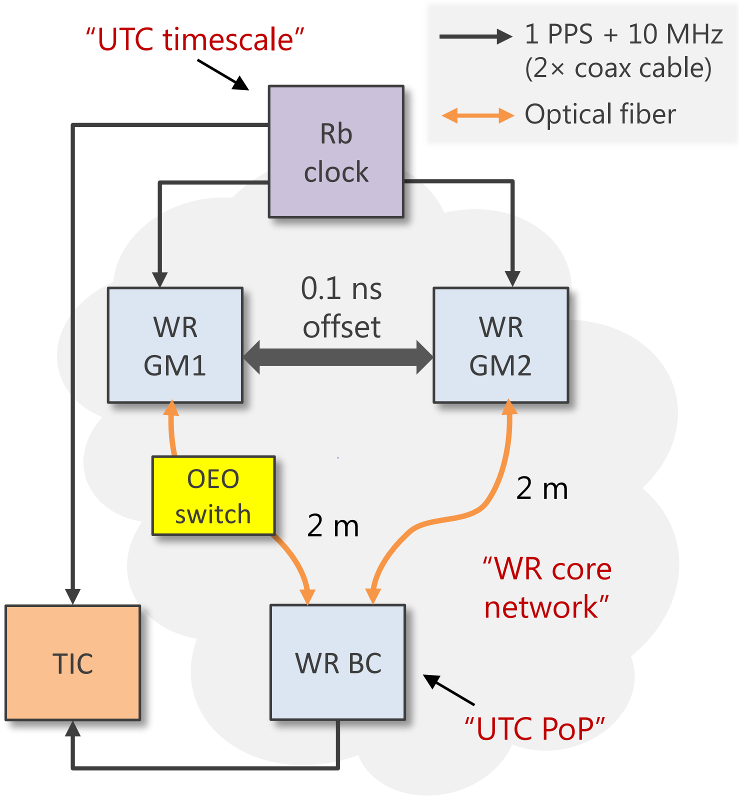
- Successful automated WR link failure detection and failover
- Can secure timing over long distances (> 100 km)
- Modified WR control loop corrects for potential phase offsets between GMs
- Smooth phase transition if offset between GMs is small (< 1 ns)



Long-Term Tests



- Optical-electrical-optical (OEO) device switches off/on link BC ↔ GM1
- Automatic failover to GM2 when link taken offline
- Automatically switch back to GM1 when link to GM1 is up again for 60 s
- Monitor response of 1 PPS and 10 MHz outputs of WR BC

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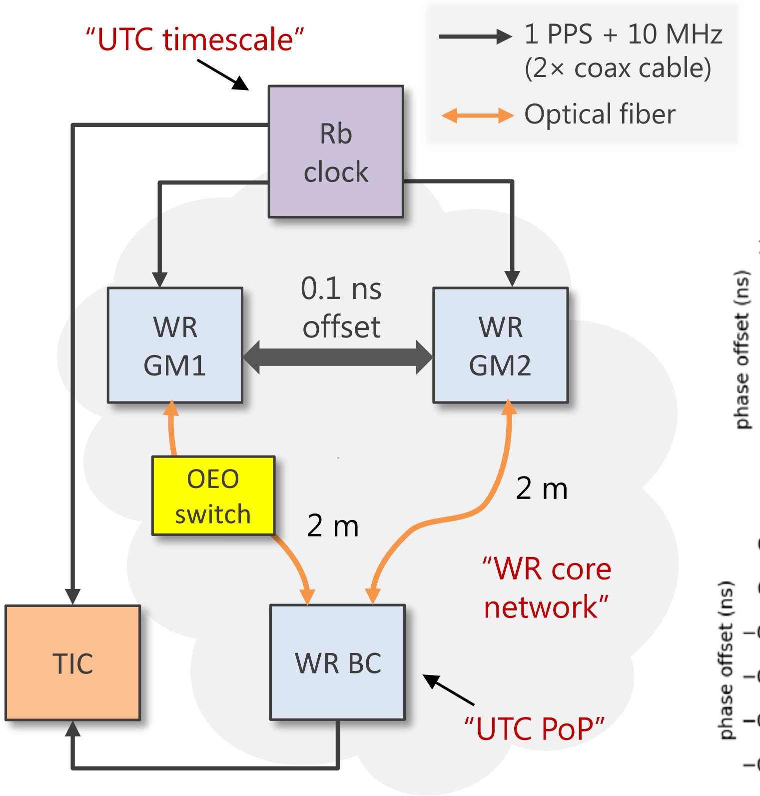

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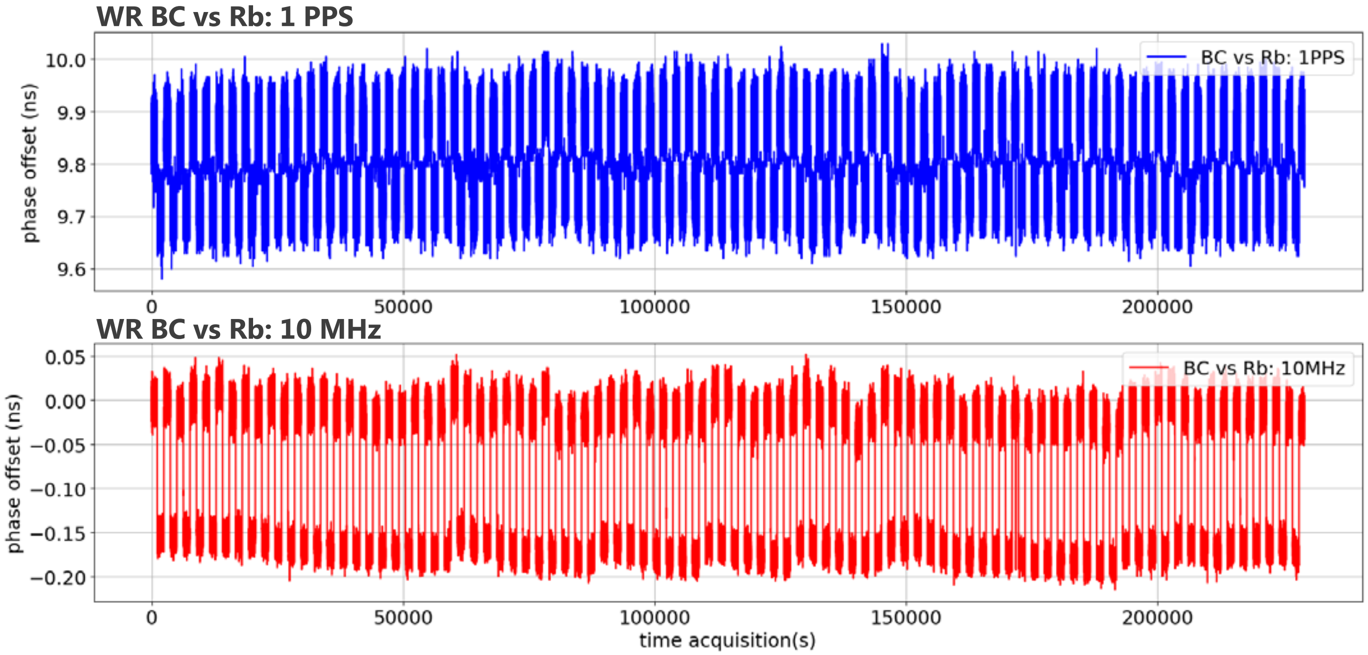

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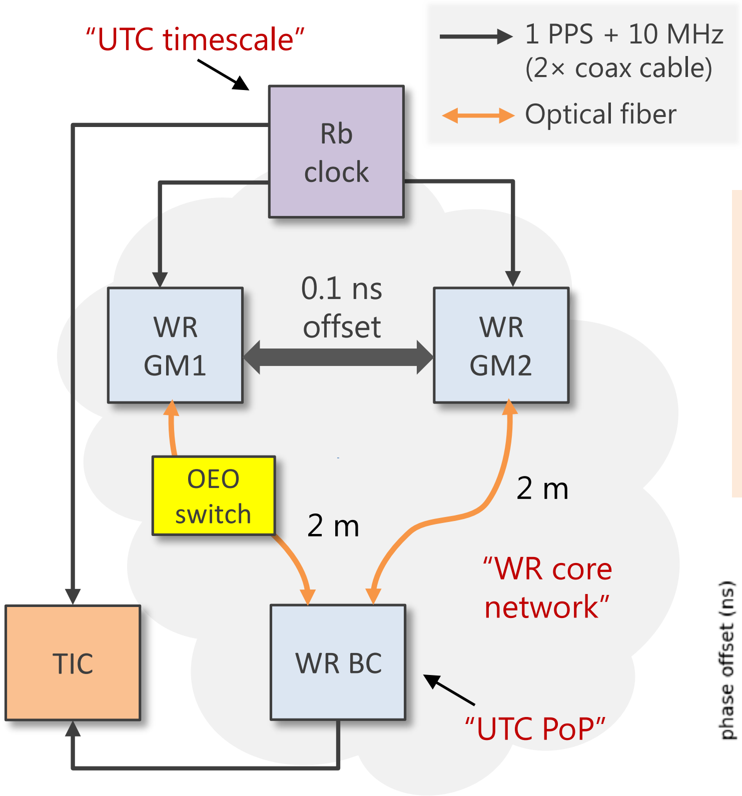

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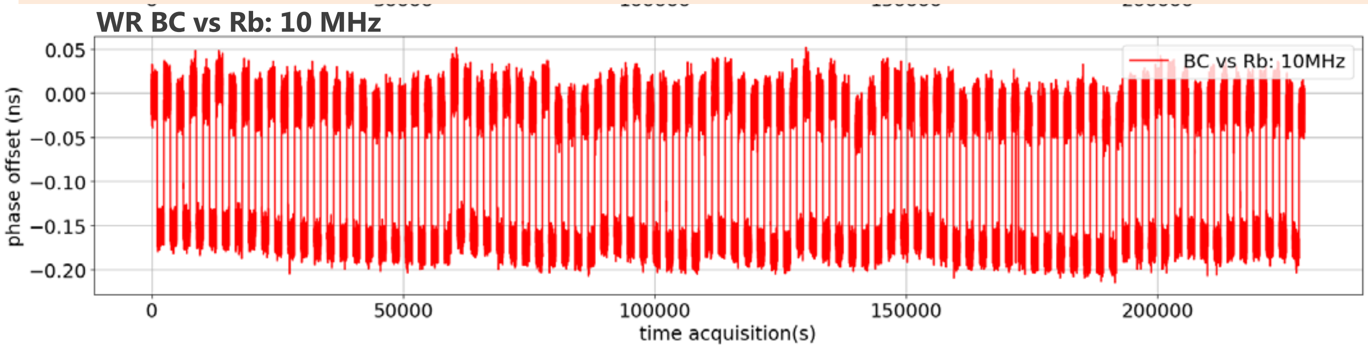
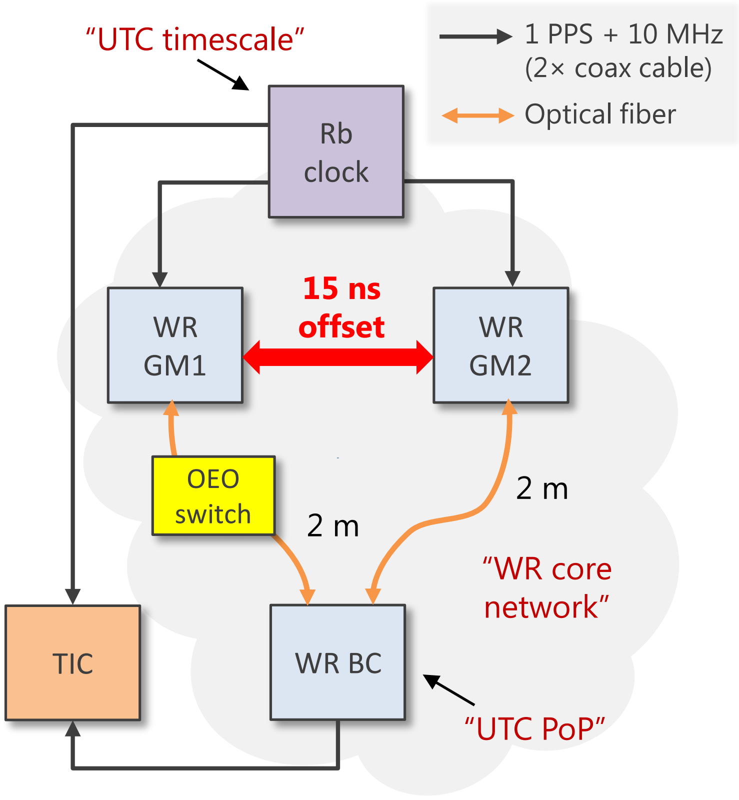
- Automatic failover to GM2 when link taken offline
- Automatically switch back to GM1 when link to GM1 is up again for 60 s
- Monitor response of 1 PPS and 10 MHz outputs of WR BC
  - Reproducible switching over 90 cycles (65 hours, longest run)
  - Modified WR automatically corrects for potential offsets between GMs
  - Smooth switching if GM relative offset is small (< 1 ns)



Handling Time Offsets between Redundant GMs

- Repeatedly switch link GM1 ↔ BC off/on every 2500 s



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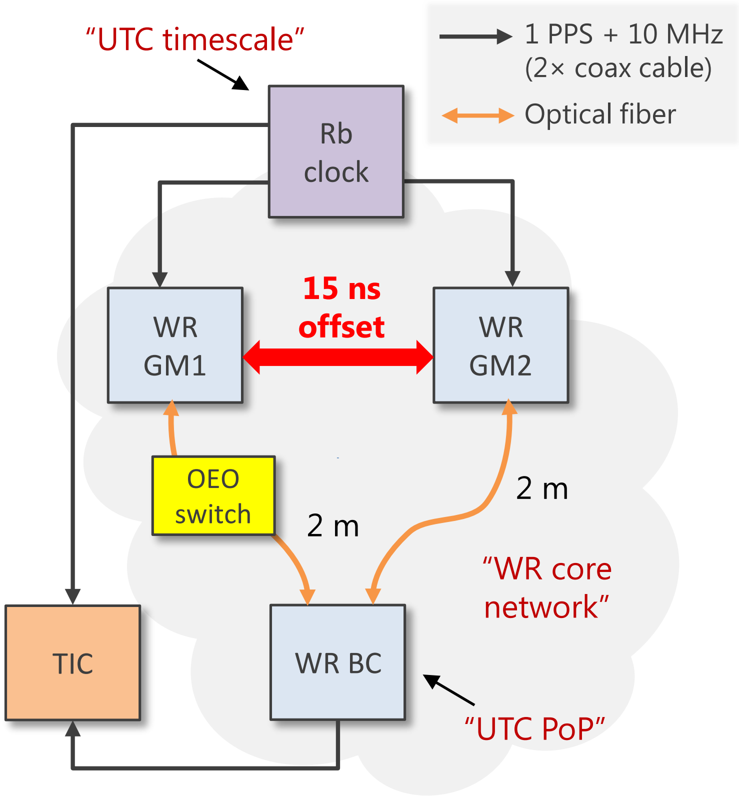

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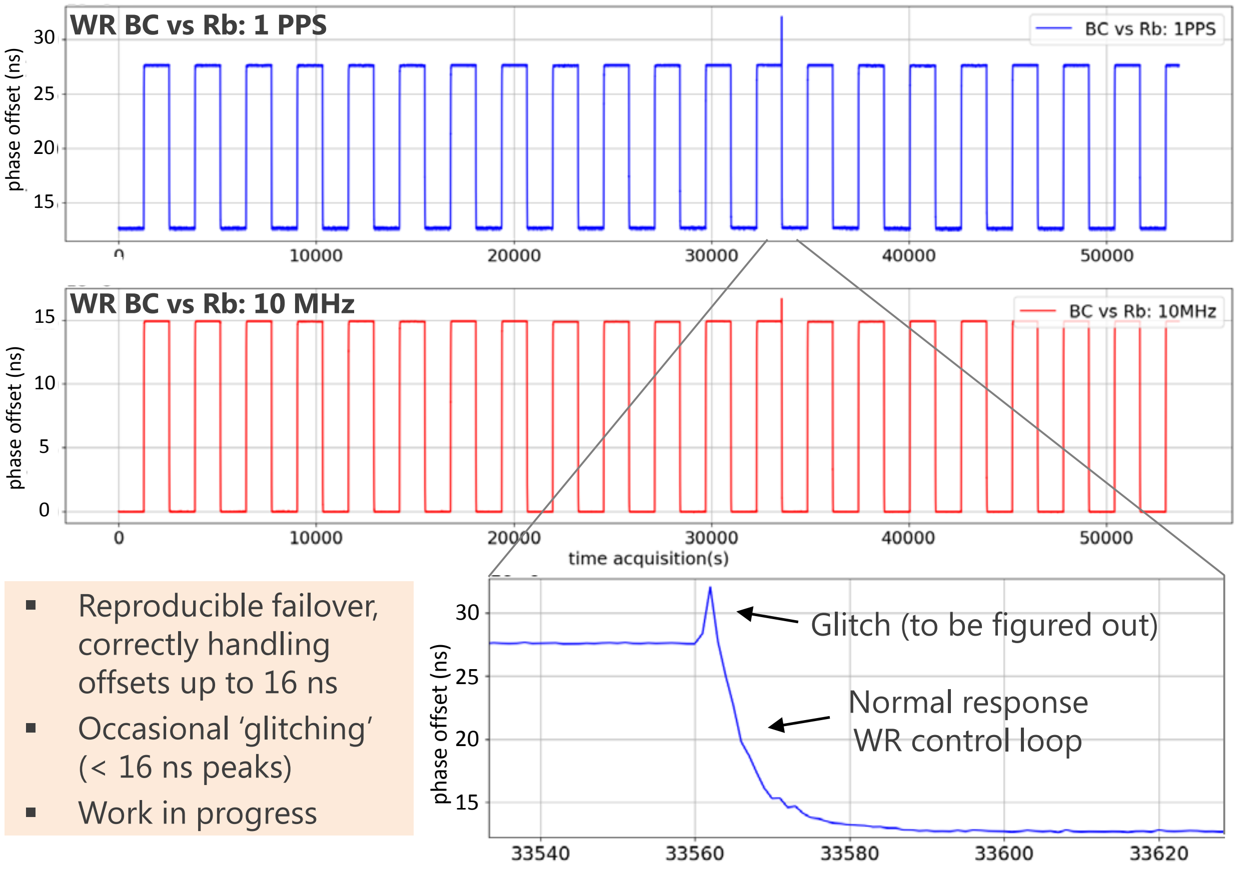
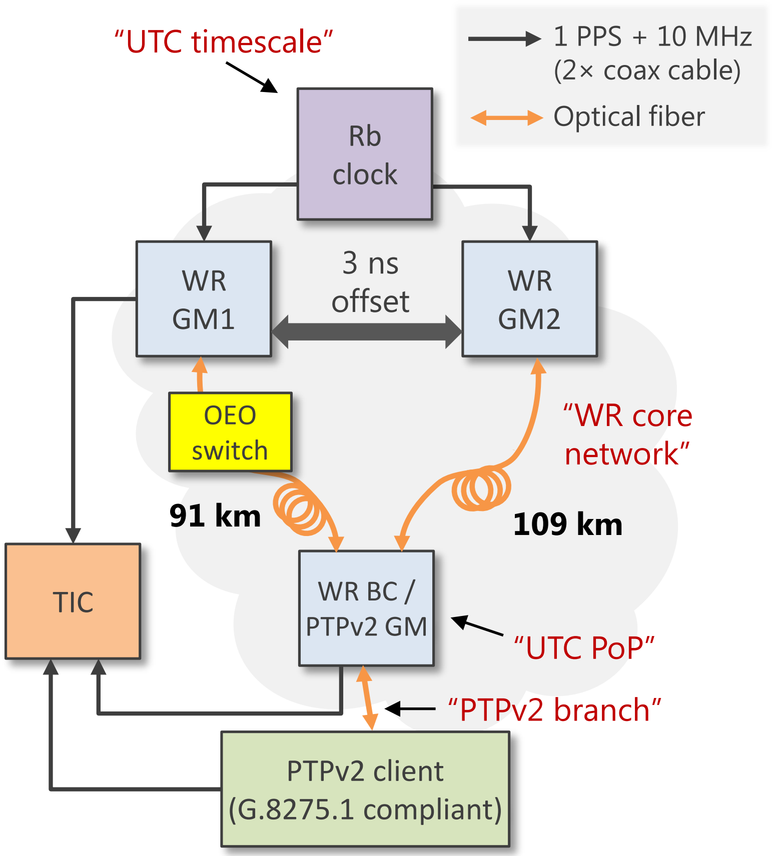


- Reproducible failover, correctly handling offsets up to 16 ns
- Occasional 'glitching' (< 16 ns peaks)
- Work in progress

Core Network Extended with PTPv2 Branch



- Demonstrate "UTC-PoP" feeding a "PTPv2 branch"
- Connect PTPv2 client using ITU G.8275.1 profile
- Monitor response of PTPv2 client to failover events in WR core network

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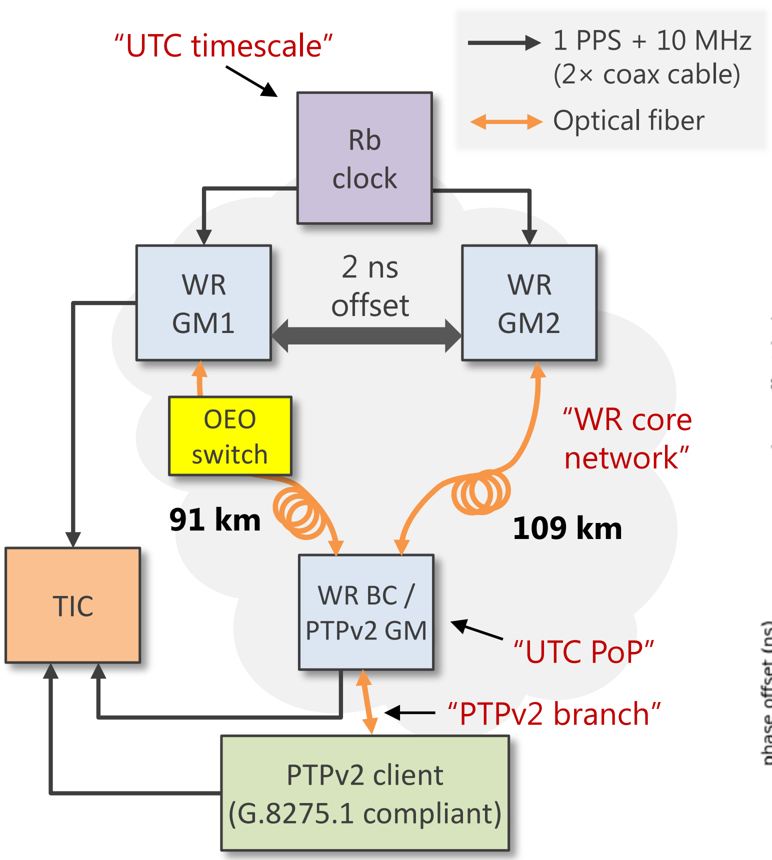
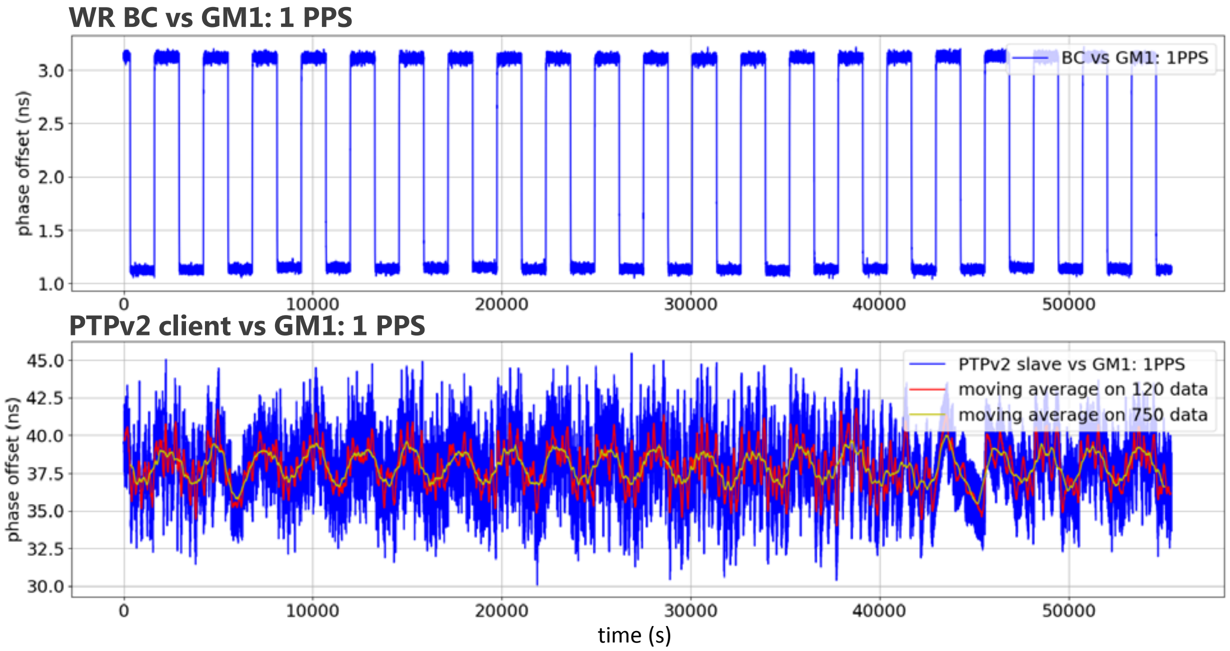
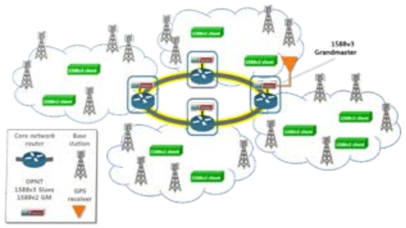


- Demonstrate "UTC-PoP" feeding a "PTPv2 branch"
- Connect PTPv2 client using ITU G.8275.1 profile
- Monitor response of PTPv2 client to failover events in WR core network
- "UTC PoP" provides a high-reliability time source for PTPv2 client

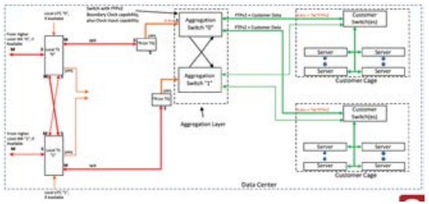


Potential Use Cases

- Mobile networks – now and for 5G:
  - WR core deployed at core and metro-core layers
  - PTPv2 to network edges (aggregation sites, base stations)
  - Improves Time Error Budget (ITU G.8271) and time stability of the network as a whole



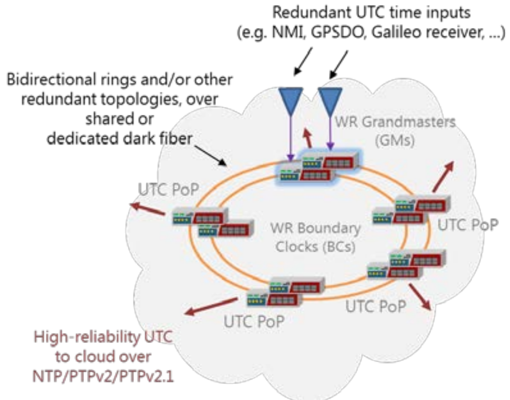
- Data centers (e.g. finance):
  - WR UTC PoP in or near data center
  - Distribution of UTC from WR PoP to local servers over PTPv2 or NTP (effectively stratum 0)



- Electrical power grid
  - WR distribution over long distances
  - Locally feed Phasor Measurement Units (PMUs) with time through PTPv2

Summary and Outlook

- An integrated WR/PTPv2 system for wide-area, redundant time distribution at various levels of accuracy is proposed
- Critical features of such a wide-area WR core network, such as redundant paths to active and stand-by Grandmasters and automated failover, were developed and demonstrated
- Nanosecond time offsets between active and standby reference clocks lead to phase jumps, which could in the future be mitigated by WR-enabled clock ensembling methods
- If the reference time of the WR core were UTC(*k*), nodes of the WR core network may serve as Points of Presence delivering UTC(*k*) locally over PTPv2, NTP, WR
- Potential applications:
  - Time synchronization of 5G mobile networks
  - Time distribution to and within data centers
  - Time synchronization of PMUs in electrical power grids



Acknowledgments

Credits to OPNT team and advisors

Thank you for your attention!