



High accuracy timing over optical fibre infrastructure

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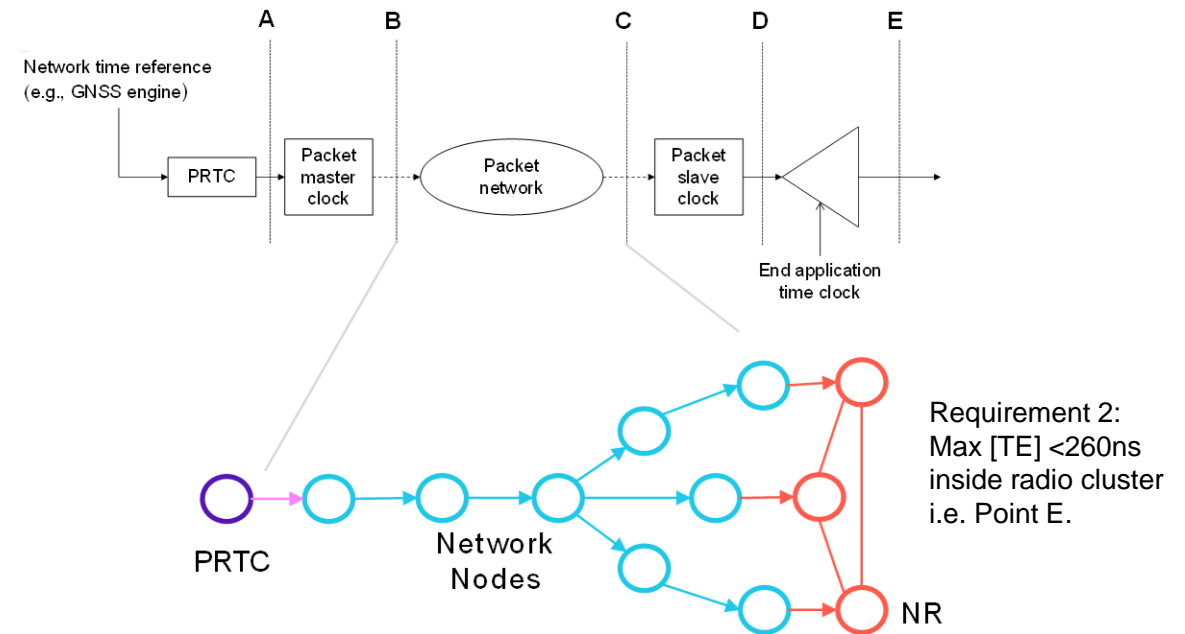
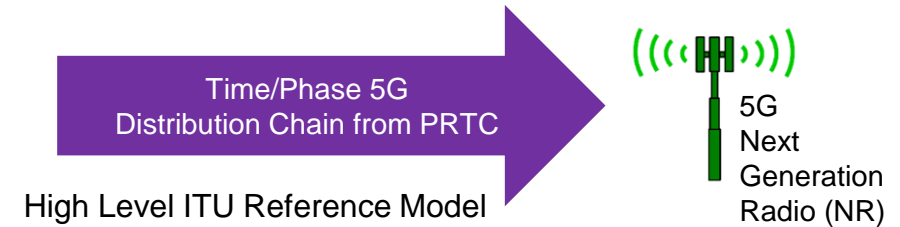
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Outline

- Requirements on timing synchronisation
- Key considerations and challenges for accurate timing transport
- Potential approaches for timing over optical fibre infrastructure
 - Dedicated fibre
 - Optical WDM systems
- Proof-of-Concept demonstration and findings
- Summary

Requirements on timing synchronisation

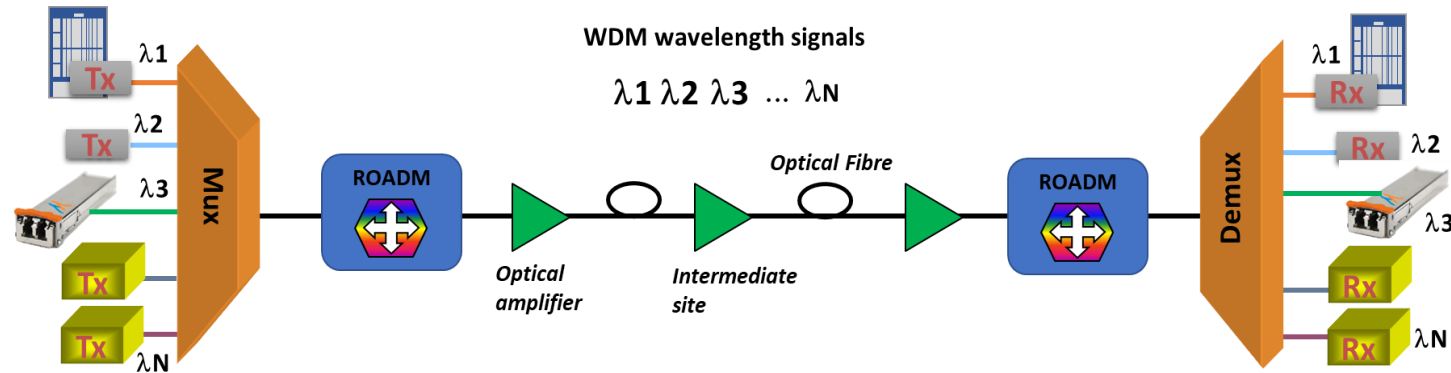
- Synchronisation is an important requirement in telecom networks
 - Frequency sync provided for many years, e.g., to support generations of mobile communications such as 3G/4G
- Increasingly many applications require accurate timing information, not only for frequency, but also time/phase synchronisation
 - 5G, with higher speeds and based on TDD, requires sub-microsecond timing accuracy
 - Highly accurate timing requirements anticipated for future applications
- Accurate and reliable clock sources located in key reference clock sites
- Standardised approach for timing distribution is based on PTP, which offers frequency, time and phase synchronisation
 - e.g., ITU PTP Telecom Profile 8275.1 developed for phase/time synchronisation with full timing support
- Optical fibre network infrastructure key to the delivery of timing information



Distribution chain of Nodes within Network Passing Timing

Requirement 1: max |TE| < 1.5µs for chain to Point E (in some scenarios < 500ns)

Optical fibre network infrastructure



Optical wavelength signals: e.g.
10, 40, 100, 200, 400Gbit/s

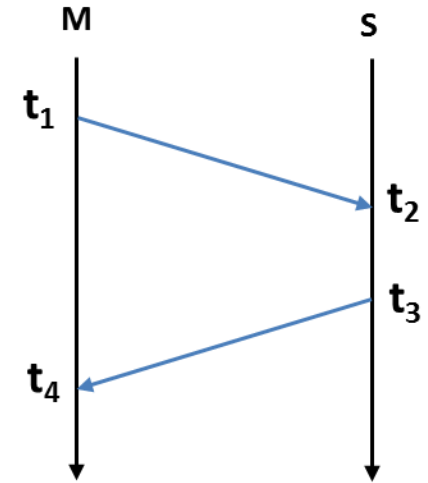
- Optical fibre underpins all the networks from access, metro and core networks
- Optical WDM networks providing network capacities to meet increasing bandwidth demands
 - Optical technologies continuing to develop enabling increasing transmission speeds
 - Optical links range from point to point systems to optical ROADM networks with wavelength traffic add/drop
 - In most of the systems, wavelength traffic transported over separate fibres for opposite directions
- **New requirement:** Support accurate timing transport for 5G and future applications

Key considerations and challenges for accurate timing distribution

Time/phase distribution using PTP is based on exchanges of time-stamped packets between master and slave clocks, network asymmetry affects timing accuracy

Key to accurate timing distribution is to minimize network asymmetry in transporting timing

- Optical fibre
 - In most of optical transmission systems, a fibre pair are used for wavelength traffic in forward and reverse direction
 - Fibre length difference causing asymmetry, e.g., 5ns per metre
- Optical wavelength
 - Same wavelength is used for forward and backward transmission in WDM systems using a fibre pair
 - In single fibre working, different wavelengths used for forward and backward directions → propagation delay asymmetry depending on wavelength separation and fibre length
- Optical node equipment
 - Line and client interfaces, e.g., with OTN mapping, FEC, DSP
 - Mux/Demux and ROADMs
- Optical amplifiers
 - Fibre lengths inside amplifiers are different among amplifiers

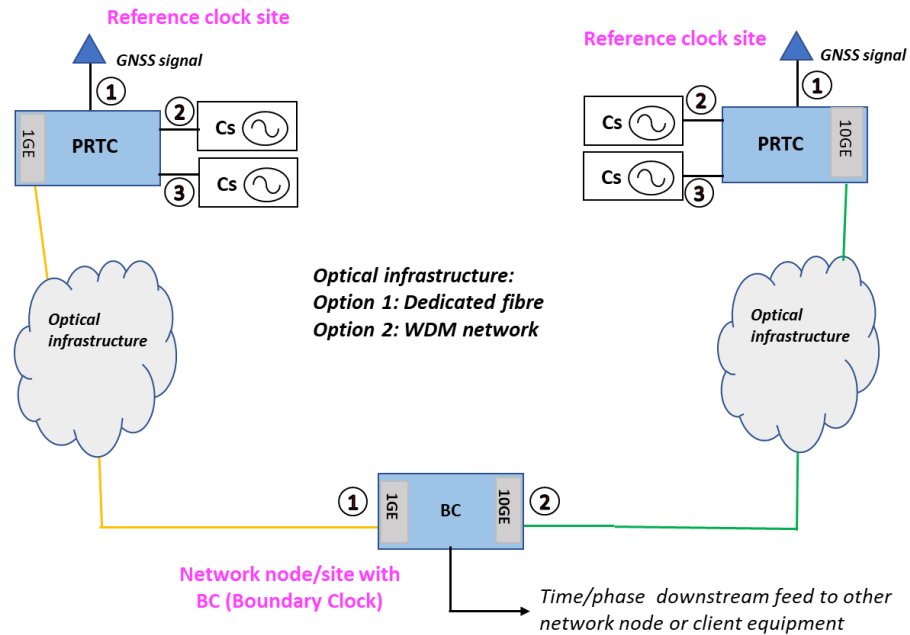


$$\text{Offset} = [(t_2 - t_1) - (t_4 - t_3) - (\text{Delay}_{ms} - \text{Delay}_{sm})]/2$$



Asymmetry when Delay_{ms} is not equal to Delay_{sm}

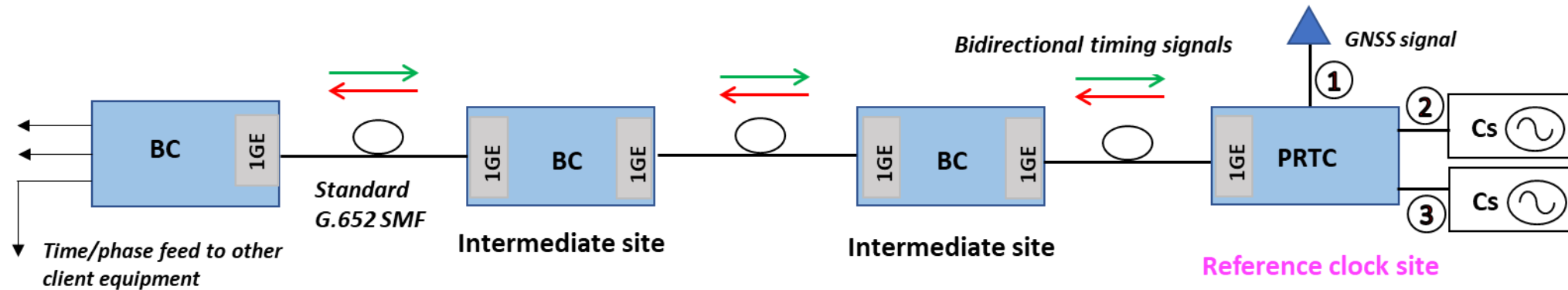
Potential approaches for transporting timing over optical infrastructure



- Accurate timing information provisioned in key reference clock sites, e.g., PRTC with accuracy of up to 30ns (enhanced PRTC)
- Boundary clocks used through the networks with full timing support, with accuracy as high as 5ns (class D)

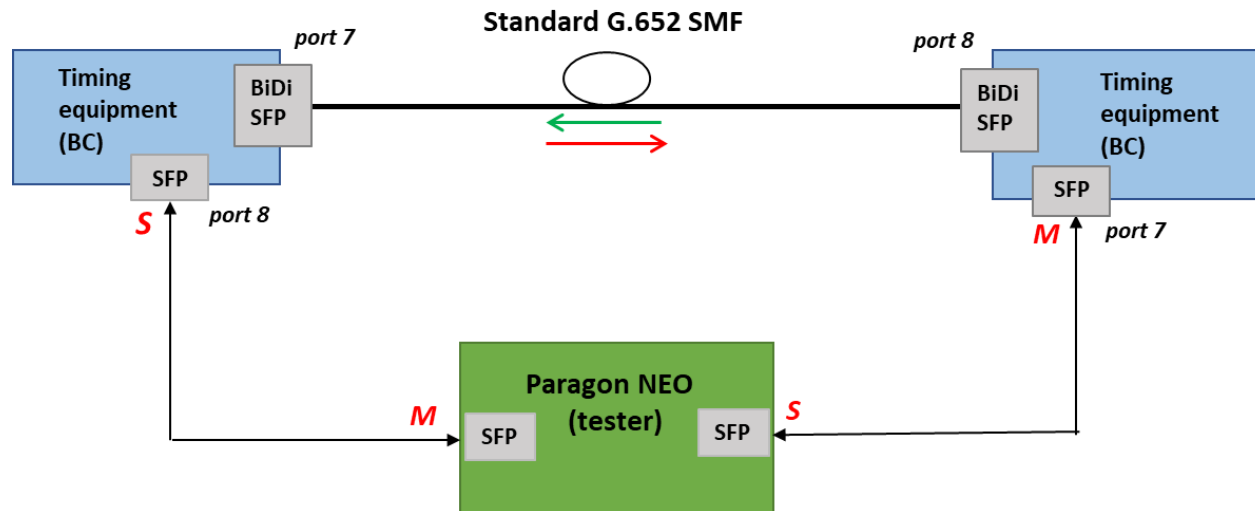
- Timing transport has different requirements from data transport over WDM wavelengths
- Options of optical infrastructure for transporting timing across the network
 - Dedicated optical fibre
 - Timing transport independent on the WDM data transport
 - Optimised for timing signals
 - But, additional fibre required, which may not be available in some cases
 - Optical WDM infrastructure
 - Shared use of optical fibre with WDM systems, so no additional fibre required
 - WDM systems need to support timing requirements to reduce or avoid network asymmetry

Delivering timing over dedicated optical fibre



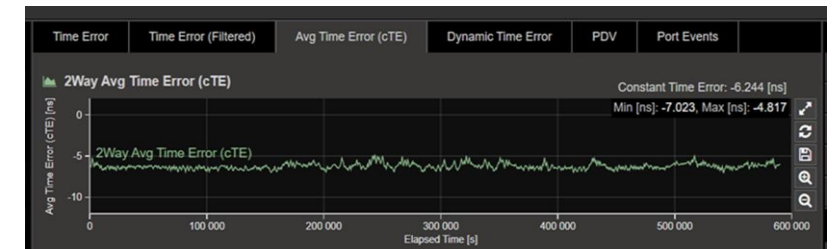
- Timing signals transported directly over dedicated optical fibre
- Using single fibre for both forward and reverse direction to minimise asymmetry
- BiDi optical transceivers required as optical interfaces in timing equipment
 - 1G port most common, 10G and 100M also supported
 - Single Fibre Working: different wavelengths for transmitting signals on opposite directions
 - Usually CWDM wavelengths used, e.g. 1510/1570nm, 1550/1310nm
 - Optical link loss and reach need to be considered: e.g. 40/80/120km

Evaluation of timing over dedicated optical fibre: BiDi transport over single fibre



- Timing equipment set up as boundary clocks with class D performance
- BiDi transport over single fibre between the two timing equipment using 1G BiDi SFP transceivers as optical interfaces
- Paragon NEO tester for high accuracy measurement
 - Master/Slave emulation
 - Standard 1GE LR SFPs used for optical interfaces in the tester

- 1G BiDi SFP transceivers with 1510/1570nm wavelengths over 75km G.652 standard SMF
 - Asymmetry due to optical fibre dispersion corrected in the timing equipment
 - Mean TE measured over 6 days: -6.244ns
 - Max |TE| measured: 8.976ns

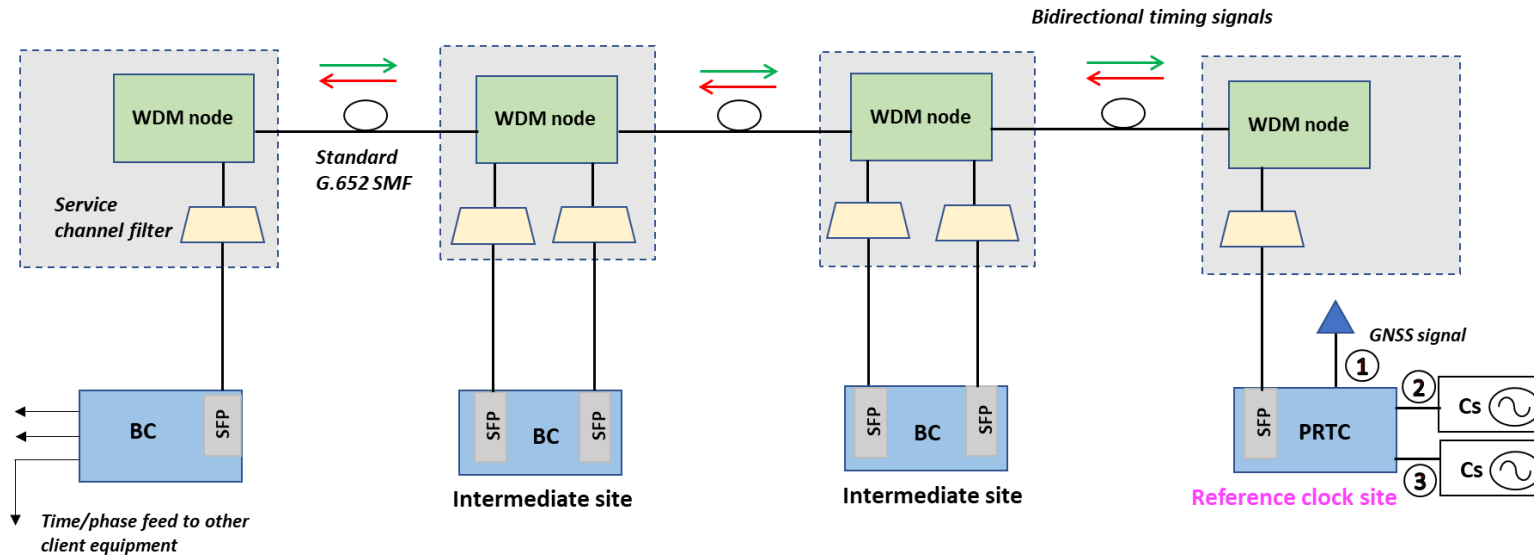


Performance of timing over dedicated optical fibre: different BiDi optical transceivers

BiDi transceiver signal speed	Wavelengths	Reach capability	Fibre distance	Time Error (TE)			
				mean	min	max	peak-to-peak
1GE	1510/1570nm	120km	75km	-6.244ns	-8.976ns	-3.351ns	5.625ns
1GE	1510/1570nm	80km	75km	-7.506ns	-10.225ns	-4.724ns	5.5ns
1GE	1550/1310nm	40km	25km	-6.646ns	-9.095ns	-4.471ns	4.625ns

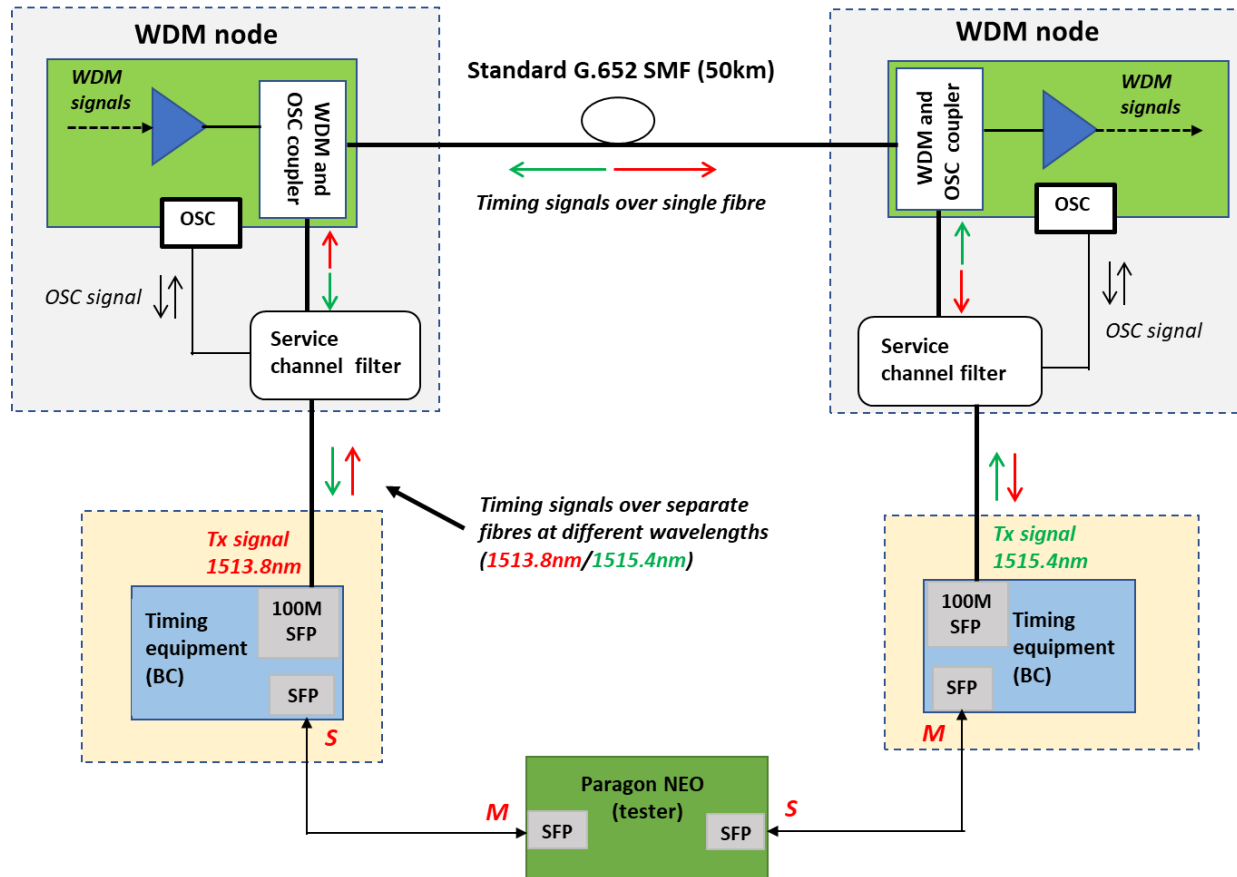
- We have evaluated potential BiDi optical transceivers with different reach capability at 40, 80 and 120km
- Different transceiver technologies depending on the reach capability
 - Wavelength pair 1510/1570nm for BiDi transceivers with 80km and 120km reach
 - Wavelength pair 1550/1310nm for BiDi transceivers with 40km reach
- Different fibre spans set up depending on the transceiver reach
 - 75km fibre span for BiDi transceivers with 80 and 120km reach
 - 25km fibre span for BiDi transceivers with 40km reach
- Good timing performance measured using the various BiDi transceivers
 - Lowest mean TE measured using 120km BiDi transceivers
 - Max |TE| measured using the various BiDi transceivers is 10.225ns

Delivering timing over optical WDM infrastructure



- We have investigated a potential solution to deliver timing over WDM systems
- Timing signals transported over wavelengths within existing OSC window in WDM systems
 - Different wavelengths for forward and reverse direction
- The timing channel added onto WDM systems via service channel filters
 - Timing signals combined with OSC channel using the filters
- Bi-directional timing signals transported over a single fibre through WDM systems
 - Bypassing WDM node equipment and amplifiers
 - Minimising asymmetry via WDM systems
- No impact on main WDM data traffic → suitable for both new build and existing WDM network infrastructure

Proof-of-Concept demonstration of timing over optical WDM system



- Timing equipment set up as boundary clocks (class D)
 - 100Mb/s SFP optical transceivers with wavelength 1513.8nm and 1515.4nm used as optical interface at different end of the optical fibre span
 - Generating timing signals
- A WDM system set up to transport timing
 - Service Channel Filters for add/drop of timing channels
 - OSC channel combined with timing channels
- Paragon NEO tester for high accuracy measurement
 - Master/Slave emulation
 - 1GE LR SFPs used for optical interfaces in the tester

Performance of timing over optical WDM system



- The 100Mb/s SFPs operating in timing equipment generate timing signals
- Timing signals transported over single fibre of 50km in the WDM system
 - Same fibre used as data traffic
- Timing performance measured for ~10 days
 - Mean TE: -9.12ns
 - Max |TE|: 11.621ns
- In the experimental setup, the timing and WDM equipment located in different buildings with fibre connections patched through over a number of panels
 - Representative of worst case scenarios in practical networks
 - Impact of fibre patching to be further investigated

Summary

- We have investigated potential approaches for high accuracy timing over optical fibre infrastructure
 - Dedicated optical fibre
 - WDM network infrastructure
 - Proof-of-Concept evaluation carried out
- We have shown good performance of timing over dedicated fibre solution
 - 1GE BiDi optical transceivers in timing equipment with different reach capabilities (40/80/120km) evaluated
 - Mean TE of better than -7.5ns and max |TE| of 10.225ns measured across two BCs and a fibre span
 - Asymmetry due to bi-directional transmission over optical fibre corrected in the timing equipment → reducing the impact of optical fibre dispersion
- We have also successfully demonstrated a new solution for timing over WDM network infrastructure
 - Transporting bi-directional timing signals over same fibre as WDM data traffic
 - Good timing performance achieved, comparable to the dedicated fibre approach
 - No impact on main WDM data traffic, hence suitable for both new build and existing WDM infrastructure
- Optical fibre infrastructures are essential to support high accuracy timing requirements for future services and applications

Thank you

