A Deep Dive Investigation into the Challenges of Sync over DWDM Networks

MAJOR TRENDS IN OPTICAL TRANSPORT NETWORKS

Figure 1: Major Trends in Optical Networking

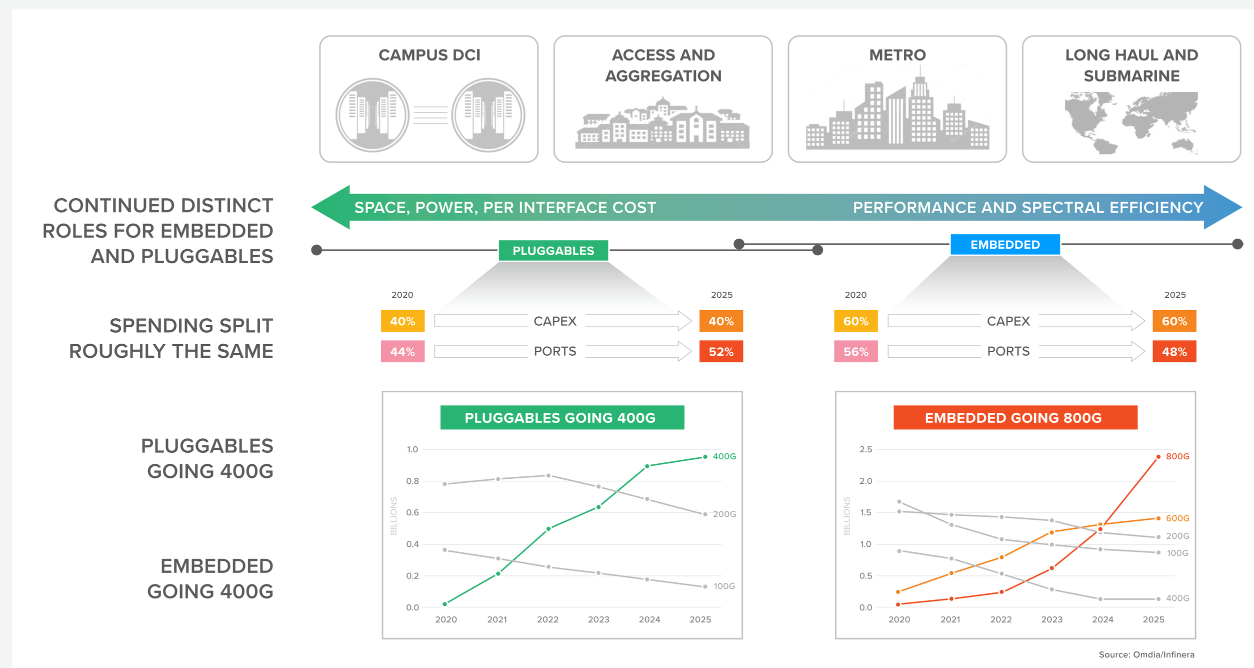


Figure 2: Coherent Optical Market Evolution

NEW OPTICAL NETWORKING ARCHITECTURE

New point-to-multipoint optical networking architectures drive additional considerations into the synchronization distribution network design. These new networks are required to support synchronization distribution in 5G, cable DOCSIS/R-PHY backhaul and other metro aggregation networks. Here both frequency and phase synchronization are required in an environment where a single high-speed hub optic is communicating with multiple lower speed optics at varying distances, and therefore time errors, from the hub.

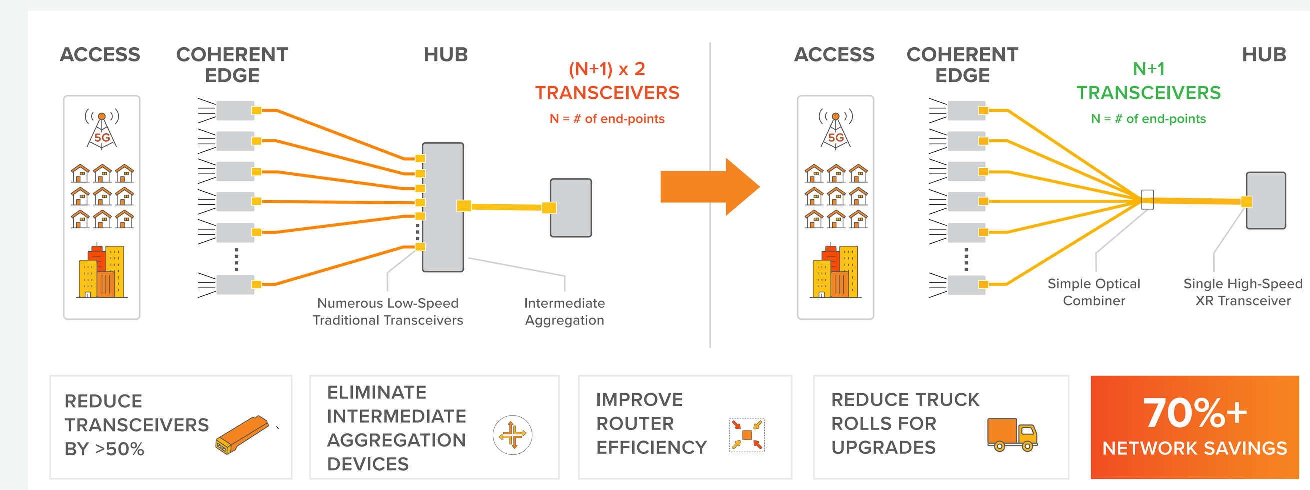


Figure 3: New Point-to-multipoint Architectures for Mobile/Cable

TIMING BUDGETS IN OPTICAL TRANSPORT NETWORKS

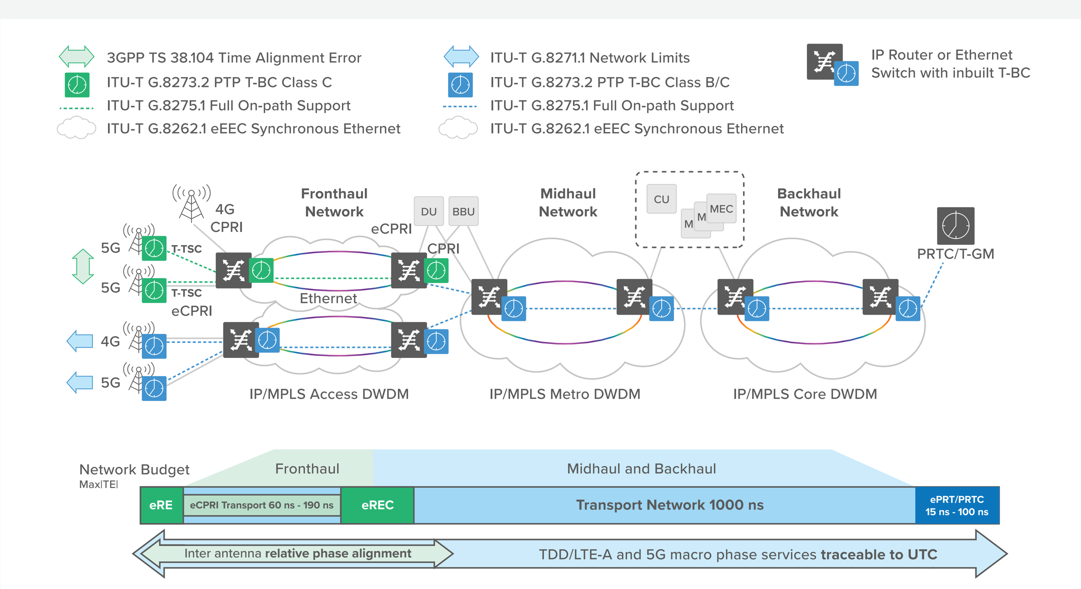


Figure 4: Delivering 5G Quality Synchronization Across the Transport Network

Time division duplex (TDD) networks, either 4G LTE or 5G, require 1.5 µs maximum time error at the cell site to ensure compliant operation. The overall absolute and relative time error budgets are shown on Figure 4. Attention is drawn to the main timing elements in the network, i.e. switches/routers with embedded T-BC functionality, but attention must be paid to the underlying optical transport network.

The maximum absolute time error (Max|TE|) is subdivided into smaller error budgets for differing segments of the network, as shown in Figure 5 for examples of 10-20 hop networks with differing classes of T-BC clocks in the intermediate nodes.

This allocation of time error allows for a total of 1,000 ns for the transport network between the T-GM and the T-TSC at the cell site, as shown between reference points B and C in Figure 5. This time error budget is largely taken up by asymmetry in the nodes and the links (fibers). Managing this asymmetry is of paramount importance in building a 5G-quality mobile transport network.

Essentially, the timing budget for the underlying optical network must be supported by the link asymmetry budget remaining after switches/routers and other T-BC elements have been taken into account. Without careful solution design and network engineering this can present a considerable challenge.

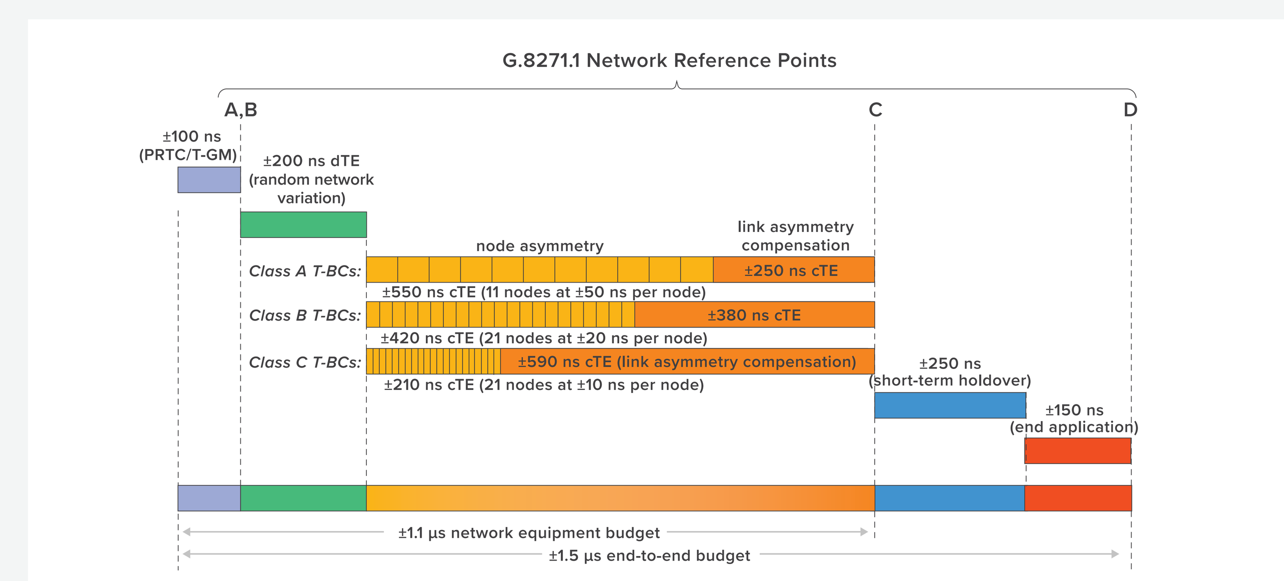
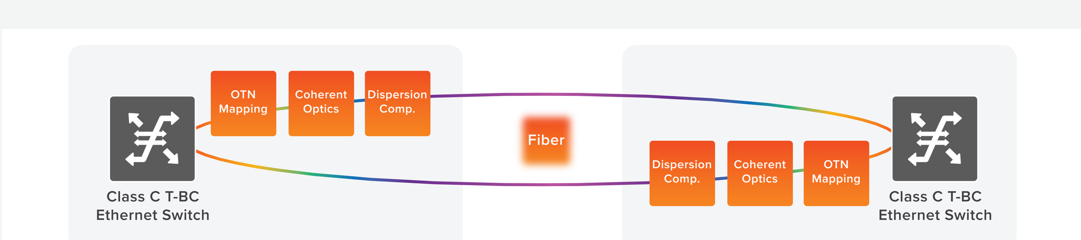


Figure 5: G.8271.1 Time Error Budget Including Type A, B and C Networks

TIMING BUDGETS IN OPTICAL TRANSPORT NETWORKS



Contributor	Fiber	Dispersion Compensation	Coherent Optics	OTN Mapping	IP Routing and Ethernet Switching
Source	Asymmetry in fiber lengths, jumper cables, etc. cTE of 2.5 ns/m.	Random asymmetry in DCF used in each direction.	FIFO buffers in DSP. Varies on restart.	Deep FIFO buffers in OTN mapping. Varies on restart.	Timestamping inaccuracy.
Impact	Large but predominantly static	Very large but predominantly static.	Varying and random.	Large and random.	Tight requirements to control impact.
Range	Fixed cTE of ±5 to 1,000+ ns.	Fixed cTE of ±5 to 20,000 ns.	Random cTE per device/interface of ±20 to 130 ns on restart.	Random cTE per device/interface of ±20 to 1,000 ns on restart.	Class A/B/C specifications. Max|TE| of 30 to 100 ns. cTE of 10 to 50 ns. dTE (low-pass-filtered) noise generation (MTIE) of 10 to 40 ns.

Table 1: Sources of Asymmetry in Optical Transport Networks Summary

Looking at the underlying optical transport network, the main consideration in synchronization-friendly network design is managing both the constant and dynamic time errors throughout all network components, paying particular attention to the asymmetry.

The main contributors to time error in optical transport networks can be summarized as follows:

- Fiber asymmetry within the network. DWDM is typically unidirectional, with each fiber being used for transmission in one direction only and a fiber pair being used for a bidirectional transmission channel. Differences in the lengths of the fibers over the route will create a constant time error. Differences occur in outside plant fiber, patch cable length, repair splicing, etc. Each meter of fiber length asymmetry creates 5 ns of additional latency with a corresponding 2.5 ns of cTE. This asymmetry is predominantly static but will change when fibers are repaired following fiber cuts or when patch cables are changed during network maintenance or reconfiguration.
- Dispersion compensation for non-coherent DWDM. Many access networks either are not yet using coherent optics or mix coherent with 10 or 25 Gb/s on/off-keyed optics that require dispersion compensation. Dispersion compensation based on compensating fiber (DCF) is most common and uses lengths of fiber cut to meet a dispersion requirement rather than a constant length. Variable length creates variable cTE issues in synchronization networks. Dispersion compensation modules (DCM) based on fiber Bragg gratings rather than fiber remove this issue, but these are less common in brownfield networks due to the higher cost.
- First-in first-out (FIFO) buffers in coherent optics. DWDM optics operating at 100 Gb/s and above use coherent optics that contain FIFO buffers within the digital signal processor (DSP). These buffers have a random latency/delay upon initial startup, which varies in each optical interface and therefore varies in each direction, creating asymmetry. This creates a random time error that is constant (cTE) over the shorter term but can sometimes be dynamic (dTE) over the longer term if there are restarts on a link due to intentional network maintenance or unintentional network instances such as fiber cuts or power grid failures. These events are not a common occurrence on an individual link in an operational network, but the size of the random cTE that can be created on initial startup and restarts can be significant.
- DWDM transponders and muxponders based on OTN mapping. OTN mapping chips also utilize FIFO buffers, which have a latency that varies on initial startup and restarts. These deep FIFO buffers are used in OTN mapping to enable the devices to accommodate a wide range of service types and can cause an even larger latency/delay than those in coherent optics. As with the FIFO buffers in coherent optics, the figures here do not vary once the network is up and running, but the size of this error is random across a large range, created on initial startup and every restart, and differs in each direction.
- Time error in IP routers and Ethernet switches. Asymmetry within the router/switch can be created through inaccuracies in timestamping. There are strict T-BC requirements on the specification for these devices for all aspects of time error, which are covered below in the ITU-T G.8273.2 section.

THE CHALLENGES OF OTN-BASED OPTICAL NETWORKS

DWDM Platform Device	Function	Client	Line	Maximum Random cTE	Maximum dTE (Low-pass-filtered) MTIE	5G Phase Sync Support?
400G Flexponder	Dual 100G/200G flexponders on a single card. 1 or 2 x 100G clients mapped into each of the 100G or 200G lines.	100G	100G or 200G	±20 ns	0 ns	Yes
200G Muxponder	200G multi-service muxponder, Various lower-speed services (OTN, Ethernet, Fibre-Channel, etc.) at rates from 10G to 100G mapped into 100G or 200G line.	10G, 32G FC, 100G, etc.	100G or 200G	±670 ns	0 ns	No
Hex-Transponder (non-OTN)	6 x 10G transponders on a single card or hardened pizza box option for street cabinet deployments. Non-OTN-based mapping.	10G	10G	±10 ns	<1 ns	Yes
Hex-Transponder (OTN framed)	6 x 10G transponders on a single card. OTN-based mapping.	10G	10G	±372 ns	<5 ns	No
440G Packet-optical switching card	440G packet optical transport switching card.	10G	100G or 200G	±37 ns	2 ns	Yes
800G Packet-optical pizza box	800G hardened pizza box packet optical transport switch.	10G or 25G	100G or 200G	±28 ns	2 ns	Yes

Table 2: Evaluation of 5G-quality DWDM Transport Options

Getting Synchronization Distribution Right

Hitting the required synchronization performance within a network requires a combination of features/functionality and measurable performance characteristics, such as cTE and dTE of networking devices. Meeting the basic synchronization performance levels enables network operators to fully utilize their most valuable asset, their spectrum. Lower synchronization performance can mean that frequency management within the RAN isn't tight enough and the spectrum can't be fully utilized or that advanced functionality such as carrier aggregation or MIMO antennas cannot be fully utilized or even activated at all. Overall, getting synchronization right is mandatory in mobile networks.

Careful selection of the underlying DWDM network is required to ensure that the required levels of time error budget are maintained. Particular attention must be paid to sources of random constant time error, such as OTN-based transponders and muxponders that can have a high cTE and one that varies in time with events such as fiber cuts, protection switches or system restarts, as shown in Table 2. Careful engineering of the DWDM solutions and networks can enable multiple options for synchronization distribution as shown in Figure 7.

In summary, delivering high-quality synchronization is a must for 5G networks, and it is not simply a case of meeting the minimum possible standard. Superior synchronization performance can bring improved network performance and user experience. It is always a balancing act over the economics of chasing ever-improving synchronization performance, but the goal should always be to get the best performance that meets or exceeds the required level for 5G without breaking the bank.

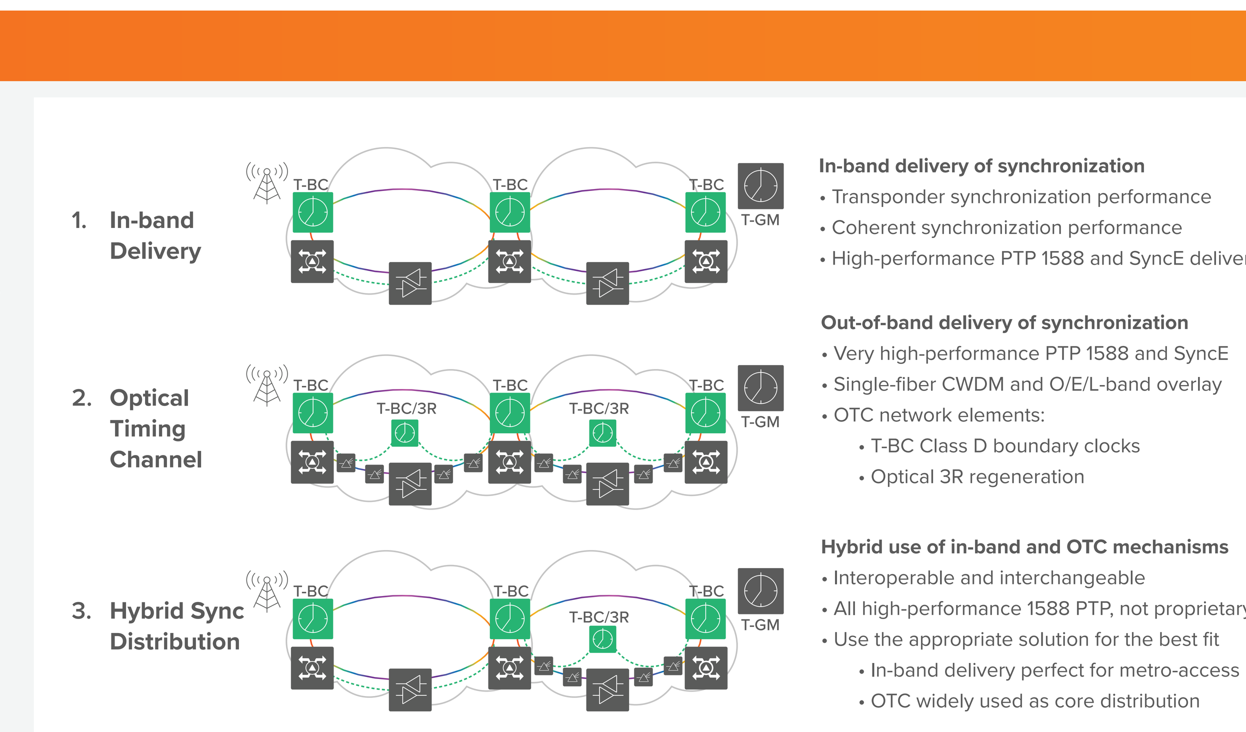


Figure 7: Synchronization Distribution Options in DWDM Transport Networks

NEW ARCHITECTURE FOR 5G AND CABLE AGGREGATION

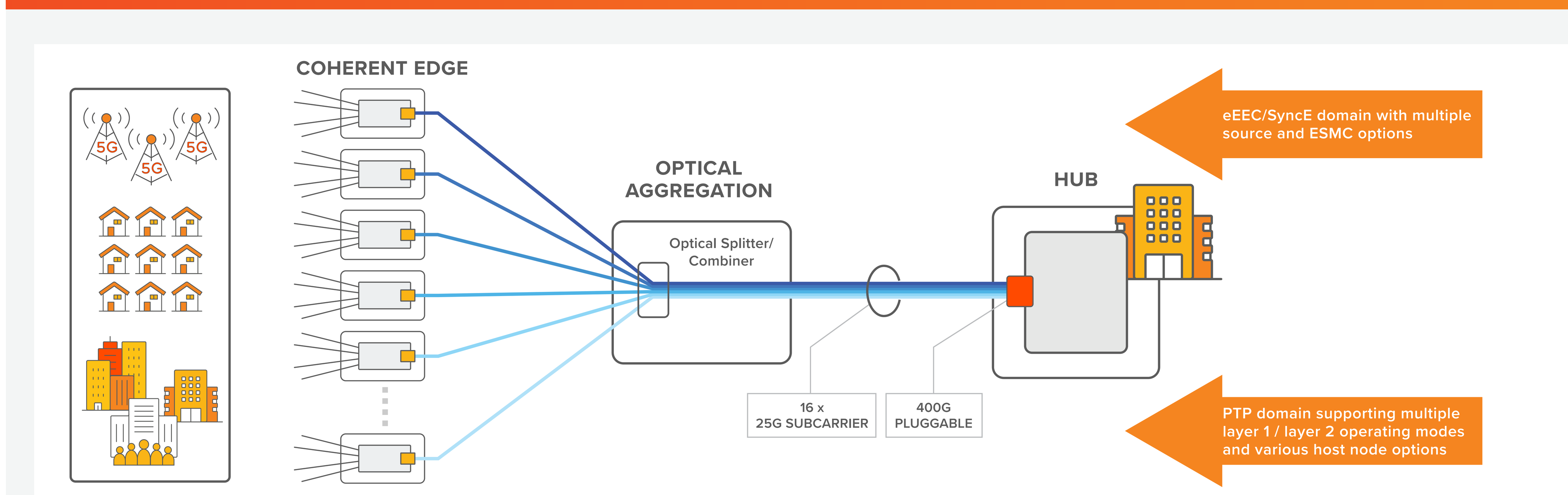


Figure 8: Synchronization Considerations in Point-to-multipoint Coherent DWDM

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