PBB-TE, PBT
Carrier Grade Ethernet Transport

PBB-TE, PBT: Carrier Grade Ethernet Transport

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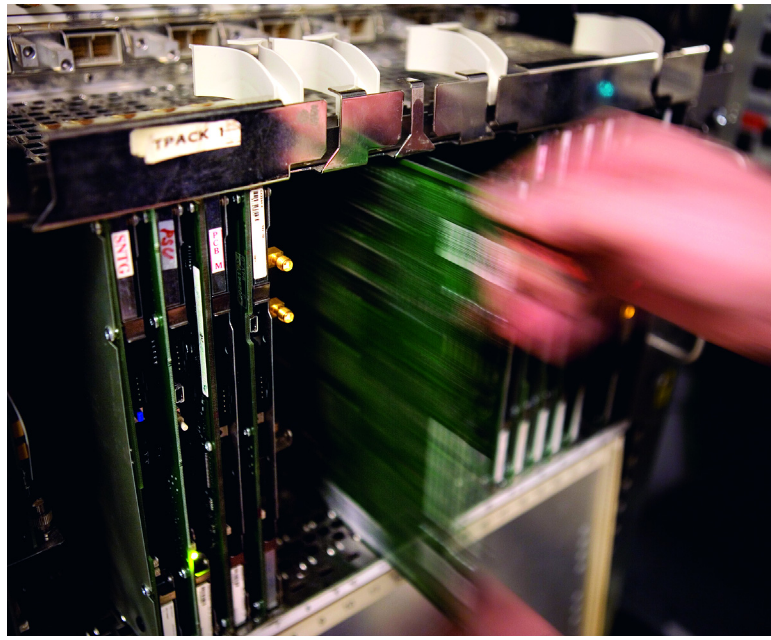

Traffic Engineered Provider Backbone Bridging (PBB-TE) is a new technology concept that promises to provide a true Carrier grade Ethernet transport network solution.

With PBB-TE, it is now possible to build networks completely based on Ethernet technology without the need for supporting networks to ensure carrier-class quality (such as SDH/SONET or MPLS).

PBB-TE is the most recent development after several years of work by the IEEE and ITU-T aimed at improving and enhancing Ethernet technology for use in carrier networks. PBB-TE addresses the needs of carrier transport applications with managed and protected point-to-point connections. Connections in a PBB-TE network are directly provisioned using a network management system rather than Ethernet's self-learning mechanisms, leading to a more deterministic and operationally simpler network.

Enhancements specified by PBB address key deficiencies in traditional enterprise Ethernet, which has hindered its adoption as a carrier protocol. Ethernet interfaces and Ethernet-based services are already established and widely deployed, but Ethernet as a transport technology has lacked the key carrier grade features that PBB-TE now provides.

The following sections provide an overview of PBB-TE providing more information on the technology and how it addresses the needs of carrier transport networks.

TPACK is focused on providing solutions that enable the transport of Ethernet data across telecommunication networks with Carrier grade quality. Ethernet over SDH/SONET and Ethernet over MPLS (including VPLS and PWE3) have proven to be the most popular methods to date.

However, with the advent of Transport MPLS (T-MPLS) and Traffic Engineered Provider Backbone Bridging (PBB-TE), new solutions are being proposed, which promise to reduce network complexity and cost, while improving scalability and control.

To better understand the benefits of T-MPLS and PBB-TE, TPACK is providing two white papers addressing these new technologies, including information on how TPACK can assist equipment vendors in capitalizing on the opportunities these technologies provide.

- The original Provider Backbone Transport (PBT) concept has been proposed for standardisation at IEEE's 802.1 Ethernet working group. As a result, an amendment to 802.1Q has been designated for development, namely 802.1Qay, and assigned a descriptor PBB-TE (Provider Backbone Bridging - Traffic Engineering). Whilst perhaps cumbersome, this white paper will use the PBB-TE designate terminology.

PBB-TE, PBT
Carrier Grade Ethernet Transport

Ethernet in Carrier Networks

Telecom carriers have spent more than 10 years developing a Next Generation Network concept that will allow them to simultaneously deliver packet-based and circuit-based services. It is now widely accepted that the Internet Protocol (IP) will form the basis for new services, as well as assist in the transition of circuit-based services to packet-based services (e.g. Voice and Video over IP).

However, it is far from certain that IP routing technology will be adopted as the transport convergence layer. IP/MPLS has been widely deployed, especially in carrier backbone/core networks as a service layer and as a convergence layer, but Ethernet is fast becoming a credible alternative candidate.

95% of all data traffic either originates or terminates as Ethernet, and data volume is forecast to grow tremendously given the impact of new video services, for example. This situation has prompted many telecom carriers to consider Ethernet as a potential convergence solution for Next Generation Networks. With its scalability, ubiquity and natural support for IP services, Ethernet provides a compelling case.

But before Ethernet can be adopted, it must be capable of supporting multiple services with at least the same level of quality as existing carrier services. In other words Ethernet must achieve a carrier grade of quality.

What is Ethernet?

It is important when discussing Ethernet to be precise in defining what part of Ethernet one is addressing. From a carrier perspective, Ethernet can be considered to include:

- Ethernet interfaces
- Ethernet services
- Ethernet transport

An Ethernet interface refers to the physical layer media and transceivers used to interface to Ethernet, whether they are RJ45, SFP or XFP based. These interfaces are produced in very high volumes thanks to the dominance of Ethernet in the enterprise environment. Although carriers in general need higher reliability and build quality, this economy of scale helps to provide carriers and their customers with a lower cost interface than traditional telecom technologies, such as ATM or SDH/SONET.

Ethernet services, on the other hand, are packet based telecom services that offer an Ethernet UNI to the customer and ensure reliable delivery of Ethernet packet data. Metro Ethernet Forum (MEF) has provided specifications for Carrier Ethernet services (E-Line, E-LAN and E-Tree) along with a number of network-based specifications and test suites designed to accelerate the deployment of Ethernet services.

It is important to understand, however, that Ethernet services do not have to be delivered using Ethernet transport. In fact, most implementations of Ethernet services actually use Ethernet over SDH/SONET or Ethernet over MPLS due to their superior carrier grade characteristics and re-use of existing network infrastructure.

Ethernet as a transport technology has, up to now, lacked the features such as network layer architecture, customer separation and manageability that carriers require for wide-scale deployment.

However, with the advent of PBB-TE, it is now possible to use Ethernet as a transport technology, making the use of Ethernet as a convergence layer for Next Generation Networks a distinct possibility.

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What is Carrier Ethernet?

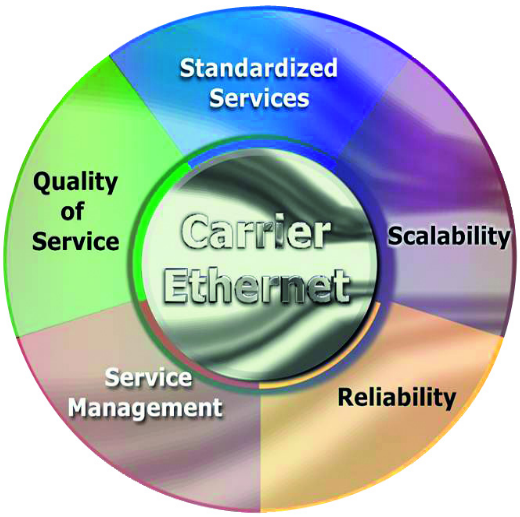

Figure 1: Metro Ethernet Forum Carrier Ethernet Attributes (source: MEF)

Metro Ethernet Forum (MEF) has provided a clear definition of Carrier Ethernet in relation to Ethernet Services. According to MEF, a Carrier Ethernet Service and the underlying equipment supporting the service must possess the following attributes:

- Standardized Services
- Scalability
- Reliability
- Quality of Service
- Service Management

While historical and LAN-based Ethernet is scalable, it inherently lacks key features to fulfill the other requirements that MEF stipulates. In particular, lack of OAM (fault management) and security (customer separation) have been recognized problems in many early deployments by carriers.

Evolution of Carrier Ethernet

Early adopters of Ethernet as a Carrier networking technology used Ethernet switches designed for enterprise Local Area Network (LAN) environments. While these switches were ideal for LAN applications, they lacked key features expected of "carrier grade" solutions.

The limitations encountered during those early deployments, such as limited scalability at 4094 virtual LANs, have led to various enhancements and additions to Ethernet standards. These enhancements have made it possible to deploy Ethernet solutions in carrier networks and PBB-TE is the latest addition aimed at addressing the specific requirements of transport networks.

Ethernet was initially deployed as an alternative to Frame Relay or ATM, first for business services, but later for residential broadband applications. For transport applications, Ethernet has typically been combined with other more established transport technologies, such as Ethernet over SDH/SONET and MPLS.

Ethernet over SDH/SONET was developed as a packet data transport solution that would allow re-use of the existing deployed SDH/SONET infrastructure. SDH/SONET also provided the carrier grade features (such as protection, management, client/server architecture) that Ethernet lacked for transport applications. Similarly, Ethernet over MPLS (PWE3) re-uses existing IP/MPLS deployments and benefits from the carrier grade features of MPLS such as Fast ReRoute.

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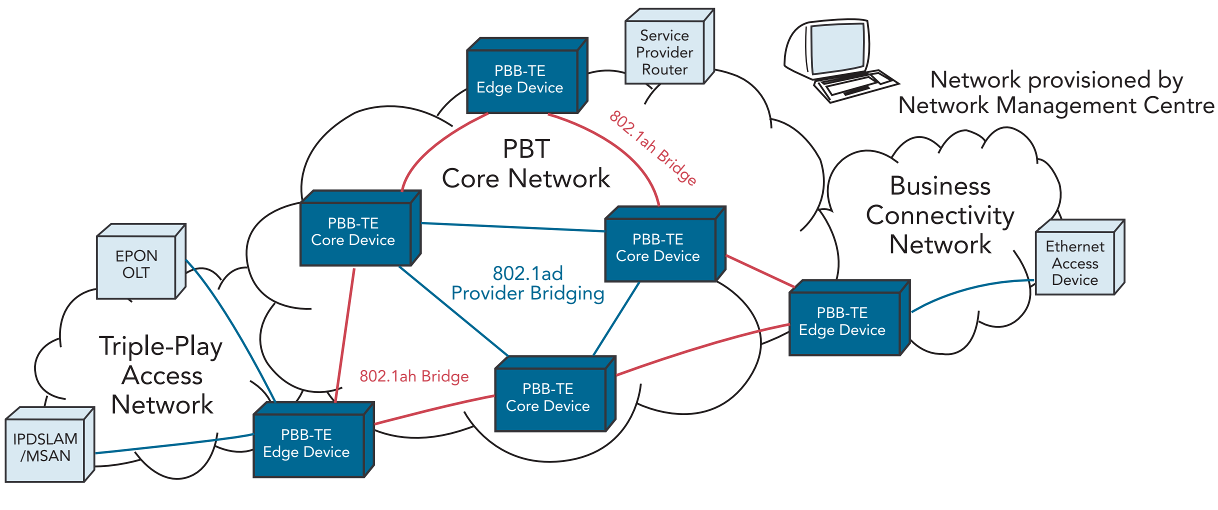

Figure 2: Example carrier network applications of PBB-TE.

IEEE has developed a number of standards providing enhancements to the original Ethernet standards (dating from over 30 years ago). These include:

- 802.1Q: Virtual LAN
- 802.1ad: Provider Bridging
- 802.1ah: Provider Backbone Bridging
- 802.3ah: Ethernet in the First Mile (with OAM)
- 802.1ag: Connectivity Fault Management (OAM)

PBB-TE builds upon these standards to provide a network solution designed specifically for transport applications. PBB-TE creates an independent connection-oriented packet-switched transport layer (see Figure 2). This allows various services, not necessarily limited to Ethernet services, to be transported transparently through the network.

Appendix A lists some of the more important IEEE and ITU-T specifications that support carrier network functions.

The following sections will concentrate on key features, which form the foundation of PBB-TE operation.

Provider Bridging (PB)

802.1Q VLAN capabilities were originally developed to provide control of virtual connections in the same Ethernet network. However, only a limited range of possible VLAN instances was defined (4094 to be precise). This is the so-called "Single Tag".

In order to improve scalability, equipment vendors added support for a second VLAN tag. The resulting "Q-in-Q" or "Double Tagging" mechanism has been formalized in the IEEE 802.1ad Provider Bridging revision to 802.1Q.

The inner tag field or C-Tag carries the customer VLAN Identifier (C-VID), which identifies a customer VLAN (C-VLAN). The outer tag field, or S-Tag, carries the S-VID, which identifies a service VLAN (S-VLAN). This tag is used to identify a service instance and defines a topological partition of the network based on the topology of this service instance. Spanning tree protocol is used to prevent loops in each S-VLAN (and independently, to prevent loops in each C-VLAN). S-VLAN provides customer separation and also isolation of customers from a carrier's network. However, the S-VLAN tag is itself too limited for large-scale carrier networks (ie. more than 4000 customers).

Independent VLAN Learning

As the name suggests, with IVL there is an independent MAC address table for each VLAN. Forwarding is based both on the VLAN and destination MAC address. With IVL the MAC address table is local to a specific VLAN, which allows isolation of addressing within a customer or service VLAN instance.

Double tagging can be used with Independent-VLAN-Learning (IVL), defined in 802.1Q. However, the tag space limits the number of S-VLAN to 4094, which limits the number of service instances that can be deployed in a single network. Thus, Ethernet's scalability problem remains.

A consequence of partitioning the single Ethernet layer network is that S-VLAN specific state must be maintained by all switches in the network, which further limits scalability. In addition, VLANs are assigned across all ports in a switch, so reuse of VLAN IDs on different links is not possible.

Provider Backbone Bridging (PBB)

PBB (also known as MAC-in-MAC) encapsulation adds layer-networking support to Ethernet. Carriers in Japan were early adopters of proprietary implementations of the PBB approach. MAC-in-MAC encapsulation is now being formalized in the 802.1ah 'Provider Backbone Bridges' draft standard.

Client PB Ethernet frames are encapsulated and forwarded in the backbone network based on new B-DA, B-SA and B-VID backbone-destination-address, backbone-source-address, and backbone-VLAN-ID fields.

MAC-in-MAC encapsulation support improves upon the separation and isolation features introduced in 802.1ad: it supports complete isolation of individual client-addressing fields as well as isolation from address fields used in the operator's backbone. 802.1ah also introduces a new 24 bit tag field; the I-SID service instance identifier. This 24-bit tag field is proposed as a solution to the scalability limitations encountered with the 12 bit S-VID defined in Provider Bridges.

802.1ah Provider Backbone Bridges operate the same way as traditional Ethernet bridges. Service is still connectionless, flooding is used when destination MAC addresses are not recognized, and spanning tree is used to prevent loops. VLAN tags are reserved on a network, rather than a per-port basis.

OAM

Draft standard IEEE 802.1ag Connectivity Fault Management (CFM) has been recently developed to address the lack of end-to-end OAM in traditional Ethernet networks. It is closely aligned with the ITU's Y.1731 Recommendation (which also defines Performance Monitoring functions). Key functions such as loopback at specific MACs, linktrace to identify network paths and continuity check are defined.

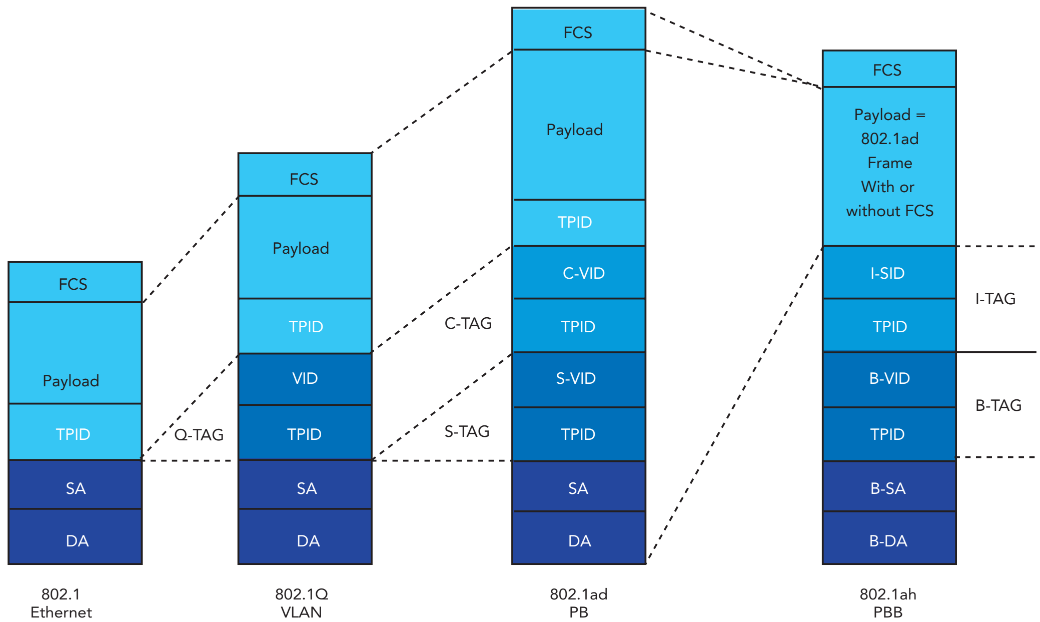

Figure 3: Ethernet frame format and evolution to Carrier Ethernet

Spanning Tree Protocol (STP)

Ethernet uses Spanning Tree Protocol to prevent forwarding loops. A spanning tree is the minimum loop-free set of links that connect each node to every other node in the network. However, spanning tree results in inefficient routing, with some links not used at all (stranded capacity) while others may be congested. This is acceptable in a LAN environment where links are cheap and lightly loaded, but is not cost effective in carrier networks. Multiple spanning tree protocol (802.1s now 802.1D) can be used to better balance load in the network, but the route inefficiency remains.

STP means that Ethernet networks are self-configuring, and also self-repairing. If a link failure occurs, STP is used to re-configure the network to obtain a working set of connections. Traffic is interrupted while STP is working and the process can be lengthy, particularly in a large network. Rapid Spanning Tree Protocol (RSTP) was developed to improve the convergence speed of the algorithm, but operation remains too slow for carrier network protection.

Shortest Path Bridging

802.1aq offers shortest path bridging, which uses a different set of shortest path trees (one for each VLAN) on each node, rooted at that node. Rooting the tree on a per-node basis is required to ensure a shortest path from one node to any other node. The objective of shortest path bridging is to guarantee loop free forwarding, while using shortest path routes. 802.1aq proposes to use IS-IS protocol to update link state information.

PBB-TE, Provider Backbone Transport

While the initiatives above have proven to be extremely useful in solving issues with Ethernet as a carrier technology, there is growing concern that Ethernet itself is now becoming too complex, which compromises some of the key advantages of Ethernet, namely familiarity, simplicity and ease of use.

The proponents of PBB-TE have provided an alternative operational model based on simplification and focus. Existing technology is re-used to as great an extent as possible, while enhancements are focused on the specific needs of carrier transport networks. In other words, PBB-TE is the application of Ethernet to transport networks.

Key Features of PBB-TE

Proposals for PBB-TE are based on existing Ethernet technologies, including:

- 802.1Q VLAN
- 802.1ad PB
- Subset of 802.1ah PBB
- Subset of 802.1ag CFM

PBB-TE reuses existing implementations of VLANs and double tagging and combines them with the network separation and layering principles of PBB.

However, it does not use flooding/broadcasting mechanisms or Spanning Tree protocols - these are switched off by definition - and is thus intended to be used in connection-oriented network applications.

In this way, PBB-TE can be operated in a managed, deterministic connection-oriented fashion, similar to other existing transport technologies such as SDH/SONET.

PBB-TE operation can be clearly differentiated from PBB. In the PBB model, the B-VID identifies a packet flooding domain which interconnects different PB networks. In the PBB-TE model, the B-VID identifies a specific path through the network, in combination with the B-DA address.

The following sections outline these key characteristics in more detail.

Forwarding Model

PBB-TE is intended to be deployed as a connection-oriented packet-switched network layer. PBB-TE exploits the forwarding-engine of Independent VLAN Learning (IVL) capable switches, which allows packets to be forwarded based on the 60-bit concatenation of the B-VID and Destination MAC address. For PBB-TE, MAC learning functions are disabled, which means that the forwarding table's B-VID+MAC entries must be set by cross connect software on instruction from a management system or a suitable control plane. In PBB-TE, broadcast frames are discarded.

PBB-TE is intended to run on any IVL capable switch. An additional requirement that these switches need to meet is that packets with unknown VID+ MAC entries are not flooded but discarded. The switch must also support software configuration of VID and Destination MAC forwarding table entries. Both 802.1Q virtual bridged and the relevant subset of 802.1ah provider backbone bridged operation should be supported.

Globally unique addresses simplify end-to-end network operation. Unique addresses reduce the potential for misconnection that can occur with technologies that use addresses with link or sub-network scope.

The 12-bit VID field is used to identify alternate paths to the associated destination MAC address. The primary application of the alternate paths is to support protection switching. For path protection, two VIDs are assigned, one each for the working and protection paths. Multiple VIDs could support k-shortest path routing, or be assigned to protection paths assigned to different failure scenarios.

The use of the VID to identify alternate routes supports in-service, independent monitoring of all of the path alternatives, before, during, and after protection switching. OAM packets follow the same forwarding paths as the data plane traffic.

Connection management is only required to populate the forwarding tables of all PBB-TE switches on the selected route between the source and destination nodes.

VID Table Management

Proposals for PBB-TE define that VID values have a scope that is local to a specific destination MAC address. This is different to the standard VLAN operation of Ethernet switches, where the VIDs are global to the LAN. With PBB-TE there is no association between different connections with the same VID.

The VID value must first be configured for PBB-TE operation. This is done by assigning the VID value a unique multiple spanning tree ID (MSTID) reserved for PBB-TE operation. In this configuration frames are then forwarded based solely on the 60-bit concatenation of the (VID, MAC) tuple. The switches must also be configured to discard frames with an unknown MAC address if their VID value has been reserved for PBB-TE. The MSTID configuration step is required on all switches in the network and for all VID values that will be used for PBB-TE.

VIDs that are not configured for PBB-TE operation can be used for MSTP or STP operation.

Protection Switching

In PBB-TE, working and protection paths are pre-calculated, and the forwarding tables in nodes on these paths are provisioned/configured with the required forwarding entries.

Both the working and protection traffic uses the MAC address of the destination node to fill the Destination MAC Address field. Working traffic uses the VID value assigned for the working path. A different VID value is used to forward the traffic along the protection path. Faults are detected and forwarded using a subset of 802.1ag connectivity fault management. Loss of Continuity Check is interpreted as a fault and also triggers protection switching. During path protection switching, the source nodes swap the VID value to redirect traffic onto the preconfigured protection path.

If span or local-bypass protection is used, VID tags are swapped at transit locations that bracket the failed span, node or sub-network connection. Switch-over times are short, because the required VID value and path are preconfigured.

Layer Network Model

PBB-TE can be thought of as an ITU-T G.805 network-layer made up of two sub-layers:

1. 'PBB-TE Path' sub-layer hosting trails with Termination Connection Points (TCPs), identified respectively by the B-SA and B-DA MAC addresses of the terminating PBB-TE-Layer (virtual) ports.

2. 'PBB-TE Route Discriminator Layer' Point-to-point, multi-hop, connection-oriented, packet switched trails, with the TCPs identified by their respective (B-VID-B-MAC) tuples.

Why two sub-layers? While forwarding is done based on the 60-bit concatenation of the (B-VID, B-DA) fields, the B-MAC field is significant on its own - it is globally unique, and two different tuples, say (VIDW, B-DA-10) and (VIDP, B-DA-10) must terminate at the same physical location in the network that has been assigned the virtual MAC address B-DA-10.

From the perspective of the client network that uses the PBB-TE trail, only the end-points matter; and the end-points are identified by their respective MAC addresses.

The VID part affects the routing, not the destination. The 'Route Discriminator' (VID) sub-layer determines how to get there, while the B-MAC determines where the 'there' is. The VID part of the tuple effectively supports multiple paths to the destination. In addition to the VID and Destination Address, the Source MAC address is also required to uniquely identify a connection.

If the VID is used for path protection, then the 'Route Discriminator' layer TCPs coincide with the 'PBB-TE Path' TCPs. However, allowing the Path layer to be routed over a series of link connections (hops) in the 'PBB TE Route Discriminator' sub-Layer will make PBB-TE more scalable. Route Discriminator Trails can be used to provide alternate routes within administrative domains. They can also be used to support protection tasks formerly reserved for SDH including schemes analogous to multiplex-section and sub-network connection protection. Note that this

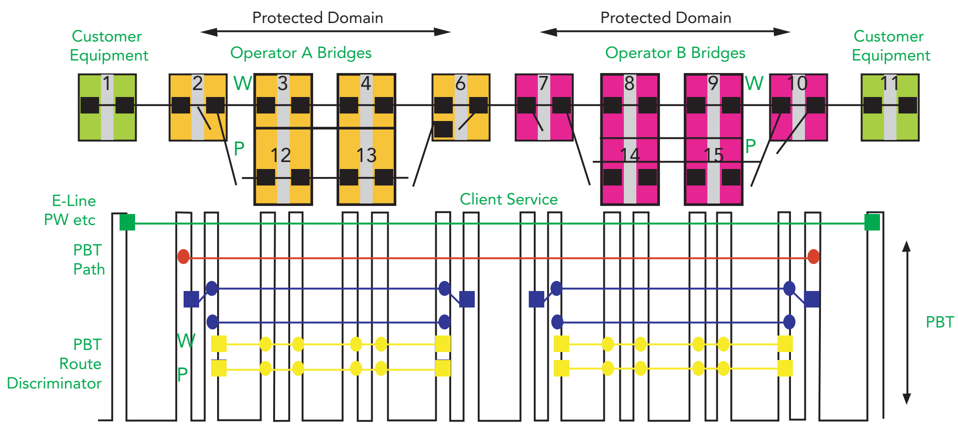

Figure 4: PBB-TE with SNC/S Protection in multi operator network

application requires support for VID swapping in the Ethernet switching hardware.

Client Services

For Ethernet to be a credible convergence layer candidate in Next Generation Networks, it is essential that a number of different client network types is supported. Ethernet's logical link control (LLC) capability can be used to support multiple client protocols. PBB-TE can thus be used to transport Ethernet services with a wide range of bandwidth, latency, jitter and frame loss requirements.

Ethernet's EtherType field supports a range of different service types. Any service with a defined EtherType can be transported over PBB-TE:

- Ethernet: Traditional Ethernet networks may be clients of a PBB-TE based transport network, so E-Line and E-LAN services can be layered on top of a PBB-TE based transport network.

- Pseudo wires: Draft-allan-pw-o-PBB-TE-01.txt describes the use of PBB-TE to transport RFC 3985 pseudo wires. IP/MPLS style labels have been proposed for the pseudo wire service label. The 802.1ah I-SID 24 bit service id tag field has been proposed as an alternative PW label. A PBB-TE based edge device (PE) will be able to either directly host PW client services, or to peer with PW/MPLS capable routers or PW/Transport MPLS switches.

- OAM Packets: End-to-end forwarding of OAM packets along the same path as user-traffic supports the accuracy required for SLA verification in transport applications.

Server Technologies

Because PBB-TE is based on Ethernet it can be transported over any lower layer technology that supports Ethernet. For example, Ethernet over SDH/SONET networks can be used to peer PBB-TE services with Ethernet over SDH/SONET or encapsulate PBB-TE for transport over SDH and SONET networks. The same can be said for Ethernet over WDM or OTN/ASON networks.

Control Plane

A key attribute of PBB-TE is the removal of Ethernet self-learning protocols such as MAC learning, and self-control protocols such as STP. Then, the management system directly provisions packet forwarding into the network switches' forwarding tables.

However, it is also possible to populate the forwarding tables using other control mechanisms.

For example, GMPLS has been proposed as a possible candidate at IETF, under the GELS moniker (GMPLS Ethernet Label Switching).

PLSB (Provider Link State Bridging) has also been proposed using IS-IS protocol that could configure Layer 3-like topologies in an OSPF-like fashion and help PBB-TE support multipoint, multicast and connectionless services.

Since the chief value of PBB-TE compared with IP/MPLS is a connection-oriented point-to-point architecture with no complex control plane, it remains to be seen how useful these advanced control plane proposals will be in practice.

Additional Standards Work

Standards work on PBB-TE in the IEEE and also the ITU-T will continue to define new requirements that will make Ethernet an even better fit for Packet Transport applications. Areas that may require standardization are listed in Appendix B.

Transport Network Challenges

To understand the significance of PBB-TE, it is important to understand the challenges of operating transport networks. PBB-TE has been driven by telecom carriers and system vendors who see these challenges and who are keen to realize a converged network based on Ethernet.

Organizational Challenges

The key issue to be understood is that the challenges faced by carriers in operating transport networks have less to do with the choice of technology used, but more to do with the definition of work processes and procedures that will allow efficient deployment and management of services.

Many of the existing carrier work processes and procedures have been developed for operating voice networks, particularly SDH/SONET transport networks. Considerable organizational experience has been amassed based on these processes over several decades.

The introduction of new packet based technology, such as IP/MPLS, into carrier organizations has proven to be difficult to align with existing work practices.

For example, IP/MPLS is essentially a connectionless technology, where forwarding decisions are made in the network rather than pre-engineered. While this is quick and efficient, it can be difficult to determine what is going on in the network, let alone determine whether resources are being used optimally. Complex configuration and options mean that more highly-skilled technicians and engineers are needed.

This has often led to the establishment of separate units in carrier organizations tasked with operating packet networks under new work practices. However, this can lead to an organizational hurdle to the establishment of a single Next Generation Network solution.

By adopting an approach based on a connection-oriented network, provisioned and controlled by management systems, PBB-TE provides a packet-based solution that resembles transport solutions (such as SDH/SONET) already deployed in transport networks. The enhancements to PBB-TE, such as protection and OAM, lend themselves to existing work practices in the transport organization and leverage the experience and expertise already accrued. This will be particularly important for carriers who have a large sunk investment in OSS/BSS for transport networks.

Financial Challenges

As the revenues from voice services continue to decline and the volume of packet-based services continue to rise, carriers are under pressure to find a cost structure, which can sustain profits in the future.

The major challenge in this case is that the revenue generated by packet-based services relative to the bandwidth they consume is much less than current circuit-based services. However, customer's adoption of packet-based services as replacements for circuit-based services is on the rise. A good example is Voice over IP.

It is therefore essential that carriers carefully consider how they deliver packet-based services. Since up to 75% of the Total Cost of Ownership of a network can be related to Operational Expenditure (OPEX) rather than Capital Expenditure (CAPEX) on new equipment, it is clear that OPEX cost management is key to a successful business case.

PBB-TE offers a simpler transport network, where carriers are in complete control of resource utilization and where customer services are protected. Revenue streams from customers are not jeopardized and optimal use is made of scarce resources.

Competitive Challenges

Carriers are used to competing against each other, but as technologies converge, so do services and new competitors are beginning to encroach on existing carrier markets. These new competitors include Multi-Service Operators (MSOs) in the US, utilities and even municipalities.

In the face of this new competition, carriers are challenged with delivering new services quickly, efficiently and with a high degree of quality first time. Often, multiple services must be delivered over the same customer connection (e.g. Triple-Play). But, while this tends to improve customer ARPU, churn cost is amplified. A single mistake can mean not only the loss of one service revenue stream, but all service revenue streams associated with this customer.

By offering a simpler, scalable transport network solution, which can support multiple client services, PBB-TE enables efficient delivery of multi-play services. By carefully managing resource utilization and protecting key transport connections, PBB-TE can help to meet customers' "Quality of Experience" expectations.

Delivering PBB-TE

We have introduced PBB-TE as a credible candidate for the NGN convergence layer. We have also established that PBB-TE aims to address key challenges of carrier transport networks. There is therefore a clear opportunity for telecom equipment providers to provide solutions to carriers based on PBB-TE, which address their existing and future requirements. However, telecom equipment vendors also face considerable challenges in providing PBB-TE solutions quickly enough to take advantage of this opportunity.

Key Vendor Challenges

The key challenges facing telecom equipment vendors are the following:

- PBB-TE is a new technology concept, so "off-the-shelf" components supporting PBB-TE do not exist
- Developing solutions internally could take up to 2 or more years using precious resources
- PBB-TE is not standardized and new changes to existing standards are expected
- Finding a one-size-fits-all solution will be difficult, so early deployments will require customization

Fortunately, this is where TPACK can assist. TPACK provides technology and solutions that allow rapid development and deployment of PBB-TE combined with the ability to adapt the solution to accommodate changes in standards and specific customer requirements.

TPACK in brief

TPACK provides ready-made hardware and software subsystems to network system manufacturers who are transitioning to a packet future and want to easily add Carrier Ethernet to their systems.

TPACK accelerates its customers' time-to-market and lowers their implementation risk by rapidly tailoring a specific subsystem solution to fit their exact needs, that can also be easily updated when requirements change.

Over the past 5 years, TPACK has assisted telecom equipment vendors in developing Ethernet transport solutions based on Ethernet over SDH/SONET and

Ethernet over MPLS (PWE3, VPLS). These solutions have ranged from customized chip solutions to full system solutions including application software and management interfaces.

TPACK's current customer base includes several Tier 1 telecom equipment vendors, who collectively account for more than 50% of the global optical transport equipment market.

TPACK solutions are typically based on a reference design, which includes a standard set of features that can be customized and adapted to meet specific customer requirements. A fully functioning reference system is built based on a reference design, which is used for demonstrations, customer tests and evaluations, as well as interoperability testing and certification.

TPACK's reference systems have been certified for compliance with MEF 9 and 14 Carrier Ethernet service support specifications.

SMARTPACK™ PBB-TE Reference System

The TPACK SMARTPACK™ PBB-TE reference system provides a fully functional PBB-TE solution in a pizzabox format. Designed as a demonstration and evaluation system, it provides interested equipment providers with a platform, which can easily be adapted to meet their specific requirements safe in the knowledge that system integration issues have already been considered and tested. While the reference system is realized as a pizzabox, the solution can easily be adapted to integrate into a shelf solution.

The reference system is realized using the FPGA-based TPX3100 20 Gbps PBB-TE Carrier Packet Engine. This is a combined packet processor and traffic manager based on parallel pipeline architecture with built in marking, policing, RED and queuing. The reference system also includes application software and a GUI based element management system (TEMS) allowing quick and easy configuration.

The reference system is designed to provide up to 20x 1 Gbps Ethernet interfaces or up to 2x 10 Gbps Ethernet interfaces allowing any combination of interfaces within these limits. It provides 40 Gbps of fully non-blocking switching capacity in normal operation based on two TPX3100 chips. In the event of a failure on one of the TPX3100 chips, the switching capacity is reduced to 20 Gbps until the issue is resolved. The TPX3100 chips do not have to be on the same physical board, but can be linked over a backplane. Combined with link aggregation, this graceful degradation feature can provide both an interface and linecard protection mechanism in a shelf application.

SMARTPACK™ PBT benefits

Fixed hardware devices like ASICs may be cheap, but typically do not provide complete or up-to-date features. Whilst software-intensive devices like NPUs require substantial development effort and may not provide the performance expected.

In contrast, TPACK'S SMARTPACK™ can be rapidly tailored to provide a specific subsystem solution to precisely fit customers' exact needs.

Using the SMARTPACK™ PBT reference system as a starting point, telecom equipment vendors can quickly develop and deploy PBB-TE solutions. Typically, TPACK customers can deploy a new solution based on a TPACK reference system in the field within 9 months.

Because SMARTPACK™ PBT is based on FPGA technology, new developments in standards can be accommodated quickly with as little impact on hardware as possible. Once standards stabilize, it is possible to convert the FPGA chip solutions to low-cost, pin-compatible structured ASICs. Telecom equipment vendors can thus decide at what point it makes sense to make this conversion.

Finally, individual customer requests can be accommodated using the same process as above. In addition, it should be noted that the SMARTPACK™ PBT solution can also accommodate existing solutions, such as 802.1Q and 802.1ad Ethernet, MPLS (including PWE3 and VPLS), as well as various line interfaces (Ethernet, SDH/SONET, RPR, WDM) to accommodate individual network application scenarios.

Contact TPACK for more information on the SMARTPACK™ PBT solution and on how TPACK can assist you in your PBB-TE development projects.

Conclusion

PBB-TE provides an intriguing new network and technology concept, which could be a credible candidate for a transport convergence layer in Next Generation Networks.

Based on a subset of PBB 802.1ah and a number of other Ethernet standards, PBB-TE provides a simple, connection-oriented approach, which addresses the key challenges faced by telecom carriers and lends itself to existing carrier work practices.

Telecom equipment providers can use TPACK's SMARTPACK™ PBB-TE solution to exploit the opportunities that PBB-TE provides. SMARTPACK™ PBB-TE helps equipment providers to get to market quickly with a solution that can easily accommodate new standards developments and specific customer needs.

References

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Appendix A

Feature	Specification	Discussion
OAM	802.3ah	OAM for Ethernet in the First Mile.
Connectivity Fault Management and Protection Switching	802.1ag	Continuity Check, AIS, connectivity fault propagation and management
Grooming and Aggregation	802.1ad 802.1ah	Double tagging and MAC-in-MAC addressing
Discovery and Registration	802.1ab 802.1ac 802.1ak	Link Layer Discovery Protocol and Multiple Registration Protocol
Routing	802.1aq	Shortest Path Bridging
Security	802.1ar	Secure Device Identifier
Demarcation	802.1aj	Demarcation devices

Table 1. IEEE standards for Carrier Ethernet

Feature	Specification	Discussion
Common Language	G.8001/Y.1354	Terms and definitions for Ethernet Frames over Transport
Functional Model	G.8021/Y.1341	Characteristics of Ethernet Transport Network Equipment Functional Blocks
Protection Switching	G.8031/Y.1342	Previously called ethps.
Architecture of Ethernet Layer Networks	G.8010/Y.1306	Layer model that follows G.805 and G.809
Ethernet Services	G.8011.X	Client Services in-line with MEF service definitions
Ethernet UNI and Ethernet over Transport NNI	G.8012/Y.1308	Demarcation devices are required to monitor the handoff of service between domains under the jurisdiction of different organizations.
Timing and Synchronization in Packet Networks	G.8261	Synchronization will be required by for some services, for example, IPTV head-ends.
Ethernet OAM	Y.1731	Continuity Check, linktrace, loopback, AIS, connectivity fault propagation and management Performance monitoring

Table 2: ITU-T Carrier Ethernet Recommendations

Appendix B

Feature	Specification	Discussion
Architecture	G.pbt	PBT has been proposed at ITU-T and is progressing as g.pbt. As of May 2007, standardization work is pending approval of a PAR by IEEE 802.1
PBT Layer network architecture	PBB-TE Layer Network	Based on G.805 layer network models
Carrier Ethernet	Carrier Ethernet over PBB-TE	E-Line and E-LAN service over PBB-TE Transport Specification
Pseudo Wire	PW over PBB-TE	PW Client Service over PBB-TE Transport Specification
MPLS	MPLS over PBB-TE	MPLS and Transport MPLS Client Service over PBB-TE Transport Specification
Data Security	PBB-TE	PBT provides security improvements over ATM and other packet switch technologies. Cross connects are provisioned based on destination MAC address. And packets with unknown destination addresses are dropped, not flooded.
Protection Switching	Protection Switching in the PBB-TE layer.	Layer Network Protection architecture, and the use of the B-VID VLAN tag field to identify and select alternate routes. Failure Detection, OAM and protection switching protocols for linear, ring and meshed network topologies.
Connectivity Fault Management	Extensions to 802.1ag connectivity fault management (CFM).	OAM mechanisms for detection of faults and triggering of protection switching in PBB-TE networks. 802.1ag methods are not ideal for point-to-point networks.
Engineered Networks, Traffic Engineering, and service routing	Traffic Engineering and layer routing	Network and Traffic Engineering and Layer routing over SDH, G709, and DWDM layer networks.

Feature	Specification	Discussion
Traffic Management	Traffic Management	Shaping and policing of user and aggregate traffic profiles to guarantee end-to-end network performance.
OAM for SLA Monitoring and Verification	SLA OAM	OAM mechanisms suitable for SLA compliance verification for both retail and wholesale point-to-point services

Table 3: Possible PBB-TE specifications

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Glossary

ASIC	Application Specific Integrated Circuit
ARPU	Average Revenue Per User
ASON	Automatic Switched Optical Network (now ASTN)
ASTN	Automatic Switched Transport Network (ex-ASON)
ATM	Asynchronous Transfer Mode
B-DA	Backbone DA
B-SA	Backbone SA
B-TAG	Backbone Tag
B-VID	Backbone VID
BSS	Business Support System
C-TAG	Customer Tag
C-VID	Customer VID
C-VLAN	Customer VLAN
CAPEX	Capital expenditure
CFM	Connectivity Fault Management
DA	Destination MAC Address
ECMP	Equal Cost Multiple Path
FCS	
FPGA	Field Programmable Gate Array
GELS	GMPLS Ethernet Label Switching
GMPLS	Generalized MPLS
IEEE	Institute of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
I-SID	Service Instance Identifier
I-TAG	Service Instance Tag
IP	Internet Protocol
IPTV	IP Television
IS-IS	Intermediate System to Intermediate System
ITU-T	International Telecommunication Union - Telecommunication Sector
IVL	Independent VLAN Learning
LAN	Local Area Network
LLC	Logical Link Control
MAC	Media Access Control
MEF	Metro Ethernet Forum
MPLS	Multi-Protocol Label Switching
MSO	Multiple Service Operator
MSTP	Multiple Spanning Tree Protocol
MSTID	MSTP Identifier

NGN	Next-Generation Network
OAM	Operations, Administration and Maintenance
OPEX	Operating expenditure
OSPF	Open Shortest Path First
OSS	Operational Support System
OTN	Optical Transport Network
PB	Provider Bridge
PBB	Provider Backbone Bridging
PBB-TE	PBB - Traffic Engineering
PBT	Provider Backbone Transport
PLSB	Provider Link State Bridging
PWE3	Pseudo-Wire Emulation Edge-to-Edge
RED	Random Early Drop
RFC	Request for Comment
RPR	Resilient Packet Ring
RSTP	Rapid STP
S-TAG	Service Tag
S-VID	Service VID
S-VLAN	Service VLAN
SA	Source MAC Address
SDH	Synchronous Digital Hierarchy
SLA	Service Level Agreeement
SONET	Synchronous Optical Network
STP	Spanning Tree Protocol
T-MPLS	Transport-MPLS
TCP	Termination Connection Point
TPID	EtherType Identifier
UNI	User Network Interface
VID	VLAN Identifier
VLAN	Virtual LAN
VPLS	Virtual Private LAN Service
WDM	Wavelength Division Multiplexing