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Meeting 5G Transport Requirements With FlexE

A Heavy Reading white paper produced for ZTE

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INTRODUCTION

Work to standardize 5G New Radio continues, and leading-edge operators are in a race to be first movers. Scale and performance requirements dictated by the 5G radio network are forcing a radical rethink of access and aggregation transport networks, and many operators report that transport networks must be built and upgraded one to two years before wide-scale launches. Under tremendous pressure to be first to market, the stakes are high for transport teams that are tasked to produce future-proof architectures.

Meeting ultra-reliability and ultra-low latency requirements, scaling capacity and economically addressing the diverse use-case requirements are the biggest challenges for 5G transport. Under the banner of "xhaul," there are many technology options available, and combined with the functional split variations defined in 5G, the situation is complex – and largely undecided.

This white paper focuses on Flex Ethernet (FlexE), an emerging transport technology choice that shows promise for 5G. The paper provides an overview of FlexE technology and describes how its attributes address the high-reliability, low-latency, capacity and economics challenges posed by 5G. Key to the value proposition are extensions to FlexE that evolve it from a point-to-point to a fully networked technology.

5G NETWORK OVERVIEW

The 5G New Radio draft specifications for the first phase were approved in December 2017, and work on the second phase (officially, Release 16) is expected to be finalized in December 2019. Even in the absence of full standardization, network operators – and governments – around the world are clamoring to attain rights to leadership status in 5G. Among the most ambitious countries are South Korea, Japan, China and the U.S. Early commercial launches are set to begin as soon as this year, though the bulk of commercial activity must wait until after full standardization, with 2020 looking to be a key year for big launches if the industry stays on its current plan.

Like other mobile generations, 5G promises greater capacity to end devices. It also promises a tenfold increase in capacity, up to 1 Gbit/s to end devices, as a practical (not theoretical) data rate. High capacity is a hallmark of the enhanced mobile broadband (eMBB) use case, which is just one of three primary use cases around which 5G is being defined and built. Massive machine-type communications (mMTC) describes Internet of Things (IoT) applications in which data rates to individual sensors can be very low (measured in kbit/s) but connected devices number in the billions. The third major use case, ultra-reliable low-latency communications (URLLC), describes mission-critical and extreme-precision applications in which end-to-end latency may be 1 ms, jitter less than 1 μs and reliability measured to six nines.

The diversity of use cases for 5G combined with the stringent and extreme attributes across the use cases, as described above, has spurred the development of new radio access network (RAN) architectures. While 4G was dominated by a distributed RAN architecture, new fronthaul and midhaul RANs are added to the mix for 5G. We define them briefly below:

- **Distributed (or classical) RAN:** All cellular traffic is backhauled to the mobile switching center and switched out to baseband units (BBUs)/cell towers as needed. There is some separation of the remote radio head (RRH) and the BBU functionality, but only along the length of the cell tower (top to bottom).
• **Centralized RAN**: BBU functionality is separated from the RRH units and pool at central hub sites, or BBU pools. As a result, the BBU process can be shared among many RRUs for greater coordination and bandwidth efficiency. In its fully centralized form, separation of RRH and BBU is limited to ~15 km, due to restrictions imposed by coordination between radios and BBU processing. However, hybrid architectures are emerging in which a portion of BBU functionality resides at intermediate points between radio and the central hub site, thus easing some of the distance and timing burden. (We discuss functional splits and variations in more detail below.)

• **Cloud or virtualized RAN**: Cloud RAN describes the introduction of NFV in the RAN network, such that compute and storage can move closer and further from individual users across the network dynamically, based on specific cell site requirements that change over time. Greater agility and adaptability are the key benefits that cloud/virtualization bring to the RAN. Defining cloud RAN cannot rely solely on the 3GPP, however, as virtualization in telecom is a broad trend, of which 5G is just a subset.

### 5G Functional Segmentation

Historically in the RAN, Layer 1-3 processing functions resided within a distributed BBU. While 4G architectures provided some separation between the RRH and the BBU, that separation was limited to the height of a cell tower, at the base of which sat the BBU. RAN architectures become more flexible – and complex – with 5G. Known as NG-RAN, the 3GPP 5G RAN architecture introduces new functional modules that place new demands on the transport network, which is tasked with providing scalable and economical connectivity between them.

In 5G, radio base station (gNB) functionality is split into three functional modules: the centralized unit (CU), the distributed unit (DU) and the radio unit (RU), which can be deployed in multiple combinations. By centralizing BBU functions, operators can share network resources and tightly coordinate radio activity to improve network performance. On the other hand, by distributing Layer 2 functionality (either to the cell tower or to an intermediate location in the RAN) aggregation and statistical multiplexing can be used to reduce (potentially greatly) transport network capacity and costs. Figure 1 provides an overview of the different functional options currently in play for 5G.

**Figure 1: 5G RAN Functional Unit Variations**

Source: NGMN, 2018
The separation of BBU functionality across distances has created two new RAN transport segments: the "fronthaul" and the "midhaul" network. The fronthaul network connects the RU to the DU across a distance (i.e., when the two are not colocated at the cell site). The Common Public Radio Interface (CPRI) Consortium built a new protocol specifically to address new fronthaul transport demands. Called eCPRI, the new specification introduces flexibility of functional splits to consistent with NG-RAN and adapts CPRI for packet-based transport to reduce transport capacity and costs.

One challenge with fronthaul is that RU to DU connections are highly sensitive to latency. The midhaul network connects the DU to the CU across a distance, using a higher-layer functional split that is more tolerant to delay. Connecting at Layer 2, it always allows for statistical multiplexing and aggregation to reduce costs. As shown in Figure 1, the DU may be located at the cell site or at an intermediate RAN location.

These two new segments complement backhaul, which remains in the 5G architecture and defines connectivity after the CU.

TRANSPORT REQUIREMENTS FOR 5G

Early on, operators realized that the transport network will play an essential role in delivering many of the attributes promised by 5G, including high bandwidth, low latency, greater density, IoT connectivity, reliability, coverage and costs. Significant challenges exist particularly in the access network, including fronthaul, midhaul and backhaul.

Through operator surveys and one-on-one discussions, Heavy Reading has identified the following as the top transport challenges for operators building for 5G.

High Bandwidth Requirements

While 5G is not solely about greater capacity, it clearly plays an important role in the migration from 4G networks to 5G, and Heavy Reading operator research shows that greater capacity will likely be the primary initial driver for this migration. 5G promises an order of magnitude greater capacity delivered to end devices (up to 1 Gbit/s to devices, as noted earlier). To be clear, the order of magnitude capacity mandate applies specifically to the radio network, but the increase in radio network capacity has ramifications throughout the entire wireline network that supports it.

In fact, many operators are planning to increase their RAN capacities at least tenfold to accommodate the coming 5G traffic. Whereas current 4G cell sites are typically served by 1 Gbit/s backhaul, operators see a move to 10-100 Gbit/s "xhaul," with variations in between, depending on the specific protocols used and xhaul segment – whether it's fronthaul, midhaul or backhaul connectivity. A metro core – which converges mobile, residential broadband and enterprise traffic – may require 400+ Gbit/s capacity in the not-too-distant future.

Densification – the expansion of wireline connectivity to new cell sites – is also one of the mandates of 5G, which calls for 10 to 100 times the number of connected devices compared to 4G, as well as up to 1,000 times the bandwidth per unit area. Densification, which comes primarily in the form of new small cells, will be another major driver of wireline bandwidth. Aggregation points must be able to accommodate ten times the number of users.
Ultra-Low Latency Requirements

In the 5G context, "ultra-low latency" has two aspects that must be addressed through the transport network. One is a user/application-driven latency requirement; the other is a RAN-imposed latency requirement. We'll address both here.

- **Application-Imposed Ultra-Low Latency**: Ultra-low latency is one of the three key use-case pillars on which 5G is being defined (as part of the ultra-reliability and low-latency use case). Ultra-low latency applications are those in which the end-to-end latency demands imposed by the applications themselves are far more stringent than previous mobile applications. Examples include self-driving cars that rely on network connectivity, virtual/augmented reality and industrial automation. For some industrial automation applications, for example, end-to-end latency may be limited to 1 ms and jitter held to just 1 µs.

- **Network-Imposed Ultra-Low Latency**: The network-imposed latency challenge is determined by communications requirements between the RUs and the higher-layer processing functions within the BBU. This was a non-issue in classical distributed RAN architectures, because all BBU processing occurred at the cell tower itself. However, with 5G’s proposed functional separation (Figure 1), limitations of latency and distance become key factors. RU/DU separation must be held to ~125 µs round trip time (and ~15 km maximum distance, based on the physical limits of light through fiber), imposing a severe limitation, regardless of the application traffic riding on top.

Diverse Application Requirements

The requirement to serve three diverse use cases poses a unique challenge to 5G compared to all previous mobile technology generations. Building separate transport networks that address each distinct use case is not economically viable. The challenge for operators is how to address the diversity of use cases – reliably and efficiently meeting the specifications for each – while sharing a single transport network.

The proposed solution for this 5G problem is network slicing. Network slicing allows multiple logical networks to run on top of a shared physical network infrastructure. Each logical network, or "slice," carries its own performance attributes, quality of service (QoS), service-level agreements (SLAs) and share of network resources end to end, thus enabling an operator to deliver an IoT sensor connectivity, gigabit broadband and vehicular communications with the same physical network.

Reliability Requirements

While building and partitioning to address all the requirements above, reliability is paramount. In general terms, operators must provide reliable services in what will be a highly competitive market environment, and many operators are positioning five nines reliability as the network benchmark.

In addition, ultra-reliability is specifically called out in one of the three main 5G use cases, URLLC, in which ultra-reliability may or may not be combined with ultra-low latency. Ultra-reliable applications can include industrial automation applications, in which a short downtime could cost an enterprise millions of dollars, or vehicular communications, in which eliminating downtime can be a matter of life and death. Ultra-reliable applications will require six-nines (99.9999 percent) uptime.
FLEX ETHERNET (FLEXE)-BASED SOLUTION

Defined by the OIF, Flex Ethernet is an interface that supports various Ethernet media access controller (MAC) rates that don't correspond to existing Ethernet physical layer (PHY) rates. Supported FlexE client rates can be higher than the Ethernet PHY rate (through bonding) or lower than the PHY rate (through sub-rate and channelization). The Flex Ethernet Implementation Agreement 1.0 was published in March 2016, with a focus on 100 GE bonding. Version 2.0 extends bonding up to 200GE rates and 400GE rates, among other added features, and was published in June 2018.

From a technical perspective, FlexE introduces three features to standardized IEEE Ethernet:

- **Bonding**: Bonding is a common technique in networking whereby two or more links are combined greater throughout on the link. In FlexE, a high 200 Gbit/s Ethernet client transmission can be supported by combining (bonding) two 100 Gbit/s Ethernet PHYs. The initial implementation agreement (IA) specified bonding for nx100 Gbit/s Ethernet PHYs; the 2.0 version extends bonding to 200 Gbit/s and 400 Gbit/s PHYs. The IA specifies a maximum of 254 FlexE groups for 100GE PHY, 128 for 200GE PHY and 64 for 400GE PHY.

- **Sub-rate**: With sub-rating, FlexE maps lower-rate Ethernet MACs (including non-standard rates) into higher-rate PHYs. For example, a 50 Gbit/s MAC could be transported over a 100 Gbit/s PHY. Bonding and sub-rate can be combined for hybrid client rates, such as a 250 Gbit/s MAC over 3x100 Gbit/s bonded PHYs.

- **Channelization**: Channelization is another common networking technique in which the available bandwidth in a link is shared among multiple clients. In FlexE, channelization can be defined within a single PHY or across multiple bonded PHYs. Channelization granularities are specified by the FlexE client definitions, which include 10 Gbit/s and 40 Gbit/s (covering IEE standardized client rates), and mx25 Gbit/s (covering standardized, as well as non-standardized, Ethernet rates composed of 25 Gbit/s building blocks). Channelization of two 25 Gbit/s MACs and one 150 Gbit/s MAC across 2x100 Gbit/s PHYs is one example of a channelization combination provided in FlexE. The FlexE IA specifies granularity as fine as 5 Gbit/s, though implementations may limit bandwidth assignment to 25 Gbit/s as the smallest building block.

**FlexE Shim**

While most of FlexE is based on standardized 802.3 Ethernet, the FlexE shim is an essential addition to Ethernet coding that makes FlexE work. The FlexE shim is inserted between the MAC sublayer and the physical coding sublayer (PCS) to provide the necessary mapping and demapping between the two for the bonding, sub-rating and channelization specified by FlexE, as described above. Thus, FlexE makes no changes to the MAC sublayer or to the physical coding, physical medium attachment or physical medium-dependent sublayers of standardized Ethernet.

A key point to understand is that, despite having "Ethernet" in its name, FlexE is really a physical layer (Layer 1) technology. The OIF coding all resides in the shim (see Figure 2), which sits in Layer 1. The physical layer location of the FlexE shim is directly responsible for the benefits of low latency, hard isolation that we discuss later in this paper. And, as noted, FlexE's ability to map standard Ethernet client payloads means that FlexE is fully compatible with all standardized Ethernet equipment/interfaces.
### FlexE Channel

Beyond the functionality standardized by the OIF and described so far, a group of network operators and suppliers, led by China Mobile Communications Corporation (CMCC), is looking to extend FlexE beyond its original point-to-point use cases to also include end-to-end, networked use cases. With these new "FlexE channel" extensions, OIF-specified FlexE shim data can be used to perform Layer 1 circuit switching across an end-to-end FlexE network. To distinguish between Layer 2 packet switching, we use the term "cross connection" to describe this Layer 1 FlexE channel function.

FlexE channel is now a new work item within the ITU-T. China Mobile included FlexE channel in its Slicing Packet Network (SPN) architecture, detailed in its white paper entitled *Technical Vision of Slicing Packet Network (SPN) for 5G Transport*, published in February 2018. China Mobile, China Ministry of Industry and Information Technology (MIIT), Telefónica and several global equipment suppliers supported SPN technology for standardization in the ITU-T Study Group 15. In the October 2018 ITU-T SG15 plenary meeting, the SPN-based new work item was approved with the name G.mtn, "Interfaces for a Metro Transport Network."

The FlexE channel cross-connect extension is important for FlexE because 5G networks require end-to-end low latency, hard isolation and reliable connectivity. Extending FlexE to include both point-to-point and end-to-end connectivity greatly expands the technology’s applicability for 5G transport and adds some compelling benefits in low latency and high reliability that we describe in the next section.
FLEXE ROLE IN 5G TRANSPORT ARCHITECTURES

FlexE work traces back to 2011 – well in advance of 5G – and was pioneered by Webscale providers, including Google and Microsoft, that needed a more efficient means to pack optical pipes for intra-data center and inter-data center connectivity. However, as standardization work progressed, FlexE evolved to also address several of the unique transport challenges being introduced by 5G, including RAN capacity, ultra-low latency and network slicing. While FlexE now has a broad context (which may continue to broaden), this section details FlexE use cases specific to 5G transport.

High Bandwidth & Flexibility

An important point of commonality between 5G operators and the Webscale providers that initiated FlexE is the requirement for high bandwidth and greater bandwidth flexibility/efficiency. Another common point is use of Ethernet as the client interface handoff (to cell sites and between elements in the network, in the case of 5G). This combination of scale and bandwidth flexibility makes FlexE appealing for 5G operators, which will be able to gradually migrate to higher data Ethernet rates, over time, including 10 GE, 25 GE, 50 GE, 100 GE, 200 GE, 400 GE and beyond, by using FlexE’s port bonding and channelization functions. With port bonding and channelization, operators can closely match bandwidth in the fronthaul, midhaul and backhaul segments to traffic needs. Since the mapping is flexible, the bandwidth allocations can move both higher and lower as applications require. Thus, FlexE’s capacity benefit for 5G transport is both its scale and its flexibility.

Ultra-Low Latency

Ultra-low latency is one of the main use-case pillars of 5G and one of the most difficult for the transport network to economically address. Ultra-low jitter will typically go hand-in-hand with ultra-low latency requirements. Meeting ultra-low latency and jitter requirements for applications is one of the key challenges for 5G packet-switched networks. As a Layer 1 transport technology, FlexE is well-suited to low-latency transport but was initially conceived as point-to-point. The addition of FlexE channel technology enables end-to-end networking that is required for a 5G transport network. Without touching the MAC, cross-connection is nearly instantaneous (less than 0.5 µs per node) and jitter is less than 30 ns. Furthermore, because of FlexE’s physical isolation from other traffic, latency and jitter are unaffected even as network traffic loads rise. Figure 3 compares Layer 2 packet switching with FlexE channel cross-connection (XC).

Figure 3: Comparison of Packet Switch & FlexE Switch

<table>
<thead>
<tr>
<th>Metric</th>
<th>Packet Switch</th>
<th>FlexE XC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single node switching latency (L2)</td>
<td>30 µs</td>
<td>&lt;0.5 µs</td>
</tr>
<tr>
<td>Traffic forwarding jitter</td>
<td>&lt;10 percent</td>
<td>&lt;1 percent</td>
</tr>
<tr>
<td>As load for single node increases</td>
<td>Jitter up; latency up</td>
<td>Jitter same; latency same</td>
</tr>
</tbody>
</table>

Source: ZTE, 2018

We noted earlier that fronthaul architectures impose their own strict latency requirements – independent of application type – based on the separation of the radios and the BBU processing (on the order of 100 µs). But we note that FlexE, in general, is compatible with fronthaul architectures as eCPRI or legacy CPRI traffic can be carried over FlexE groups.
Ultra-Reliability

Ultra-reliability in FlexE is achieved through the combination of FlexE groups and FlexE channel cross-connection. FlexE groups can be physically defined as working and protection sections, and FlexE channel performs the protection switching in case of failure. As with other high-reliability protection schemes, operators can implement 1+1 protection (traffic sent over work and protection paths simultaneously) or 1:1 protection (traffic switches to pre-defined protection path on detecting failure).

In the 1+1 FlexE channel protection, the client service is sent via two channels at the transmitting end. The QoS statuses of the two channels are detected at the receiving end, and the client service is received from the channel with high QoS, as determined by the receiving end. Due to concurrent transmission, utilization is limited to a maximum of 50 percent.

In the 1:1 FlexE channel protection, there are two FlexE channels: an active channel and a standby channel. Normally, the client service is transmitted in the active channel. When the active channel fails, it sends the automatic protection switching (APS) message to the receiving end while switching the client service from the active to the standby channel. With 1:1 protection, low-priority traffic may drop during a failure, but high-priority traffic will always be guaranteed. Automatic protection switching time is less than 50 ms, and utilization of up to 100 percent can be achieved with 1:1 protection.

Network Slicing

FlexE – combined with the cross connect functions of the FlexE channel – provides a physical layer-based option for network slicing that is an alternative to the packet-based slicing options that have been proposed so far. With FlexE, individual network slices can be built using FlexE bonding and channelization that maps the Layer 2 client traffic to the physical transport ports (the FlexE group). Adding FlexE channel, end-to-end network slices can be created through the transport network, bypassing intermediate switching nodes along the route and ensuring strict physical layer service isolation across the entire route. FlexE-based network slicing – combined from FlexE group efficiency and FlexE cross connection – provides some unique and important advantages when compared to alternative approaches to network slicing:

- Physical-layer isolation completely independent of the packet layer, which is not possible with packet-based slicing technologies.
- Ultra-reliability using FlexE-based protection switching.
- Ultra-low latency that can be maintained independent of network loads.
- Flexible and efficient use of transport network capacity that is not possible in wavelength-based slicing.
- Uniform correlation with IEEE Ethernet client interfaces that dominate the RAN.
- On-demand network reconstitution: The sliced network can be reconstituted in network topology and node capability to meet service needs. Different network slices are isolated from each other and have independent topology and network resources.

As a final note, FlexE network slicing will not be needed for all 5G applications and traffic types, but it may be essential for delivering the ultra-reliable and ultra-low latency applications that are one of the primary challenges in architecting transport networks for 5G. Significantly, because FlexE is fully compatible with Ethernet, FlexE traffic and Ethernet traffic coexist on the same networks and within the same switching equipment.
OPERATOR TRIAL PROOF POINTS

China Mobile

As noted earlier, China Mobile is a strong FlexE proponent and its SPN architecture is now the basis of the ITU-T's "Interfaces for a Metro Transport Network" (G.mtn). During the 20th China International Optoelectronic Expo (CIOE 2018), in September 2018, China Mobile held an SPN for 5G summit in which five leading SPN vendors conducted on-site SPN interoperability demonstrations. ZTE was one of the participating suppliers. The demo results showed that the one-way forwarding latency of FlexE based SE-XC was superior to the latency of traditional packet switching. The demonstration also verified that FlexE-based network slicing can achieve strict isolation when carrying multiple services at the same time, and showed that performance attributes – such as bandwidth, latency and jitter – do not affect each other across slices.

Telefónica

Along with China Mobile, Telefónica is another operator champion for FlexE and the SPN architecture. In August 2017, Telefónica worked with ZTE to complete the first phase of a 5G transport test at the Future Networks Lab in Madrid, Spain. The Phase I test showed that NGFE/eCPRI and CPRI services can be transported correctly through a 25 GE UNI and 100 GE NNI interface with FlexE-based packet equipment (supplied by ZTE in the test). The test achieved less than 0.5 µs per node ultra-low latency forwarding with FlexE cross-connection and less than 1 ms protection switchover with 1+1 FlexE channel protection. These performance specs satisfy the service transport requirements for NGFI/eCPRI/CPRI.

CONCLUSIONS

While 5G NR standardization continues, and as operators race to be first to market with their initial launches, there is growing recognition that underlying transport networks must be upgraded before 5G can be rolled out at scale. Chief among operators’ concerns in 5G transport is how to cost-effectively address the ultra-low latency and ultra-reliable use cases that 5G will introduce.

To solve 5G’s unique transport challenges, new technologies will be needed. Among the new technologies gaining traction is the OIF’s FlexE, which reuses Ethernet mature supply chain and has backing from leading operators and Webscale providers. Significantly, new FlexE channel extensions that adapt FlexE from a point-to-point technology to a fully networked technology greatly broaden FlexE’s applicability to 5G for the ultra-low latency and ultra-reliable use cases. Here, FlexE has innate advantages in ultra-low latency forwarding and securely isolated network slicing that Layer 2 and Layer 3 technologies can’t match. FlexE channel standardization, as part of the coming ITU-T G.mtn standard, will widen FlexE’s appeal as a 5G solution for operators and increase the number of suppliers adding this technology to their optical systems. The G.mtn standards track is encouraging for the future of the FlexE channel function.