ETN – Ethernet Transport Network for 5G Mobile Transport, Metro, and DCI Network

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讨论了以太网传输网络（ETN）体系结构，ETN网络提供了七种功能，即包括CBR SDH服务和可变速率以太网服务在内的多服务访问，确定性和无损L1.5转发，硬业务隔离的ETN通道，分层业务复用，灵活的L1.5 / L2 / L3转发，多层OAM功能。除了为eMBB，uRLLC和mMTC应用程序提供服务外，其还有望实现更多的垂直创新。其对ETN原型交换机的初步实验评估表明，ETN可以成为未来5G传输，城域网和DCI网络解决方案不可或缺的一部分。

***Abstract*—The past decade has witnessed the large shipments of Ethernet switches and IP routers. The wide availability of commodity Ethernet ASICs and the publicly open interoperable Ethernet/IP network standards have made Ethernet/IP equipment the preferred deployment option in the campus, data center, and mobile service operator's 3G/4G LTE backhaul network. In this paper, we present an end-to-end Ethernet Transport Network (ETN) framework which features multi-service access, deterministic forwarding latency, hard traffic isolation, hierarchical traffic multiplexing, flexible and adjustable L1/L2/L3 forwarding, and multi-layer OAM mechanism. We envision ETN to be a unified solution for the future 5G mobile transport, metro, and data-center interconnects (DCI) network. In the end, we present the preliminary evaluation of our ETN prototype switch boxes implemented using commercial FPGAs and share our future vision for ETN evolution.**

***Keywords*—ETN, low latency, deterministic forwarding, reliable forwarding, packet delay variation, multi-service access, hierarchical multiplexing**

I. Introduction

With the 4G LTE mobile network widely deployed across the globe, the Internet traffic has grown at a unprecedented rate thanks to the mobile data traffic. High resolutions video and interactive AR/VR(Augmented Reality/Virtual Reality), automated driving, and the Internet of Things applications further drive up the demand for larger bandwidth, lower latency and more connections in the upcoming 5G mobile network. The cloud computing trends have also placed greater bandwidth and throughput demand on the data center and data center interconnect(DCI) networks. The wide deployment of broadband enterprise lease line and residential fiber or copper fixed line broadband network have also called for a metro network with sufficient bandwidth capacity and versatile vertical integration capabilities. It is expected the next generation 5G mobile transport network, DCI, and metro network technology shall be able to meet the applications' requirements and open up more vertical integration business opportunities for the service providers.

On the other hand, the mobile, fixed line, and Internet service providers become more aware of the network CAPEX and OPEX when choosing the next generation network technology. An integrated network technology that can combine the transport, DCI and metro network wild bring the cost benefit and simplify the future maintenance and operations. In addition, they expect a long-term evolvable network with great extensibility and scalability. Ethernet/IP has become the dominant service traffic in campus network, residential broadband network, data centers, and the 4G LTE network. It is natural and most cost-effective that the future network architecture evolves over the Ethernet/IP technology.

A. Converged Infrastructure

A converged infrastructure centered around Ethernet/IP technologies is the future network trend. However, such a converged infrastructure still needs to address several issues posed by future applications and operations. In this paper, we present the unified Ethernet Transport Network(ETN) which can meet the requirements of future mobile transport and metro applications and the expectations by the service operators.

II. ETN Characteristics

A. Multi-service Access

Despite the fact and the trend that most of the traffic in the data center, mobile transport, and metro network is Ethernet/IP packet data, there remain some other types of traffic services in the network.

For example, the majority of the 2G mobile backhaul transport network is built with the wireline SDH(Synchronous Digital Hierarchy)/SONET(Synchronous Optical Network) equipment and the constant bit rate(CBR) STM-1/4/16/64 containers are still in use to transport the cellular voice service. Despite the growing number of deployments providing medium-rate to high rate L3/L2 enterprise lease line services, there are still many service providers offering legacy low rate SDH enterprise lease line services for the bank, insurance and security companies, government offices, and small company customers due to SDH's low cost and security.

For the upcoming 5G cellular network, the mobile transport network can be further splitted into fronthaul, midhaul and backhaul under the C-RAN(Centralized – Radio Access Network) scenario[1]. The fronthaul is the network segment between the RRH(Remote Radio Head)/AAU(Active Antenna Unit) and DU(Distributed Unit) and is likely to carry the eCPRI[4] traffic.

ETN is designed to be a multi-service transport network[21] and is capable of carrying the SDH and eCPRI traffic. Although ETN is built on top of the asynchronous Ethernet interfaces[2], the frequency and clock information in eCPRI will be preserved by ETN via well-designed idle control block insertion/deletion synchronization mechanism. Optional, ETN can deploy SyncE[12] interfaces whose system clocks have a $\pm$4.6ppm frequency variation instead of the $\pm$100ppm frequency variation in Ethernet clocks. The frequency and clock signals transferred from the DU to the RRH can enter the ETN network via ETN ingress node and be properly recovered at the ETN egress node. The same

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principle is applied to CBR Ethernet traffic with clock information by the ETN network. The CBR services are transported by ETN via a bit transparent approach where the CBR service bit streams are transported in the ETN network without any modifications to its payload bits.

In addition to supporting the CBR traffic with clock information as the ETN clients, ETN's primary client signals include the 1GE, 5GE, 10GE, 25GE, 40GE, 100GE, 200GE, and 400GE variable bit rate(VBR) Ethernet service traffic. The Ethernet client signals including 1GE, 5GE, 10GE and 50GE need to be undergoing a codeword transcoding process entering the ETN network and be restored in the ETN egress node.

B. *Deterministic Forwarding Latency and Lossless Delivery*

The Ethernet/IP packet network delivers the client service traffic on a best effort basis. It does not provide guarantee delivery of the client traffic and the traffic transport time depends on the packet network's congestion conditions. If some network element(NE) in the packet network experiences traffic congestion and the ingress port's packet buffer is full, then any upcoming traffic will be discarded by the NE in absence of any QoS mechanism.

In addition, the packet forwarding in Ethernet/IP/MPLS requires a table lookup in the respective MAC forwarding database, route tables, or label database. The table lookup and any potential packet buffering adds up to the packet traffic's total indeterministic processing time in each network element. Even in the most state of the art commercial switch/router, the forwarding/routing time for a certain packet in a packet switch is usually at least 1µs at very ideal non-congested conditions and can be as high as several milliseconds when the ingress traffic load is high.

ETN offers a deterministic forwarding mechanism which operates at the 64B/66B PCS layer of the 100GBASE-R PHY protocol stack as shown in Figure 1. The incoming client traffic is first encoded into a sequence of 66-bit blocks and the 66-bit blocks are switched/cross-connected in the multi-hop ETN network elements to the final egress port using a planned 66-bit block stream circuit. This switching mechanism is also known as L1.5(layer 1.5) switching[6] as it is slightly above the L1 PHY but below the L2 MAC forwarding. The L1.5 switching greatly reduces the processing latency incurred on each network element and provides more latency room on the fiber distance on 5G mobile transport network under the same latency constraints. With this circuit-switching mechanism, the lossless delivery can be provided as long as the ingress traffic volume is provisioned below the planned circuit capacity.

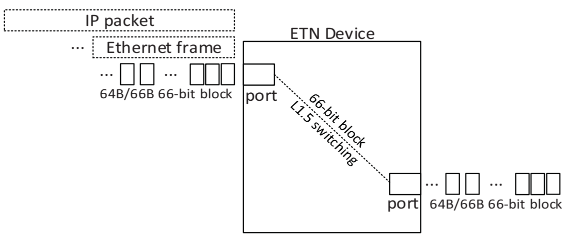

Figure 1 Illustration of L1.5 switching scheme

C. *TDM Channels with Hard Traffic Isolation*

OIF FlexE Ethernet(FlexE[3]) Implement Agreement released on 2016 enhanced the Ethernet interfaces with channelization, bonding, and subrating capabilities. FlexE introduces a FlexE Shim layer which operates over the PCS(Physical Coding Sublayer) of the IEEE 802.3 100GBASE-R PHY protocol stack. FlexE creates 20 x 5Gbit/s calendar slots which are time-division multiplexed over the PCS 64B/66B blocks of a 100GBASE-R PHY. Multiple 100GBASE-R PHYs can be bonded to form a single FlexE Group which in turn offer n x 20 x 5Gbit/s calendar slots. The FlexE calendar slots are used to carry the FlexE clients which may correspond or not corresponding to an existing Ethernet standard MAC data rate.

As shown in Figure 2, the FlexE calendar slots enable channelization over the standard Ethernet interfaces.

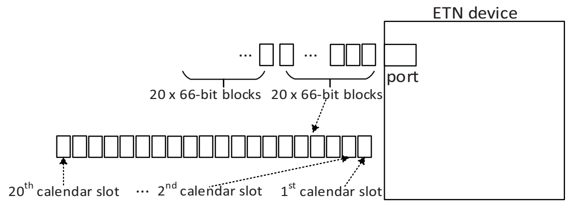

Figure 2 Illustration of FlexE channelization

The FlexE TDM channels on the Ethernet interfaces with the deterministic L1.5 switching enable the channelization across multiple network elements and an end-to-end channel in the network. As shown in Figure 3, ETN provides two end-to-end channels(ETN Channel 1 and 2) with hard traffic isolation from each other.

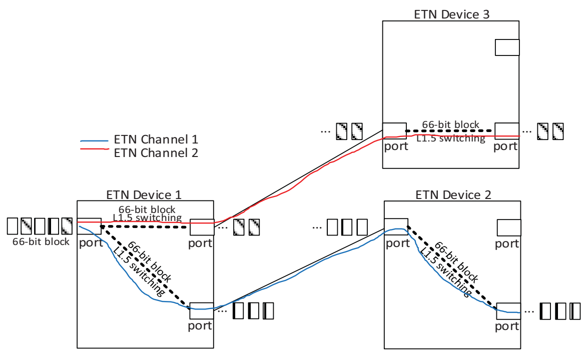

Figure 3 Illustration of L1.5 switching scheme

The conventional packet technology can offer soft transport network slices with no hard traffic isolation. The resulting integrated transport network would have to be carefully planned to ensure the actual traffic at the converging point would not exceed 50%[19] of the overall theoretical capacity such that no heavy congestion will occur and the mobile traffic will not be affected by the overflow of other data services.

With the hard traffic isolation provided by ETN's TDM channels, the network capacity can be more aggressively utilized in each channel without the traffic interference from other channels. Figure 4 shows a ETN use case where two "hard pipe" channels are used to carry respective 5G mobile midhaul and enterprise private line service traffic. As shown in Figure 4, the three ETN devices create two hard pipe channels for the two types of packet services. Each service can be Ethernet VLAN or MPLS-TP services. With the hard transport network channels, the convergence ratio between the access layer and the aggregation network level will be reduced but the network load can be better utilized without the concern for inter-slice traffic congestion as in the statistically multiplexed packet network. The intra-channel traffic congestion can be easily avoided with the transport network slice capacity planning since each channel only carries one type of packet service which provides more predictable traffic volume pattern and is more amenable to some static capacity planning without dynamic bandwidth change. ETN helps provide multiple hard traffic isolated channels with more deterministic latency (low packet delay variation from path ingress to egress) and higher network utilization rates than the pure packet network.

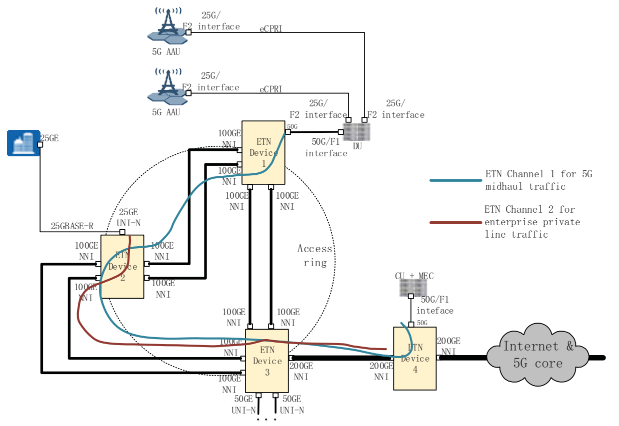

Figure 4 ETN use case for hard traffic isolated channels

D. *Hierarchical Traffic Multiplexing*

Although the end-to-end ETN channels come with the traffic isolation benefits, there are situations where the number of channels needs to be limited for simplified control and management purposes. ETN offers a hierarchical traffic multiplexing scheme where the multiple small-granularity ETN channels are multiplexed into a large-granularity ETN channel. The number of ETN channels can be reduced in the transport network segment directly connected to core network and the management overhead associated with the ETN channels is reduced correspondingly. When the client signal is restored from the multiplexed ETN channel (high-level channel), the small-granularity ETN channel is first de-multiplexed and then the client signal is recovered from the low-level ETN channel. Figure 5 shows the hierarchical multiplexing of two ETN channels into one large-granularity ETN channel.

E. *Flexible L1/L2/L3 Forwarding*

In addition to the hard traffic isolated ETN channel and multiplexed channels, ETN is envisioned to be a packet-friendly architecture with built-in Ethernet/IP/MPLS forwarding support. For the use cases where the end-to-end hard traffic isolation is not necessary, the conventional statistical multiplexing forwarding can be in place. Figure 6 illustrates the flexible L1/L2/L3 forwarding.

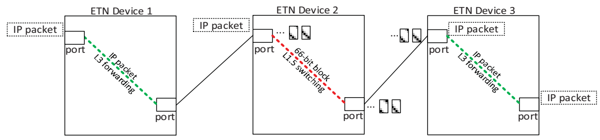

Figure 6 Mixed L1 and L3 forwarding in ETN network

Typically speaking, the L2/L3 forwarding can be used for VBR packet client traffic where no timing information is involved and higher-level application protocols such as TCP can be used to provide data integrity. The L1 or L1.5 forwarding is used to transport CBR client traffic with strict frequency and timing requirement or where the congestion-caused traffic loss/retransmission is undesirable. For the enterprise lease line use case, some enterprise lease line services for the low-end customers(company branch) can be established using L2/L3 MPLS VPN while some other private line services for the high-end/important customers(bank branch) can be deployed via the dedicated ETN channel. The L2/L3 MPLS VPN and the ETN channel can be configured and transported in the same ETN switch without the need to purchase two sets of different network equipment.

The seamless integration/transition of the underlying forwarding mechanism offered by ETN allows it to be easily and smoothly integrated with existing Ethernet/IP packet network technology that has been widely deployed in today's transport and metro network.

F. *Multi-layer OAM Mechanism*

As ETN provides multi-layer forwarding options, ETN also offers the multi-layer OAM mechanism. The conventional ITU-T G.8013 Ethernet OAM[20] is available at the L3 and L2 forwarding levels. The L1.5 switching utilizes an innovative in-path mechanism[16] to provide the OAM functions besides G.8013 OAM.

The L1.5 OAM frame is a dedicated 64B/66B control block with the block type field value 0x4B carrying an

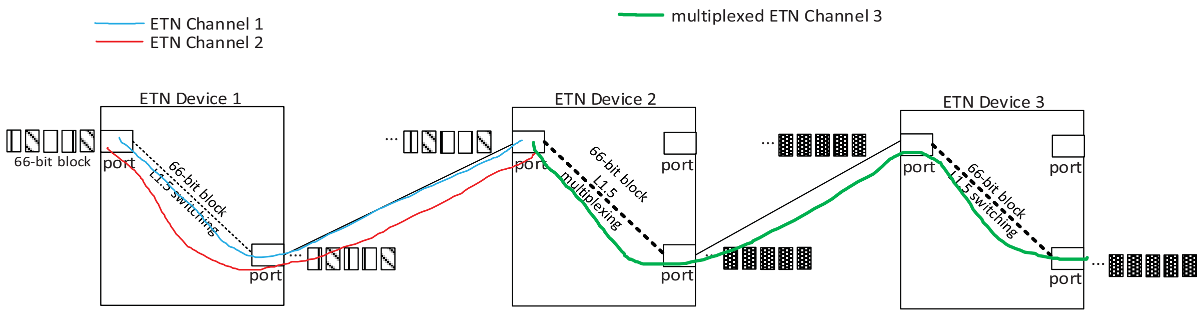

Figure 5 Illustration of ETN hierarchical multiplexing scheme

ordered set with a designated O code value. Figure 7 shows a possible OAM frame format implementation. The L1.5 OAM frame is inserted into the IPG(Inter-Packet Gap) between the L2 Ethernet frames in the client signals. To avoid increase the client signal data rate, the corresponding number of idle control blocks in the IPG will be deleted to make room for the inserted OAM frame. The L1.5 OAM frame is inserted at the ETN ingress node and transported along the same path as the carried client signal in the ETN network. Depending on the functions, the L1.5 OAM frames are one-time or periodical. The OAM frame contains specific field to denote different OAM functions. A complete set of OAM functions including RDI(Remote Defect Indication), Continuity Check(CC), Connectivity Verification(CV), DM(Delay Measurement), APS(Automatic Protection Switching) are offered in the L1.5 OAM mechanism.

When the hierarchical traffic multiplexing is involved, the L1.5 OAM can be enabled/disabled for different levels of ETN channels.

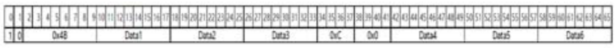

Figure 7 One possible ETN L1.5 OAM frame format

To summarize the ETN's target network applications, Figure 8 gives the overall picture for the envisioned ETN architecture.

III. ETN PROTOTYPE EVALUATIONS AND DISCUSSIONS

Putting the ETN concepts and architecture into real-world practice, we developed the ETN prototype switch box with the multi-service access support for the CBR SDH STM-4/STM-16 and CPRI Option 7, deterministic L1.5 forwarding, hard traffic isolated ETN channels, 2-levels hierarchical traffic multiplexing, and L1.5 OAM. These ETN switch box functions are implemented on a commercial FPGA model at a clock speed of 390.625MHz.

We did preliminary experimental evaluation of the multi-service access, hard traffic isolation capabilities, 2-levels hierarchical traffic multiplexing, and L1.5 OAM capabilities of the ETN boxes under the experiment setup as shown in Figure 9.

Two 10Gbits/s ETN channels are created with one transporting the CBR SDH STM-4 traffic and the other transporting 100GBASE-R Ethernet traffic. With the Ethernet ETN channel traffic load at more than 10%(i.e., more than 10Gbps), no traffic impact on the STM-4 ETN channel is observed which implies the hard traffic isolation.

For the 2-levels hierarchical traffic multiplexing, two ETN channels carrying STM-4 and STM-16 client signals at 5Gbits/s and 10Gbits/s are multiplexed into one 15Gbits/s ETN channel and the SDH client signals are successfully de-multiplexed at the egress ETN switch.

For the L1.5 OAM, RDI, CC, CV, and DM functions are conducted and the test results meet the expected outcomes.

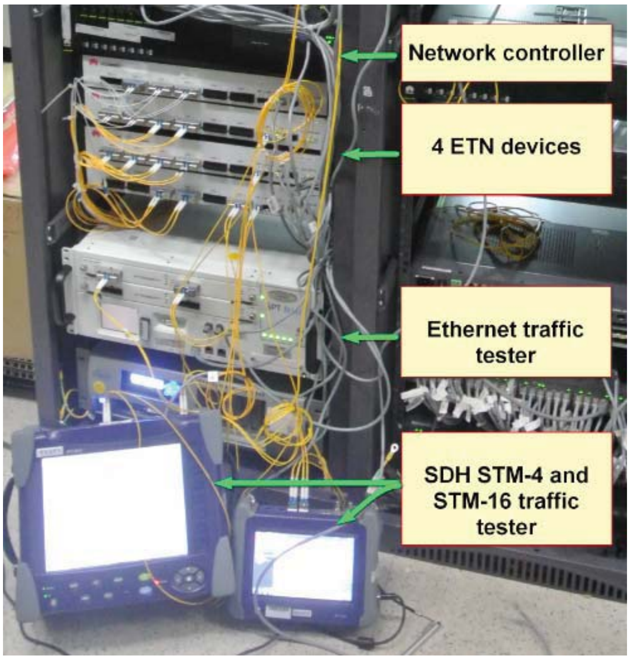

Figure 9 ETN prototype switch boxes lab experiment setup

IV. CONCLUSIONS

This paper presents and thoroughly discusses an Ethernet Transport Network(ETN) architecture which is envisioned to be the future transport and metro network answer. Our ETN network provides seven capabilities namely multi-service access including CBR SDH services and varying-rate Ethernet services, deterministic and lossless L1.5 forwarding,

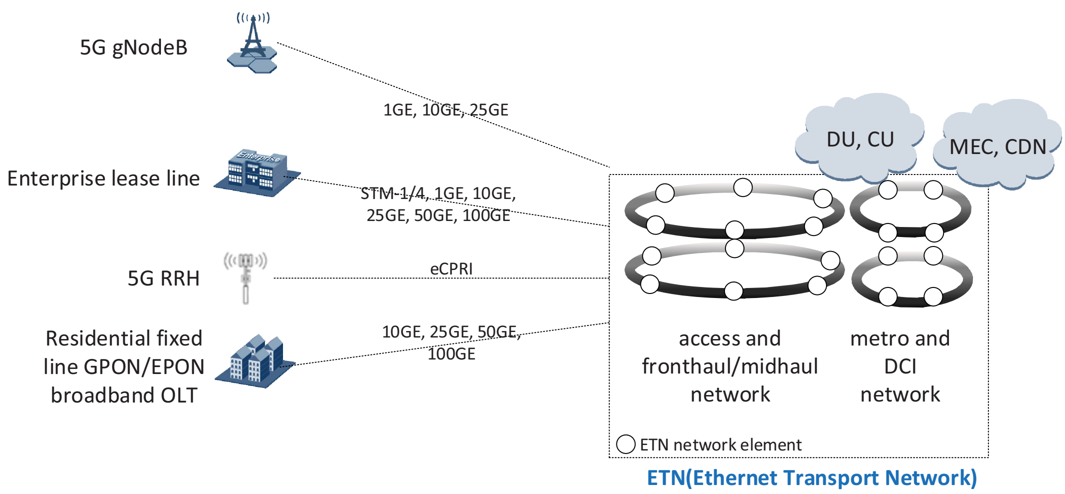

Figure 8 ETN Architecture

hard traffic isolated ETN channels, hierarchical traffic multiplexing, flexible L1.5/L2/L3 forwarding, and multi-layer OAM capabilities which are all essential functions in the next generation transport network which is expected to enable more vertical innovations in addition to serving eMBB, uRLLC, and mMTC applications. Our preliminary experimental evaluation of ETN prototype switch boxes shows that ETN can be the integral future 5G transport, metro, and DCI network solution.

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