Benefits of Flex Ethernet in Cloud and Telecom Service Provider Networks

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1. Revision History

1.1 Revision 1.0

Revision 1.0 was the first release of this document.

1.2 Revision 1.1

Converted to Microchip branding.

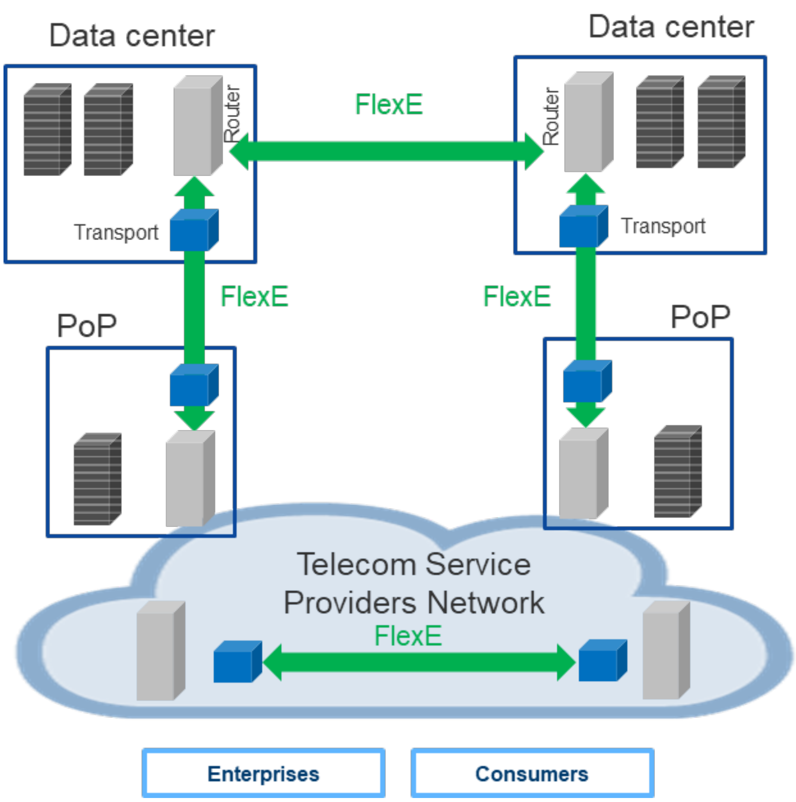
1.3 Revision 1.2

Updated images and document status.

2. Introduction

Flexible Ethernet, or FlexE, originated to solve challenges and inefficiencies in today's packet and transport networks by providing flexibility and higher capacity, while also enabling the optimal usage of new technologies such as highly flexible coherent optical transmission. The data rates that have been standardized by the IEEE do not always align with the needs of Cloud and Telecom Service Provider networks, and creating new rates can take four or more years to complete. FlexE provides a layer of flexibility to close the gap between what networks require and the Ethernet rates that are standardized, while also enabling lower cost solutions. FlexE has the capability to support large packet flows across multiple ports very efficiently, which allows it to support rates beyond the highest standardized Ethernet rate, and to do that at the lowest cost per bit by leveraging low cost, high volume optics. With the availability of flexible rate Coherent optical solutions used to interconnect data centers and central offices, FlexE allows the fiber links to be configured to the optimal rate, even if that rate is not a standardized Ethernet rate, greatly improving network capacity while reducing fiber plant capital expenditure. For these reasons and additional benefits, the ecosystem is coming together to enable FlexE roll out in networks, with the portions of the network using FlexE shown in Figure 2-1. FlexE will be used between data centers (East-West traffic), from data centers to points of presence (North-South traffic), and within telecom service provider networks.

Figure 2-1. FlexE Usage



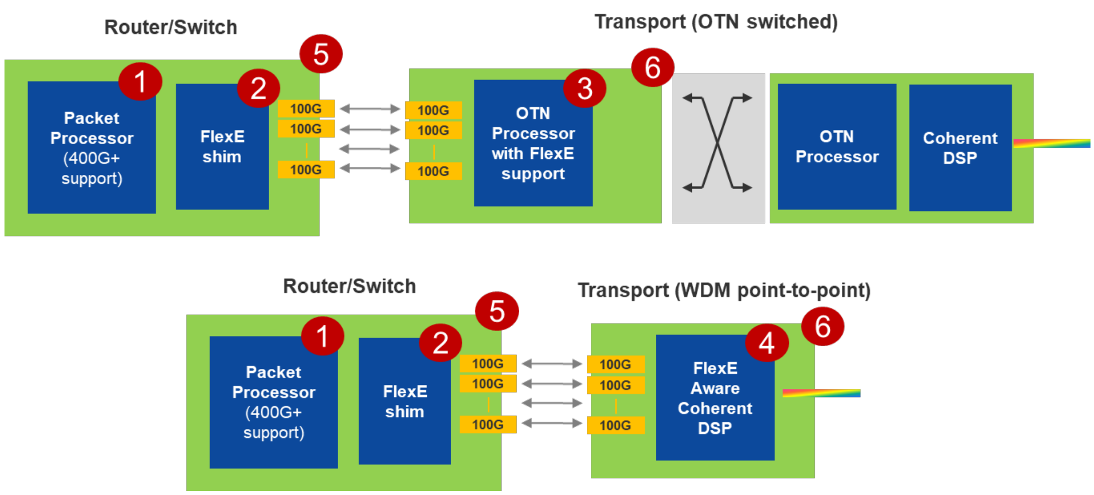
3. Flex Ethernet Ecosystem and Deployment

The initial FlexE standard, which is based on nx100G connectivity, was finalized in the Optical Interconnect Forum (OIF) in 2016. In the time since, the industry has been building the necessary technology to enable deployments of FlexE, with the key components as follows, and shown in Figure 3-1.

1. Packet Processor capable of supporting a 400G or larger packet flow
2. FlexE shim
3. OTN Processor supporting a FlexE shim
4. Coherent DSP that is FlexE aware
5. Router equipment integrating these components
6. Optical Transport equipment integrating these components

Although many of the benefits of FlexE are tied to the transport network, FlexE needs to also originate on the router or switch. The complete set of components and systems to enable end-to-end FlexE are on track to be available in 2019, allowing service providers to start full FlexE trials.

Figure 3-1. FlexE Components



FlexE originated based on requirements from Hyperscale Cloud Service Providers, and supported by companies such as Google and Microsoft in the standardization process [1]. The Hyperscale Cloud Service Providers are also expected to be among the first to deploy the technology, with a focus on FlexE bonding and subrating. Cloud network architectures are such that data centers are geographically distributed across different metros and continents, and the fibers that connect these data centers are expensive and scarce resources. Therefore, when using coherent links to connect them, it is important to maximize the capacity going across the fibers. FlexE subrating enables the rates to be configured with a low granularity of 25Gbps incremenets, optimizing the fiber resource and providing capital expenditure savings. As Cloud Service Providers are extremely focused on cost, FlexE bonding will allow them to support high rate logical ports from the router without the need for new transport equipment, as described by authors from Google in [2]. FlexE bonding can also be used as a more efficient alternative to Link Aggregation Grouping (LAG).

Telecom Service Providers have also started initial FlexE demonstrations, such as the one announced by Vodafone in June, 2018 [3]. Full FlexE trials are anticipated for 2019, driven by similar benefits as those anticipated by the Cloud Service Providers, along with potential to use FlexE channelization along with the OTN switched networks that have already been deployed in many geographies around the world. Also, for Service Providers using MPLS, FlexE bonding enables a larger label switch path, simplifying network management.

4. FlexE Modes and Benefits

Fundamentally, FlexE is providing a layer of flexibility to support data rates that may not correspond to an existing Ethernet rate, or data rates that do not match the port rate supported on a system. To do this, there are three modes of FlexE, adding flexibility to solve different types of rate mismatches:

1. Bonding: When the desired rate is higher than the port rate
2. Subrating: When the desired DWDM rate does not match a standardized Ethernet rate
3. Channelization: When the desired client rate is well below the aggregated port rate

4.1 FlexE Bonding

FlexE bonding can be used to support very large packet flows over multiple lower speed physical ports, as shown in Figure 4-1. There are many benefits to this, enabling both capital expenditure and operational efficiencies. In the example shown, a 600G packet flow is being bonded across six 100GbE ports. This allows the support of greater than 100G rates while leveraging high volume, low cost 100GbE optics (e.g. QSFP28). To support greater than 100G rates, 400G client optics are starting to become available. However, 400G QSFP-DD and OSFP optical modules are bringing new challenges to the industry to support PAM4 and an eight lane electrical interface within a small form factor. It is expected that optical module vendors will need some time to ramp to high volume production, which is needed to achieve lower price points. An alternative to QSFP-DD or OSFP optics is to use FlexE to bond 400G across 4x100GbE with QSFP28, which enables the use of modules that are shipping in the millions of units today, and have achieved a lower price point in terms of $/bit.

FlexE bonding also allows Service Providers the ability to upgrade their routers and switches to support 400G or higher rates, without needing to upgrade their deployed transport equipment supporting 100G clients. With 400G bonded across 4x100GbE, the transport equipment can be “FlexE Unware”, meaning that it does not need to know that FlexE is being used in the system, and treats the clients as though they are just 100GbE. The router or switch on the other end of the link then uses the deskew capability built into FlexE shims to re-combine the multiple 100Gs back into the larger packet flow.

There are alternative solutions that exist today to bond ports together, such as LAG. However, FlexE is a more efficient solution. LAG uses a hashing algorithm to assign traffic to each link in a way that can be 20% to 30% inefficient. FlexE uses a calendar based system using codewords that enables full bandwidth usage and requires fewer ports than LAG, therefore reducing capital expenditures. LAG also has a limitation that limits the largest flow to the rate of a single link, whereas FlexE can have the flow be the same as the combination of all the links.

FlexE also enables operational benefits. Cloud Service Providers need to support many terabits of traffic, so a scalable solution is paramount. Instead of the Network Management System having to manage many individual 100G links, FlexE can be used to bond links together, creating a virtual port and significantly reducing the number of links that need to be managed. This reduces complexity, saves cost and enables the level of scalability that is required.

Figure 4-1. FlexE Bonding

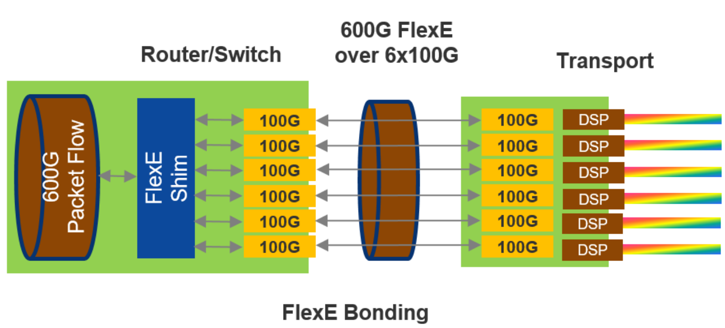


Figure 4-2. FlexE Substrating

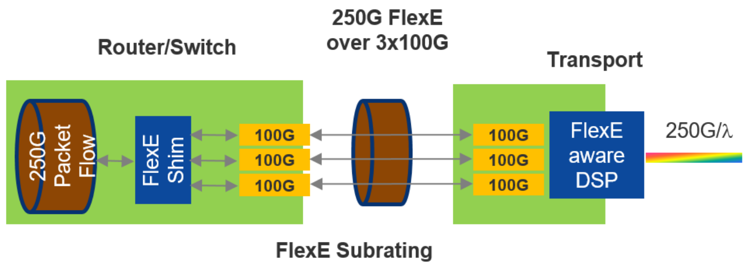
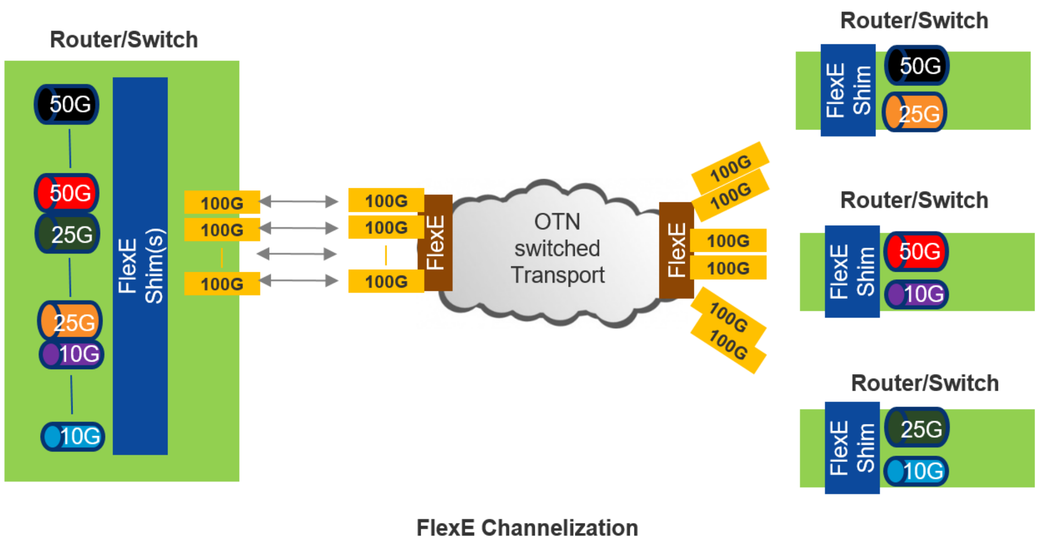


Figure 4-3. FlexE Channelization

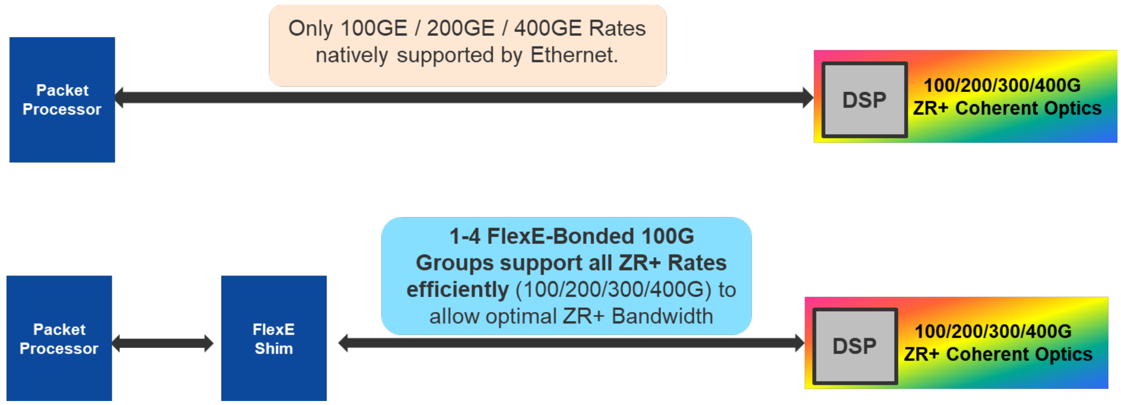


4.2 FlexE Subrating

A second mode of FlexE, FlexE subrating, can be used to take advantage of advances in Coherent DSP technology that support flexible modulation schemes. The Coherent DSPs shipped in volume in 2018 generally supported 100G per wavelength using DP-QPSK or 200G per wavelength using DP-16QAM. Coherent DSPs that ship in 2019 will both increase the baud rate to achieve higher data rates, and add the ability to select a modulation scheme to configure the data rate across each wavelength at a 25Gb/s or 50Gb/s granularity. The low granularity allows for more optimal bandwidth efficiency across the fiber, and reduces the number of router and transport ports required, reducing capital expenditures. An example is shown in Figure 4-2. In this case, the long haul optical link can support a 250G wavelength, but there is no corresponding Ethernet rate. FlexE can enable support of the 250G rate, and uses the FlexE calendar system and bonding to have the 250G go between the router and transport equipment appearing as 3x100GbE, so that off the shelf 100GbE optics can still be used. On the transport platform, the FlexE aware DSP can use a standard 3x100GbE interface to the client optics, then ‘crunches’ to the desired 250G rate to send across the fiber. Without FlexE, it would have been required to use a 200G wavelength that aligns with an IEEE standard rate, but allowing the use of the 250G wavelength provides 25% more capacity. FlexE subrating allows supporting granularities down to 25Gb/s. Doing an analysis to quantify the benefits that technology like FlexE subrating can enable on their long haul data center network, Microsoft found that on top of the capacity gain from going to 50Gb/s granularity, going to 25Gb/s granularity provided an additional capacity gain of 16% [4].

400ZR optics will support 400G with coherent optics in a small, pluggable form factor. Following this will be 400ZR+, adding support for 100G, 200G, and 300G rates over longer reaches. As 300G is not an IEEE standard rate, the packet processor to DSP interface needs a way to support it. FlexE is a solution to this, and can use bonding to create a 3x100GbE interface to the DSP, without any bandwidth inefficiency.

Figure 4-4. FlexE Enables Optimal Use of 400ZR+



4.3 FlexE Channelization

A third mode of FlexE is FlexE channelization. This mode allows support for client rates that do not match the port rate, as shown in Figure 4-3. In this figure, the router on the left side is using FlexE to multiplex together different client rates, and then bonds these across multiple 100G ports. This allows the router to support a high density of low rate clients, without being limited by the optics that can fit on the faceplate. For example, ten 10G clients can go over a single QSFP28 port, which enables a higher faceplace density than using QSFP+ in a breakout mode, or using SFP+. This is similar to one of the advantages enabled by using multi-link gearboxing (MLG). The advantage of FlexE is that it provides additional flexibility in how different rates are supported and multiplexed together, and could enable any combination of clients spread across nx100G links.

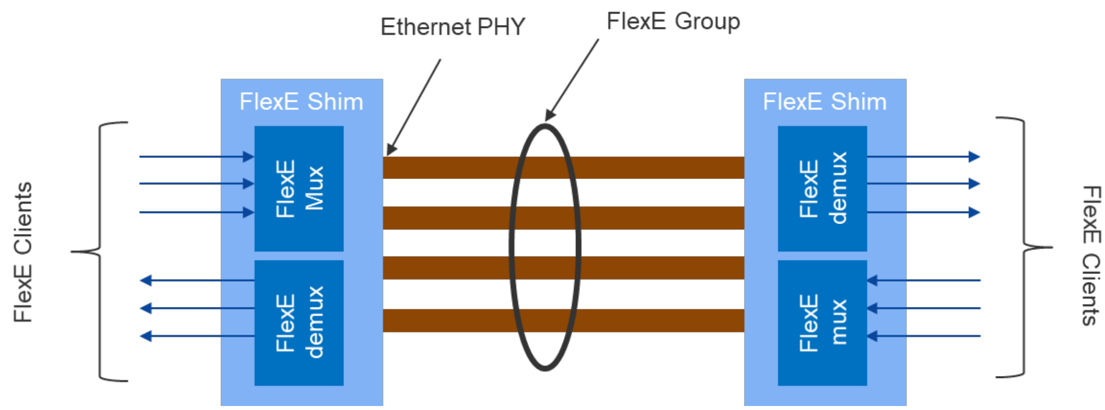
FlexE channelization can also be supported within an OTN switched network. An OTN Processor with FlexE capabilities can terminate the FlexE group, then map the FlexE clients to flexible OTN containers to be switched in the OTN domain. Using FlexE on both router and transport allows for optimized faceplate density and eliminates the need for transport equipment to use expensive and high power packet processors on Ethernet Virtual Private Line (EVPL) cards.

FlexE channelization also enables Service Providers the ability to reconfigure the client rates they are supporting without having to do a truck roll. The combination of 10G, 25G and 50G clients shown in the example in Figure 4-1, Figure 4-2, and Figure 4-3 can be reconfigured through software only, as the FlexE layer can continue to mux the different clients onto the same 100G ports already connected to the OTN switched transport network, reducing operational expenses and reducing the time to bring up new services.

5. FlexE Terminology and Basic Operation

The basic elements of FlexE are shown in Figure 5-1, with key terms described below.

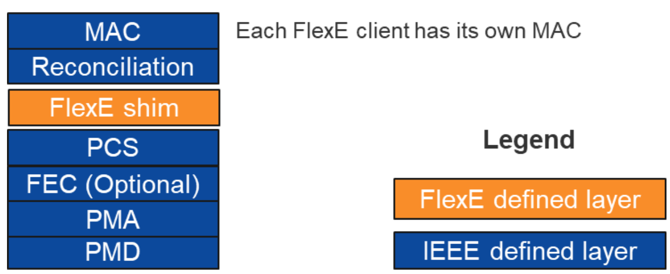
Figure 5-1. General Structure of FlexE



- FlexE Client: Ethernet flow based on a MAC data rate that may or may not correspond to any Ethernet PHY rate (Passes through a Flexible MAC). The FlexE client MAC rates supported with FlexE 1.1 and FlexE 2.0 are 10, 40 and mx25Gb/s.
- FlexE Group: Carries 1 to n bonded Ethernet PHYs (FlexE 1.0 and 1.1 support 100GbE PHYs and FlexE 2.0 adds 200GbE and 400GbE PHYs).
- FlexE Shim: The layer that maps or demaps the FlexE clients carried over a FlexE group.
- FlexE Mux: The portion of the FlexE shim that maps the clients into the FlexE group
- FlexE Demux: The portion of the FlexE shim that demaps the clients from the FlexE group

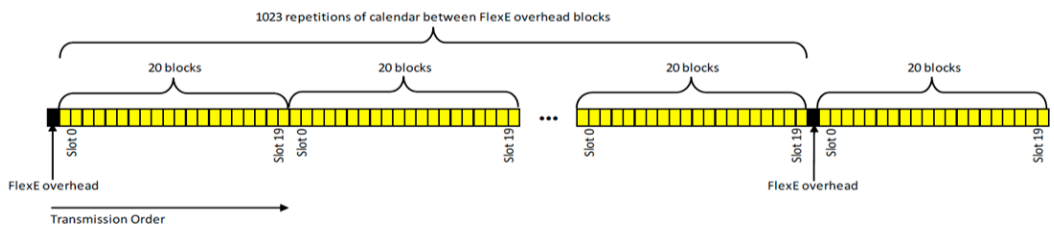
The relationship between FlexE and the standard IEEE stack is shown in Figure 5-2. Each client has its own Flexible MAC, which feeds into the FlexE Shim, where the clients are placed into the FlexE Calendar system. The calendar is partitioned across Nx100GE (Flex 1.1) PCS layer(s) and fed through the IEEE 802.3 stack (PCS, FEC, PMA, PMD).

Figure 5-2. FlexE Relation to IEEE 802.3 Stack



The FlexE calendar system is a key feature enabling many of the advantages of FlexE, including being more efficient than LAG, acting as a next generation MLG, and enabling Flexible rate Coherent DSPs to select the optimal rate. Each Calendar slot has 5G granularity, and for FlexE 1.1, there are 20 calendar slots per 100G PHY as shown in Figure 5-3. Clients can occupy two or more of these calendar slots depending on the rate. The 20 calendar slots are represented as 20 blocks (66b codewords) that repeat. 20 blocks repeat 1023 times prior to a FlexE overhead block.

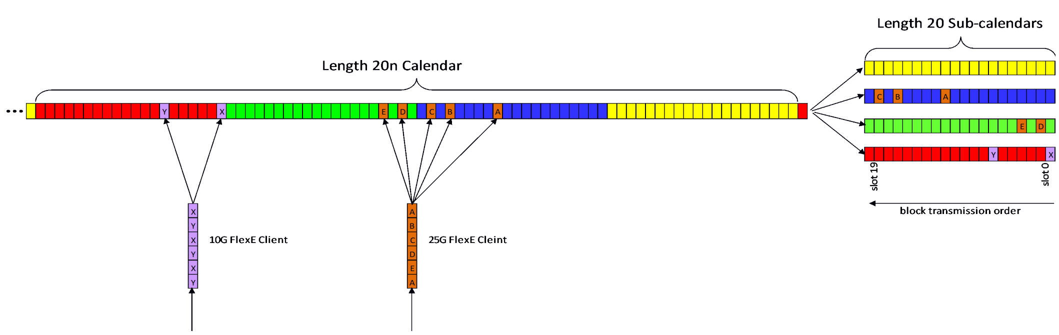
Figure 5-3. FlexE Calendar System



Source: OIF Flex Ethernet Implementation Agreement, IA # OIF-FLEXE-01.1

When a FlexE group contains multiple PHYs, there is a master calendar to manage the slots across the PHYs. For example, for a 400G FlexE shim, there will be 80 total calendar slots (4x20). The FlexE clients can then be distributed across the 80 total calendar slots. An example with a 10GbE and a 25GbE client is shown in Figure 5-4. The 10GbE client uses two calendar slots and the 25GbE clients uses 5 calendar slots. The calendar slots used do not need to be contiguous. This methodology allows for bonding across multiple PHYs, without the inefficiency of LAG. It also allows for clients of different rates to all be combined into a single FlexE group, overcoming some of the limitations of MLG.

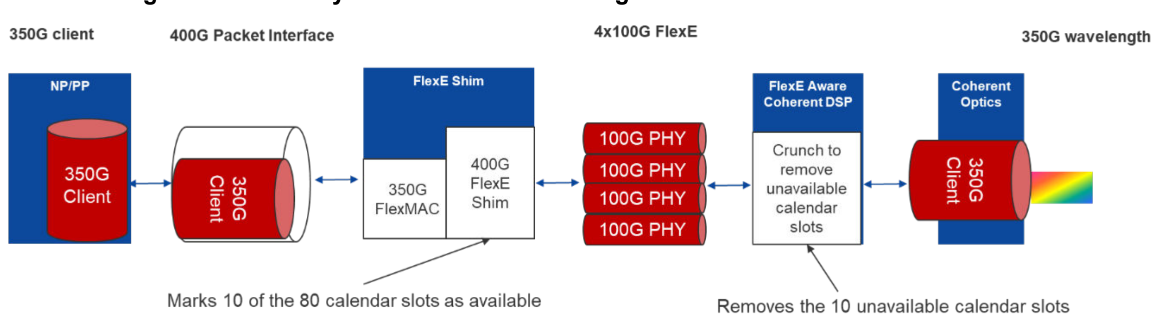
Figure 5-4. FlexE Clients and Calendar Slots



Source: OIF Flex Ethernet Implementation Agreement, IA # OIF-FLEXE-01.1

The calendar system is also used to enable subrating. An example with a 350G client is shown in Figure 5-5, where the goal is to support the 350Gbps rate over the long haul link. In this example, a 400G packet interface is used between the packet processor and FlexE shim. The FlexE shim would create a group of 4x100G PHYs, comprised of 80 calendar slots, and would then mark 10 of those 80 slots as unavailable, leaving 70 calendar slots, or 350Gbps, as available. The FlexE aware Coherent DSP would then discard those 10 unavailable calendar slots to get to the desired rate.

Figure 5-5. Using the Calendar System for FlexE Subrating

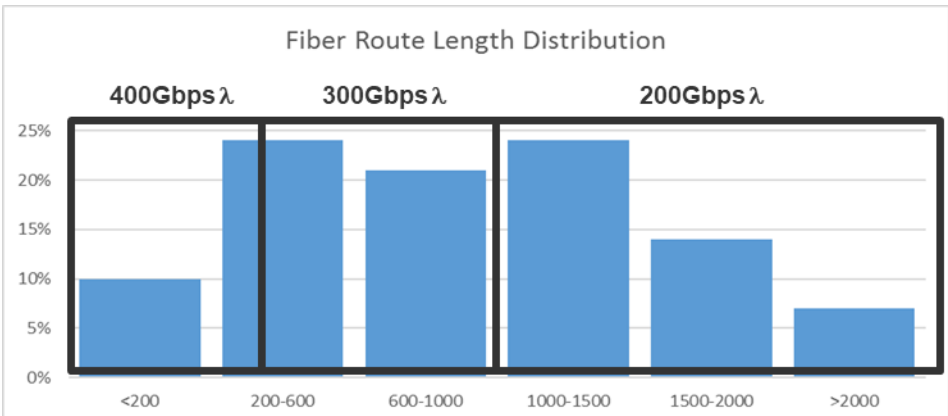


6. FlexE Case Studies

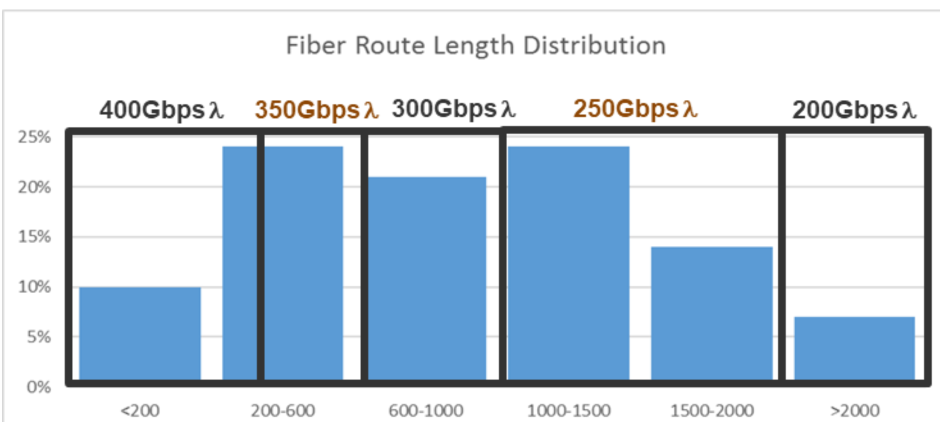
6.1 FlexE to enable Capex Savings for the Backbone

The ability to use a combination of FlexE subrating and Flexible Coherent DSPs allows for the optimization of metro and long haul links to reduce the number of router ports and transport equipment required, reducing capex.

According to IHS [5], transmission capacity is growing by 30% annually, and by 2022, over 70% of the deployed bandwidth will be using wavelengths greater than 100G. This means that a large percentage of the transmission capacity can take advantage of the flexible rate coherent DSPs, and their ability to support fine granularity in the supported data rate. FlexE can enable the service provider to take full advantage of the coherent DSPs flexibility and fine granularity. To quantify the potential savings, the data provided in [4] on the fiber route length and distribution for Microsoft's North American backbone will be used. Without FlexE, wavelengths in 100G increments can be supported using a combination of defined Ethernet rates and LAG. Based on the reach supported at each of the data rates, the chart below shows which portion of the fiber length distribution is supported by each rate.



By now using FlexE, a granularity lower than 100G can be supported. For a Coherent DSP that supports 50G increments, the chart below shows the updated overlay of data rates, and the portion of the distribution that is covered. Whereas originally 200G wavelengths were used to cover everything from 1000 km and higher, now 250G wavelengths can be used to cover the 1000 km to 2000 km portion, with a 25% improvement in bandwidth efficiency. 350G wavelengths can also be used to cover a portion where previously only 300G wavelengths were used.



To obtain the overall savings for the long haul network, the number of wavelengths needed for Case 1, with no FlexE, has been normalized to 1,000. With FlexE now used, enabling 50G granularity, only 852 wavelengths are required, resulting in a savings of 14.8%. This means that 14.8% fewer transponders are needed, as well as a reduced number of fibers and amplifiers, all resulting in significant capex savings.

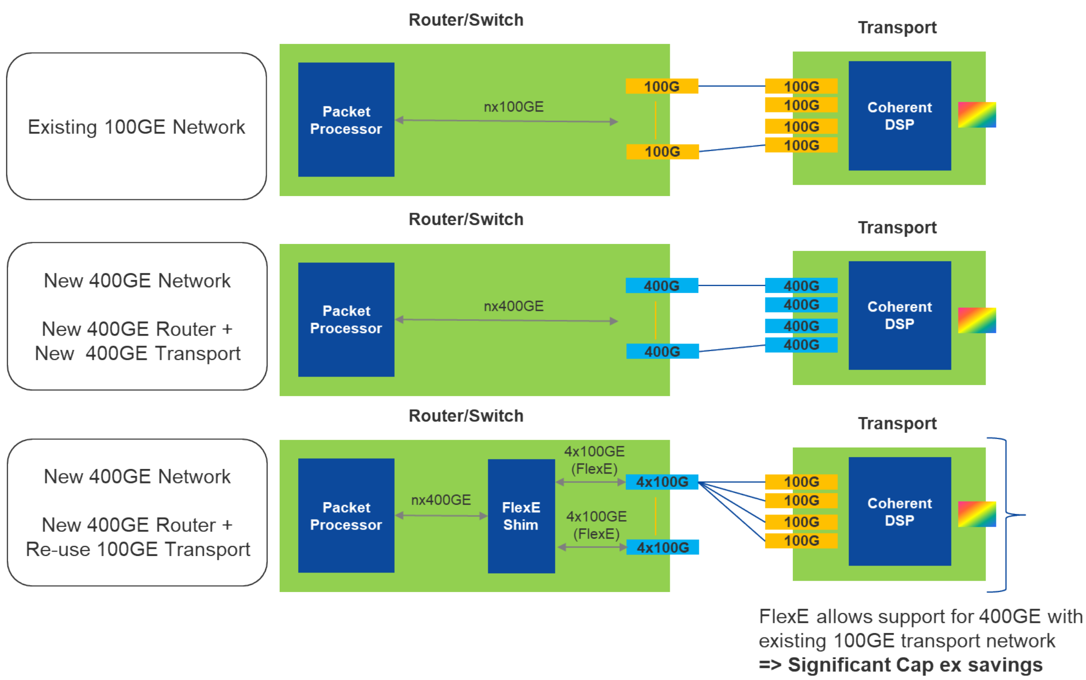
6.2 FlexE Bonding to Enable Capex Savings

The IEEE has standardized the 400GbE rate, and the ecosystem is coming together with routers, switches, coherent DSPs and optical modules supporting 400GbE becoming available. This will drive Cloud and Telecom Service Providers to upgrade their networks to take advantage of the higher rate to support growing bandwidth needs. However, upgrading the router and transport portions of the network, as well as the optics that connect them, is a significant cost. FlexE provides a solution to reduce this upgrade cost, as shown in Figure 6-1.

The first portion of the figure shows an existing 100GbE based network that the service provider needs to upgrade to support 400GbE. The middle portion of the Figure 6-1 shows one potential way to perform the upgrade, which is to upgrade both the routers and transport equipment to support 400GbE, as well as all the optics connecting the two. This comes with a significant cost.

An alternative option is shown at the bottom of the figure. In this case, the router is still upgraded to support 400GbE, but the router now also includes a FlexE shim. This FlexE shim can take the 400GbE and use FlexE bonding to create a 4x100G bonded FlexE group. This 4x100G FlexE group can now connect to the existing transport network already in place, allowing it to now supported 400GbE via FlexE. As Service Providers can often spend 30% to 40% of their cap ex on transmission, FlexE offers a very significant capex savings.

Figure 6-1. FlexE Bonding to Reduce Cost to Upgrade to 400GbE



6.3 FlexE to Scale MPLS Networks

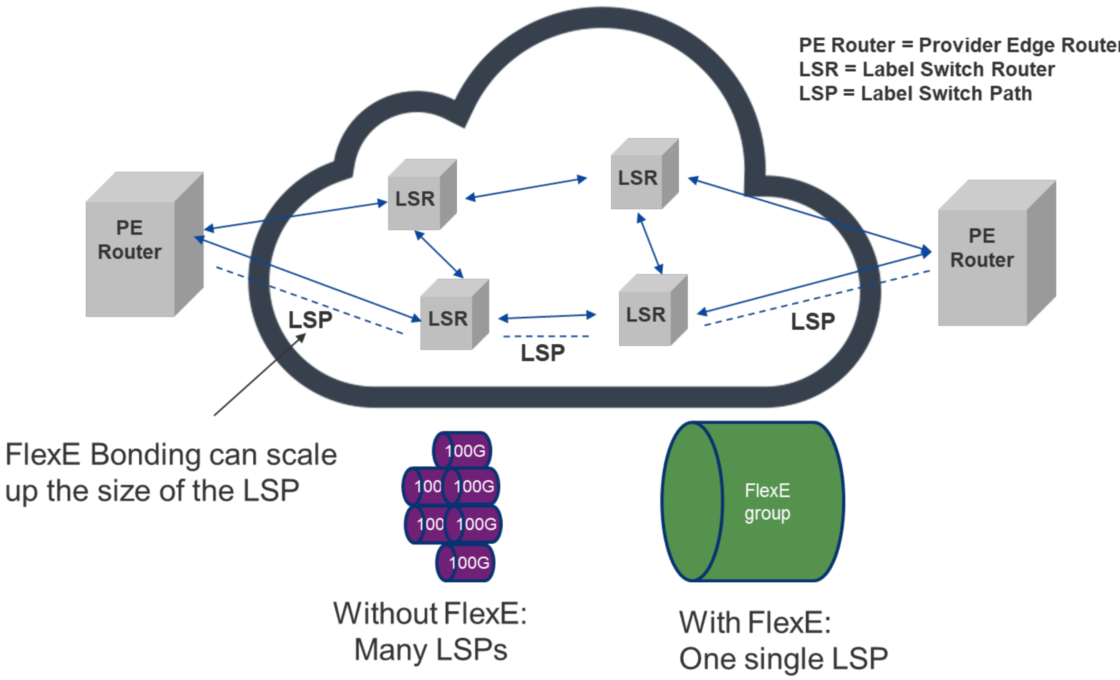
With MPLS networks, scaling and supporting large flows (elephant flows) is a challenge. When a flow exceeds the maximum port rate, one solution is to split the flow across multiple LSPs (Label Switch Paths). One challenge with this solution is that the pool of labels is limited, and cannot scale indefinitely. Also, each label added requires the associated OAM (Operations, Administration and Management) to go along with it, and creates more paths to consider when doing load balancing, adding complexity to the management plane.

LAG can be used to bond ports, but is not a good solution in this situation. One reason is that there is a loss in bandwidth efficiency due to the hashing used to spread the traffic across ports. Also, with LAG, each flow is limited to the maximum rate of a single port, and therefore LAG cannot support elephant flows higher than the port rate.

FlexE can solve all the issues listed above. Compared to LAG, FlexE can bond together multiple ports without any bandwidth inefficiency, and can support flows larger than the rate of a single port. Compared to splitting the flows across multiple LSPs, FlexE required only a single LSP to be used, allowing the bandwidth to scale with the existing management plane.

An example is shown in Figure 6-2. In this case, the network is using 100G ports. To scale, FlexE can be used to bond together multiple 100G ports in a single FlexE group, creating a virtual pipe. The entire FlexE group only needs a single label, instead of splitting the group across multiple LSPs requiring a label for each flow. This concept extends to deployments using 400G ports as well. Multiple 400G ports can be bonded together to create greater than 1Tbps virtual pipes, years before 1Tbps type Ethernet rates are standardized.

Figure 6-2. FlexE to Scale MPLS Networks

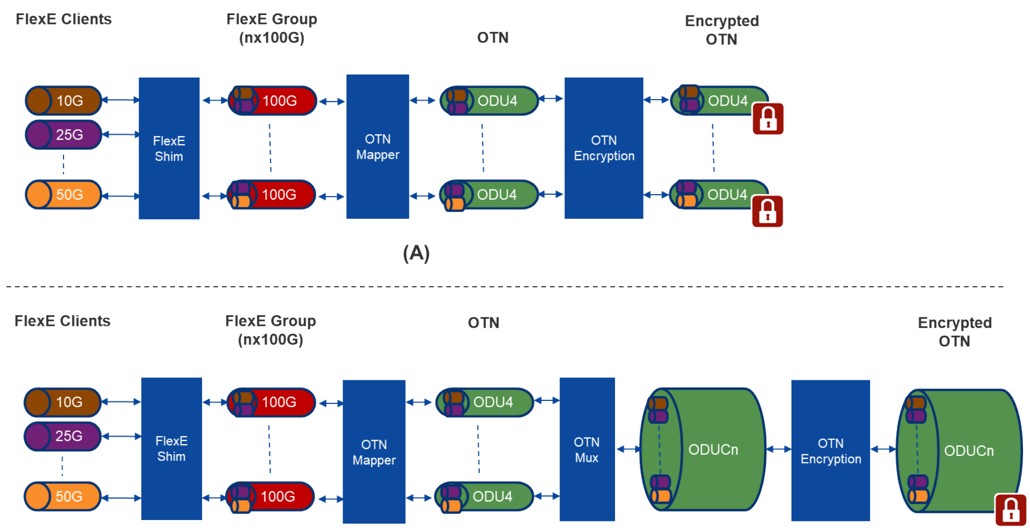


7. FlexE and Encryption

As FlexE will be used in Data Center Interconnects and for metro and long haul links within Telecom Service Providers networks, support for data security will be of high importance. FlexE is compatible with multiple layers of encryption in order to meet this requirement.

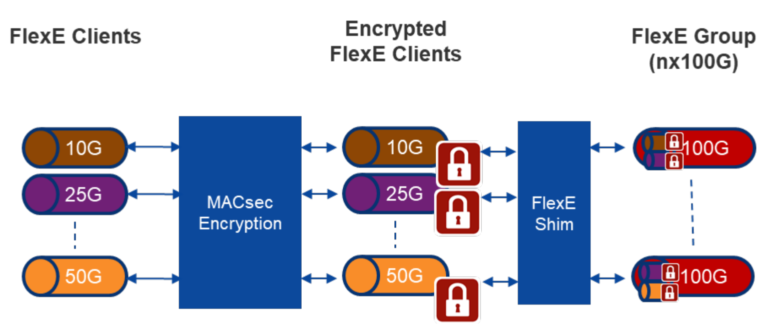
One option is to use Layer 1, or OTN encryption, in conjunction with FlexE. Once the client(s) are mapped in FlexE and bonded across nx100G, there are two ways to use layer 1 encryption, as shown in Figure 7-1. The first is to map each 100G into an ODU4, and then individually encrypt each ODU4 to protect the FlexE clients within it. The second is to map each 100G into an ODU4, as done previously, but then multiplex the ODU4s into an ODUCn, and then to encrypt the ODUCn. Again, this protects the FlexE clients within the encrypted OTN payload.

Figure 7-1. FlexE and OTN Encryption



A second option is to use Layer 2, or MACsec encryption, and shown in Figure 7-2. In this case, each client can be individually encrypted using MACsec, and the encrypted clients are mapped into a FlexE group. This FlexE group can then be safely transported, carrying only encrypted clients.

Figure 7-2. FlexE and MACsec Encryption



8. FlexE and Timing

FlexE will be deployed in multiple parts of the network, including portions that need to be able to communicate timing information between different nodes within the network. To support this, FlexE is compatible with IEEE 1588 Precision Time Protocol (PTP). As with encryption, FlexE can support PTP in multiple ways.

The first option is to support PTP over the FlexE client that is transported as part of a FlexE group. In this scenario, the timestamp packet within the FlexE client is updated within the device containing the FlexE shim. Because the start of frame delimiter (SFD) could be on any lane and any calendar slotof the FlexE group, there will be some level of uncertainty and this method is only applicable for applications that require a coarse level of timing accuracy.

A second option is to support PTP over the FlexE Overhead. This method was standardized as part of FlexE 2.0. With this methodology, a synchronization message is carried in the FlexE overhead, and it contains timing information that applies to the entire FlexE group. This method removes the calendar and lane uncertainty on the PTP messages and is capable of supporting applications that require highly accurate timestamping, including in mobile networks supporting 4G and 5G.

9. FlexE Roadmap

FlexE was designed to be inherently scalable and is already defined in a way to support next-generation bonding and subrating across 400GbE optics, and can leverage these once they are available in large quantity and low prices.

While FlexE was conceived to solve Cloud Service Provider network challenges, the FlexE concept is being leveraged in applications beyond the Cloud, such as FlexE channelization used as the basis of next generation mobile backhaul networks as a way to isolate certain traffic classes to meet requirements for latency and network slicing. These additional use cases will drive further expansion of components and systems supporting FlexE, and further drive a larger FlexE ecosystem.

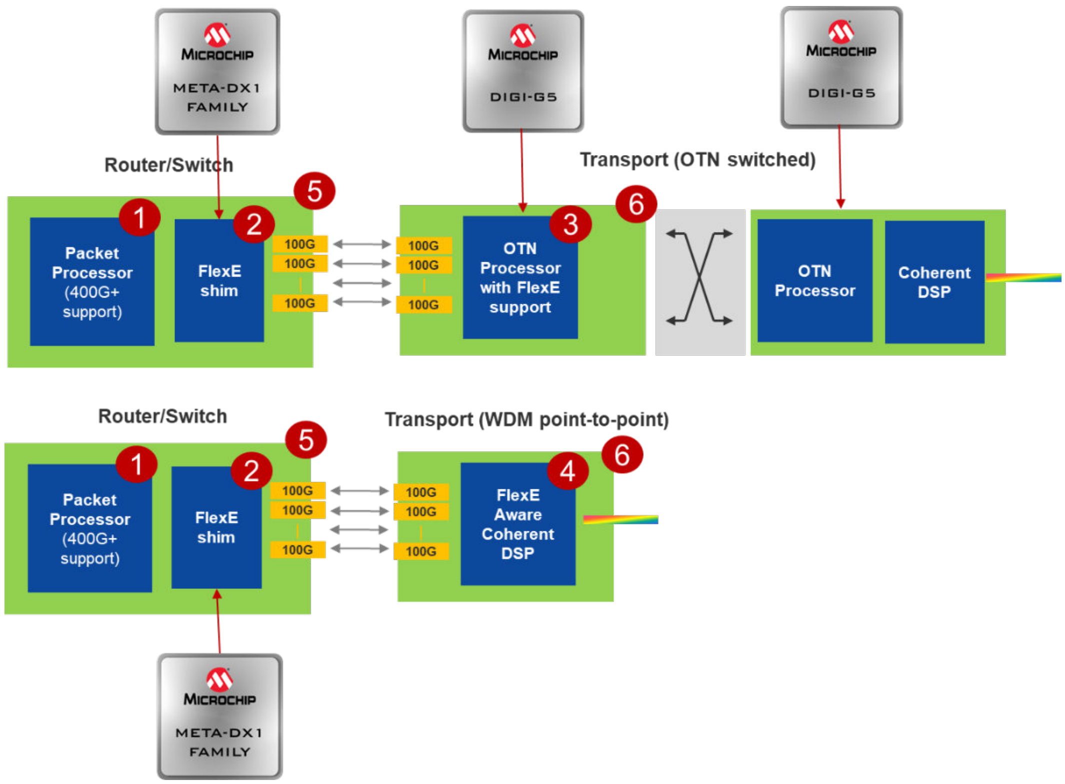
10. Microchip and FlexE

Microchip was an early contributor to the effort to define FlexE, joining before FlexE was brought into the OIF. Once at the OIF, Microchip made numerous contributions towards the FlexE Implementation Agreements.

In addition to the standardization effort, Microchip has invested in bringing the key components required to enable the FlexE ecosystem. Microchip first announced FlexE in the DIGI-G5 OTN Processor, enabling FlexE support on Optical Transport Equipment. The DIGI-G5 integrates a FlexE shim with an OTN encryption engine, allowing combined support for FlexE and layer-1 security.

To address FlexE on routers and Ethernet switches, Microchip announced the META-DX1 family of multi-purpose PHYs with integrated FlexE shims. The META-DX1 family also supports MACsec, combining FlexE and layer-2 security. The META-DX1 family and DIGI-G5 are key components to enable the FlexE ecosystem, and will be used in routers, switches and transport equipment that will be deployed by Cloud and Telecom Service Providers that are taking advantage of the benefits that FlexE provides.

Figure 10-1. Microchip Delivering Key FlexE Components to Enable the Complete Ecosystem



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[3] https://www.vodafone.com/content/index/what/technology-blog/vodafone-pioneers-flexible-ethernet-in-uk.html#, June 2018

[4] Filer et al, "Elastic Optical Networking in the Microsoft Cloud," Journal of Optical Communications and Networking, July 2016, Vol 8: pp. A45-A54

[5] IHS Markit Telecom Optics and Components Market Tracker, October 2018

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