Importance of Transport Infrastructure Design to the Performance of Carrier Ethernet Services

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ABSTRACT

Looking to the access, aggregation and core parts of the current telecommunication networks a wide spectrum of transport technologies is applied by the carriers. In one hand, it is because of the intention to save the already existing investments in legacy networks, but on the other hand the new broadband and interactive services often require new technologies to implement in the network immediately. In the new era of Carrier Ethernet services and the development of high-fashion applications less attention is paid for the underlying transport infrastructure. In this article we demonstrate the importance of transport infrastructure design to the performance of end-to-end Carrier Ethernet services. We mainly focus on the core segment to perform availability analysis of the recent transport network architectures, but we also illustrate the end-to-end service performance by analyzing case studies on real network implementations.

INTRODUCTION

It is a well-known fact that currently almost all data traffic is originated from Ethernet-based local area networks (LANs). Since Ethernet is the technology of choice in the residential and enterprise customer domain it is therefore a desirable choice in the service provider domain, as well, to eliminate potential interworking problems and to provide cost-effective broadband services beyond LANs. Not that long ago, enterprises would either lease SONET/SDH circuits or buy Frame Relay services to provide data connectivity between their branch locations. Carriers have recently begun building their Next Generation Networks (NGNs) using the IP/MPLS technology for uniform transport of all type of enterprise services like voice, video, broadband data, wireless backhaul, and so on [1]. From a carrier's perspective the native Ethernet protocol has deficiencies with respect to reliability, scalability, QoS and service management. To address these limitations Carrier Ethernet architecture and services are defined by Metro Ethernet Forum (MEF) providing an end-to-end Carrier-grade Ethernet platform [2]. The definition of the Carrier Ethernet Services (CES) is independent of the physical network infrastructures they run across making expansion to new transport technologies easy. The architecture of Carrier Ethernet allows movement of data between the Ethernet demarcation points or User Network Interfaces (UNIs). When traffic moves between UNIs it is tunneled through the transport layer. When it reaches the edge of a Carrier Ethernet network the data is transmitted to the customer as its original Ethernet frames [2]. Nowadays, Carrier-grade Ethernet is playing an increasingly important role in the access, metro aggregation and core network infrastructure to deliver both triple-play for residential and broadband Ethernet services for new enterprise applications.

The remainder of the article is organized as follows. The Carrier Ethernet Services and their implementation options are discussed from the carriers' perspective. Next, an end-to-end Ethernet transport infrastructure is introduced covering the access, metro aggregation and core segments of the service providers' network. Focusing on the core networks, the Ethernet transport options are discussed form the mature Ethernet over SONET/SDH and Ethernet over MPLS architectures to the newly developed Provider Backbone Bridging with Traffic Engineering (PBB-TE) and Transport-MPLS (T-MPLS) solutions. The implementation options are briefly investigated and evaluated from the network reliability and service availability points of view. Finally, some simple case studies are presented to demonstrate the end-to-end Carrier Ethernet service performance implemented in real network environments.

CARRIER ETHERNET SERVICES AND IMPLEMENTATIONS

Recently, if one simply hear Ethernet, that could mean many of things. Ethernet is originally a Layer 2 protocol, is also a widely used network interface, and is now an end-to-end service, as well. Especially the Carrier Ethernet name denotes a carrier-grade service, taking the traditional characteristics of Ethernet protocol and strengthening them to meet the carrier-class requirements. MEF is the primary leader for the definition and adoption of Carrier Ethernet while Institute of Electrical and Electronics Engineers (IEEE), International Telecommunication Union – Telecommunication Standardization Sector (ITU-T), and Internet Engineering Task Force (IETF) have also standardization activities on that.

Currently, two different service types have been standardized by MEF [2]; the point-to-point like E-Line and the multipoint-to-multipoint like E-LAN. The third service type, the point-to-multipoint like E-Tree is being investigated. The Ethernet Private Line (EPL) and Ethernet Virtual Private Line (EVPL) services are two examples for E-Line service type. The main difference between them is that the port-based EPL service is totally transparent while the VLAN-based EVPL service allows invoking multiple services on a single UNI. The Transparent LAN Service (TLS) is an example for E-LAN that makes the service provider domain look like a LAN. According to the MEF's intention all the service characteristics are consistent therefore can be monitored and controlled much easier. The transport network technology is completely hided by creating a standardized plug-and-play Ethernet demarcation point and physical interface. Service Providers are able to interconnect worldwide networks with consistency, even if each service providers' network uses different technologies [2].

From the carriers' perspective, the technical implementation of CES depends on the service definition, the bandwidth requirements, the existing/available network technology, and so on. Integration of CES with existing Layer 3 (e.g., IP Virtual Private Networks), Layer 2 (e.g., cell or frame based services), and Layer 1 (e.g., leased lines) services is very important and carefully managed task. So, one of the main requirements towards the standardization bodies is that Ethernet service shall be specified by features and quality parameters without defining the transport technology.

Taking the existing or available access, aggregation and core network infrastructures into account there could be several implementation options for CES. In the first-mile beside the fiber, cable and wireless access solutions the copper-based xDSL is the mostly used technology for residential access. In the aggregation or second-mile network section (where some cases there is no strict demarcation from the enterprise customer access) the switched Ethernet over Fiber solution is dominant, but the SONET/SDH and some cases the Resilient Packet Ring (RPR) technologies are also used for aggregate Ethernet traffic. In the core segment the Ethernet over SONET/SDH (EoS) transport architecture has still 50% of usage (according to the recent Heavy Reading research report [4]) while Ethernet over MPLS (EoMPLS) and Ethernet over WDM transport options have almost 30% of usage equally. Looking to the revenue predictions form the applied architectures in the near future (for 2008-2010 according to Ovum-RHK [5]), the copper based Ethernet access (xDSL solutions) and EoMPLS core architectures (Virtual Private LAN service implementation will grow from 20% to 50% of MPLS deployments) have the highest growth, while EoS remains a wide spread option.

END-TO-END CARRIER ETHERNET TRANSPORT INFRASTRUCTURES AND RELIABILITY

The definition of the Carrier Ethernet Services is independent of the physical network infrastructures they are implemented on. Thanks to this feature, the incumbent and new-comer service providers can have different approaches to implement these services tailored to their preferences. The incumbent operators have intention to reuse their existing SONET/SDH circuit layer as Ethernet aggregation and/or core transport, and also to exploit the wide coverage of copper-based access network. The new-comer operators prefer to gain significant market shares quickly, so they rather implement cost-effective Ethernet over WDM or Ethernet over Fiber transport solutions. The migration of he IP cores to MPLS, i.e. the rate of penetration of MPLS technology in the core network domains enables the MPLS based Ethernet transport. Beside the mature transport options the Provider Backbone Transport (PBT) or often called Provider Backbone Bridging with Traffic Engineering (PBB-TE) solution [6] defined by IEEE and the Transport-MPLS (T-MPLS) solution [7] proposed by the ITU-T are emerging. Now we quickly run through the network sections (Fig. 1) to describe an end-to-end Ethernet platform for residential and enterprise services.

Ethernet based access solutions

The original concept of Carrier Ethernet comes from the metro environment solving the historical problem of metro bottleneck interconnecting enterprise LANs. Since then, Carrier Ethernet has expanded to the access and beyond traversing an ever increasing variety of technologies. The access or first-mile section of the networks is the most variable in terms of physical media, such as copper, coax, fiber and wireless as well as their hybrids.

The triple-play services are the main drivers of the current residential multimedia trends requiring higher and higher bandwidth. The Ethernet in the First Mile (IEEE 802.3ah) Study Group [3] has standardized several xDSL-based access solutions with impressive bandwidth and reach parameter pairs to leverage existing copper deployments. The copper based access is getting used together with fiber solutions expanding the network footprint and bridging the fiber availability gap in the residential area. The relevant enterprise applications such as VoIP, security, video, network backup and hosted applications are forcing the Fiber-to-the-x (FTTx) access deployments where x could be curb, cabinet, building, now even office or desk. The use of fibers provide a seamless end-to-end Ethernet access for metro and core networks, however, fibers reach only a limited number of customers today and it is very expensive to extend fiber to the premises. Some market research predictions [8] show that the transition from copper to fiber access networks is inevitable, and will result in the replacement of most copper access networks over the next two decades. Because EPON (Ethernet Passive Optical Network) is currently the solution of choice in most leading Asian countries, it is assumed that it should dominate overall deployments through the next five years. GPON (Giga-byte Passive Optical Network), however, will dominate in the US and Europe since it now appears certain to be used by both major incumbent carriers [8].

Since the Ethernet access is the most active area of development in the MEF, there are some new ambitious technologies emerging. The wireless access solutions such as WiFi and WiMAX (IEEE 802.16) offer good and flexible reach up to 50 Mbps bandwidth. Point-to-point microwave provides over 50% of connections to the wireless base stations worldwide, so Ethernet access over microwave links has higher importance for backhaul of mobile and remote video traffic. The hybrid technologies such as Ethernet access over Hybrid Fiber Coax (HFC) or Ethernet access over Wireless optical mesh are also emerged. Optical wireless can offer extended reach up to 10 Gbps, and the meshing capabilities increase scalability and reliability.

QoS (Quality of Service) and reliability are the main drivers of developments in the access networks. QoS in xDSL access can be provided by PPP (Point to Point Protocol) or by DHCP (Dynamic Host Configuration Protocol) together with Ethernet 802.1p/Q priority bits. The main advantages of DHCP over PPP are the better scalability and the multicast functionality. Based on IEEE 802.1p/Q standard eight levels of priority can be assigned to a VLAN, if bandwidth shaping or policing are also applied, it is possible to define a maximum and minimum bandwidth (i.e. QoS profile) for the VLAN of end used. This technique reduces traffic loss, but introduces delay and jitter into the traffic stream. In case of residential xDSL access usually there is no physical path redundancy, but in case of Ethernet access over fiber solutions fully or partially redundant access equipment and diverse paths may exist for the enterprise customers. However, in the access section of the networks a single fiber or twisted pair cut affects only a limited number of customers, while the aggregation and core network failures are more critical in that sense.

Ethernet in the aggregation

The many-to-one relationship between the access node and a single or limited number of centralized points as service points (e.g., broadband access server, video server, edge router) is called aggregation. The metro network identifies the network section beyond the access node. The aggregation network section may lie on new optical fiber plants or reuse traditional SONET/SDH rings.

The new deployments have typically tree topology, because of the highly cost-demanding solution. In this case the Optical Ethernet aggregation is the obvious choice with its tree-based operation although the pure tree topology has limited physical reliability. If there is possibility to build or use cross links in the trees the standard spanning tree protocols can be used to enhance network performance. The STP (Spanning Tree Protocol) is originally designed to adapt the network to topology changes. This rather slow solution (30-60 s recovery) was superseded by RSTP (IEEE 802.1w - Rapid STP) that is designed for faster recovery providing reasonable restoration times about 1-5 s. The MSTP (IEEE 802.1s - Multiple STP) was standardized to limit spanning tree size and allow better network utilization using more than one active tree. The traffic can be load-balanced among the trees using different source VLANs. EAPS (Ethernet Automatic Protection Switching) specified in RFC 3619 allows switching between VLANs within 50 ms thanks to the predefined disjoint VLAN trees and efficient hello protocol. LACP (IEEE 802.1ad - Link Aggregation Control Protocol) allows bundling multiple physical links into a single logical unit at the point-to-point link level. If one of the component links fails, traffic is automatically distributed over the remaining links by the load-balance protocol. This solution avoids the immediate STP reconfiguration in case of single link failure, hence provides better network reliability. Beside the pure Optical Ethernet solution the new generation of Ethernet equipment is ready to introduce MPLS (Multi-Protocol Label Switching) capabilities in the aggregation. The MPLS-based protection and restoration techniques [9] allow reducing the network response time down to the order of 100 ms in case of single failures. Building a tree-based aggregation network there is always a trade-off between the network reliability using available cross links in the trees by the aforementioned protocols and the total implementation cost of the fiber infrastructure.

For the incumbent network operators the obvious solution is to reuse the existing fiber rings of the TDM networks, where it is possible. Based on these rings the Next Generation SONET/SDH technology can provide reliable Ethernet transport with 50 ms response time thanks to the standard protection schemes. Moreover, the Resilient Packet Rings (IEEE 802.17) is a high-speed MAC-layer protocol that is optimized for packet transmission in resilient ring topologies. RPR offers wrapping and steering protection solutions and fairness for proper partitioning of opportunistic traffic. Ethernet over WDM architecture is one of the most promising ring-based aggregation network solutions since most of the WDM vendors now offer Ethernet OADMs (Optical Add Drop Multiplexers) with integrated Layer 2 switching functionalities in a single equipment. This joint implementation enables to apply effective interaction between the Ethernet and the optical layer in case of failure detection and localization. For example, the loss-of-light signal of the WDM layer can be used for immediate notification of the ring-based STP protocol, eliminating the typical STP timers in case of topology reconfiguration.

Ethernet transport in the core

In the core segment the Ethernet over SONET/SDH (EoS) transport architecture has also played key roles because of the well-known historical reasons. In order to guarantee the end-to-end transparency, each Ethernet stream/interface can be mapped in a specific Virtual Containers, by means of different GFP (Generic Framing Procedure) encapsulation methods according to ITU-T G.7041 Recommendation. Beyond mapping Ethernet flows onto the circuit-based core network the EoS features introduce wire speed classifying, policing and scheduling capabilities, as well. Per customer traffic flow management with low bandwidth granularity, segregation and QoS are just few of the value added arguments that this solution offers to the carriers. Regarding the network reliability the Automatic Protection Switching (APS) protocol can be used in case of SONET/SDH rings over optical fiber infrastructure. This protocol is fully compliant with the 50 ms reconfiguration time defined in the ITU-T G.841 Recommendation.

In the core segment in line with the NGN strategy the network operators has started to migrate their transport architecture from SONET/SDH to IP/MPLS that provides uniform transport of all type of data services. In case of pure IP networks the L2TP v.3 (Layer 2 Tunneling Protocol, Version 3 defined in RFC 4719) can be used as a control protocol and for data encapsulation to set up Pseudowires (PWs) for transporting Layer 2 frames across an IP network. Especially, an Ethernet PW emulates a single Ethernet link between exactly two endpoints (i.e. IP routers). Where MPLS functionality is implemented Ethernet over MPLS (aka “draft Martini” defined in RFC 4448) can be the proper tunneling protocol where a PW is used to carry IEEE 802.3 Ethernet frames over an MPLS network. This encapsulation method now is extended to transport of any Protocol Data Units (PDUs) of Layer 2 protocols such as Frame Relay, Asynchronous Transfer Mode, Adaption Layer 5, Ethernet, and also for providing a SONET/SDH circuit emulation service across an MPLS network. Comparing the pure IP and IP/MPLS transport options from the reliability perspective, it can be said that the IP/MPLS end-to-end LSP protection or fast reroute mechanism [9] has advantages over the standard restoration (e.g. Open Shortest Path First protocol based rerouting) in the IP networks in terms of response time and manageability.

Using the IP/MPLS platform for Carrier Ethernet transport provides a functionality-rich and very robust core platform but, as such, fairly expensive solution and requires highly skilled engineering staff. This fact motivates the standardization bodies (i.e. ITU-T and IETF) to introduce a lightweight MPLS protocol for Carrier Ethernet transport, called Transport-MPLS (aka “Dry Martini”) [7]. The premise of T-MPLS is that MPLS and its associated standards already provide the carrier-class mechanisms and maturity. The only issue to be addressed is the ability to maintain OAM integrity on an end-to-end basis that enables sub 50 ms protection switching of LSPs. The simplification is done by removing the IP specific (non-transport related) functionalities such as Penultimate hop popping (PHP), LSP merging and Equal Cost Multiple Path (ECMP) routing.

For carriers who have not already made a widespread migration to MPLS, the Provider Backbone Bridging with Traffic Engineering (PBB-TE) solution [6] defined by IEEE is viewed as more familiar to their SONET/SDH infrastructure than IP/MPLS. PBB-TE technology based on using existing IEEE 802.1 protocols such as VLAN tagging for carrier scalability and flexibility. It reuses the existing Ethernet QoS mechanisms (e.g., IEEE 802.1p/Q) and adds OAM capabilities (specifically IEEE 802.1ag Connectivity Fault Management) to monitor end-to-end tunnel integrity. On the other hand, PBB-TE eliminates the Ethernet inefficiencies by replacing MAC learning and STP with provider-provisioned MAC forwarding tables.

From the migration viewpoint PBB-TE and T-MPLS are more a replacement for SONET/SDH than a competitor to IP/MPLS. They are both relatively new technologies, but T-MPLS is more mature than PBB-TE having its basis in MPLS. PBB-TE is expected to have economic advantages over T-MPLS as Ethernet-based technologies often have. Some vendors like Nortel, Extreme, Siemens, Meriton, etc. are pushing PBB-TE, while Alcatel, Ericsson, Fujitsu, Huawei, Lucent, Tellabs, etc. are voting to T-MPLS. Other vendors like Cisco, Atrica, Juniper Networks, etc. do not see the really need for either technology [10]. Making MPLS more connection-oriented is not fully inline with the trends in the packet-based IP/MPLS core, and PBB-TE is also problematic because it has no fast reroute function already found in MPLS. Moreover, both PBB-TE and T-MPLS, have been positioned and discussed for point-to-point services only [10].

The main lesson that we have learned from this overview is that the optimal Carrier Ethernet transport technology choice has to be evaluated carefully case by case.

AVAILABILITY ANALYSIS METHODS FOR LARGE-SCALE NETWORK INFRASTRUCTURES

The aim of this work presented in the remainder of the article is to analyze the end-to-end performance of the Carrier Ethernet services using an all-Ethernet service platform covering the access, aggregation and core network segments. The service performance can be described by the overall availability (in yearly or monthly basis) of the end-to-end service run on the network. From the transport network point of view the service availability is obviously determined by the underlying network reliability therefore the network robustness and resilience are decisive features. Out of the parameters affecting the availability, the only one that can be modified is the recovery strategy. The others are pre-determined by the transport equipment itself. Different recovery strategies can promote the recovery time, the resiliency against multiple failures, or the resources usage optimization. Moreover, QoS differentiation can be achieved by the Differentiated Reliability (DiR) concept in the transport layer.

Importance of availability analysis

The importance of network reliability and the complexity of its derivation are reflected by the vast number of papers over the past two decades [11]. The reliability analysis of the real-size network infrastructures is a highly important issue to ensure service availability by the carriers. However, the real networks may apply a large number of components, thus the exact availability analysis of a multi-layer, multi-domian and multi-technology network is a highly complex problem.

The traditional approach in analyzing network reliability is to determine end-to-end availability for a few reference connections. This is done mainly because it is easy to model and the computation time can be short. However, since this approach does not evaluate each end to end service, the results of the reliability evaluation cannot be used to make specific design modification for reliability improvement or to determine the performance of multi-layer services. In case of multi-layer and multi-technology networks the contribution of downtimes due to the transport elements can be significant. Therefore, the end-to-end availabilities of a few reference connections are no longer good representatives of the services in the network. Thus, it is necessary to investigate the overall outage behavior of each end to end service in order to assess the adequacy of the network reliability [12].

Analysis methods and applications

Summarizing the main measures introduced and applied to the expression of network reliability, the following classification can be obtained [11]:

- Connectivity measures
- Maxflow (capacity) measures
- Multi-commodity flow measures
- Performability measures

The first three categories of measures take into account the potential degradation of network capacities. Since the recovery strategies influence the network performance significantly, performability measures obviously give more information about the degradation of service provided by the network. However, the derivation of this kind of measures requires more detailed knowledge about the network operation.

The failure of network components affects the service provided by the network in several forms. Many of these effects can be formalized with the following general expression [13]:

$$NPI = \frac{E(Perf)}{Perf_{nom}} = \frac{\sum_{S_n \in S} Perf(S_n) * P(S_n)}{Perf_{nom}} \qquad (1)$$

The Network Performance Index (NPI) can be calculated as the expected value of network performance normalized by the maximum value of network performance when all network components are up. The expected value of the network performance is the sum of the performances in different failure states multiplied by the probability of the given state.

Since, even in the simplest network models the number of bi-state components is in the range of a few hundred, while in case of multi-layer models it could go up to a couple of thousands, "taking a full walk" in the state space for evaluating the availability measures is clearly out of reach. To analyze real-size network configurations approximate and/or statistical methods can be used because of the complex resilient schemes, large number of network components and failure states.

The main idea of the approximate methods (e.g., Li-Silvester method [11]) is to obtain upper and lower bounds based on an analyzed subset of network states and assuming maximum and minimum performance for the rest of the states. Most probable states can be assigned for analysis, and the accuracy of the bounds can be controlled by the accumulated probability of the not analyzed states. Statistical methods can be based on blind selection of samples like the traditional Monte Carlo method. To speed up the convergence, i.e. to provide acceptable estimation based on the analysis of a relatively small sample size, extra knowledge about the network structure and its behavior can be applied, and the network states can be grouped according to their assumed performance. Stratified (or Structural) Sampling oriented approaches are based on the experience that, efficient strata definition can be performed according to the network element categories [13]. Network states with single, double, etc. link or node failures can be assigned to strata, and with appropriate sample distribution techniques estimation with acceptable variance can be obtained efficiently.

CASE STUDIES ON END-TO-END CARRIER ETHERNET SERVICE PERFORMANCE

In the followings we illustrate the performance of end-to-end Carrier Ethernet services by a real-life implementation of the Transparent LAN Service (TLS) at Magyar Telekom [14] (member of the Deutsche Telekom Group), the largest network operator and incumbent service provider in Hungary, Europe. The first case study focuses to the core network and the availability of both the EoS and the EoMPLS architectures as the most widely used transport options. In the second case study the end-to-end performance of the TLS applying different access and aggregation network implantations is investigated.

Case Study 1: Availability analysis of the Carrier Ethernet transport options in the core

The Magyar Telekom's IP/MPLS core network consists of 2 main nodes in Budapest and 8 nodes in the rural regions depicted in Fig. 2. According to the redundant node architectures the Cisco Catalyst 6500 Series access switch/routers are dual-homed to the Cisco 7600 Series core routers as well as to the two Cisco CRS-1 terabit routers in Budapest. The general node architecture is being migrated towards the duplicated core router structure in the rural regions too. The core routers are interconnected using Cisco ONS 15400 Series DWDM equipments with 10G interfaces. There is no protection switching applied in the optical layer, only IP/MPLS restoration is implemented in Layer 3.

The Magyar Telekom's SDH core network nodes share the same collocation places with the IP/MPLS equipment (Fig. 2) and use exactly the same DWDM transport network infrastructure. The Alcatel-Lucent 1670SM multi-service nodes could be equipped width Ethernet switch cards providing Ethernet connections towards the access switch/routers. Beyond mapping Ethernet flows onto the SDH network the Ethernet switch cards introduce wire speed classifying, policing and scheduling capability empowered by carrier class Ethernet switching engine. The SDH node architecture is not redundant, but 1+1 dedicated path protection is applied in the SDH layer.

In the first case study the reliability of the aforementioned core network architectures is compared. The basic availability parameters (i.e. Mean-time-between-failure) of the IP/MPLS and SDH equipment are given by the vendors, the Mean-time-to-repair parameters are also provided by the Network Operation Centre (NOC) of Magyar Telekom. Based on these parameters the mean values of the core network Down Time Ratio (DTR) are shown in Fig. 3. The left columns show the DTR of the non-protected network, while the right columns refer to the protected network cases. Beside the EoS and EoMPLS solution the third group of columns shows the enhanced reliability of the EoMPLS architecture by fully duplicated IP/MPLS core routers after the proposed migration.

Some availability predictions have been also performed for the newly developed PBB-TE and T-MPLS solutions. Since there are no real network implementations using these technologies, it is assumed that the complexity of a T-MPLS capable node could be equal with a multi-service transport node while the complexity of a PBB-TE is more or less equal with an IP/MPLS switch/router. In that sense, the predicted DTRs of the PBB-TE and T-MPLS solutions assumed to be implemented in the Magyar Telekom network are shown in Fig. 4.

Case Study 2: Simulation results on the end-to-end Carrier Ethernet Service availability

Looking to the aggregation and access network segments an end-to-end Carrier Ethernet service platform is now presented at Magyar Telekom. For the simplification of the overall performance analysis only copper-based xDSL and Ethernet over Fiber access methods are investigated. In the aggregation network section Cisco Catalyst series Ethernet switches are used. In case of tree topology of the fiber infrastructure no protection method is applied, but if more available fiber pairs per cable are available the LACP load-balancing can be used for port protection. In case of partially meshed fiber topology the standard Ethernet xSTP protocols can be enabled in the aggregation to enhance the reliability.

The result of the end-to-end TLS performance analysis is expressed by the percentage of unavailable service endpoints in the function of the failure state probabilities (Fig. 5) in the access, aggregation and core network sections respectively.

Conclusion

In this article we briefly survey the wide spectrum of available transport technologies to implement Carrier Ethernet services. We realized that there is no universal solution; the actual transport technology choice has to be evaluated case by case. However, the main transport features that have to be carefully considered are the QoS capability and the reliability of the network. Our main objective was to emphasize the importance of designing a reliable Ethernet transport infrastructure as an end-to-end service platform.

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References

[1] Brian Pratt: "The right transport foundation for carrier Ethernet services", Telephony Online, July 9, 2007
[2] Metro Ethernet Forum - Carrier Ethernet in the Access, Metro and Core, http://www.mertroethernetforum.org
[3] Ethernet in the First Mile (IEEE 802.3ah) Study Group - Tutorial, Portland, OR, July 8, 2001
[4] Heavy Reading: "SONET/SDH-to-Ethernet Migration Strategies" December, 2005
[5] Ovum-RHK: "Ethernet revenues 2005-2010", 2005
[6] P. Bottorf, D. Allan (Nortel): "Provider Backbone Transport Overview", November, 2006
[7] ITU-T G.8110.1/Y.1370.1: "Architecture of Transport MPLS (T-MPLS) Layer Network", November, 2006
[8] Heavy Reading: "FTTH Worldwide Market & Technology Forecast, 2006-2011" June, 2006
[9] IETF RFC 3469 "Framework for Multi-Protocol Label Switching (MPLS) based Recovery", February, 2003
[10] Paula Bernier: "PBT, T-MPLS try to transport Ethernet, MPLS", Virgo Publishing, January, 2007
[11] László Jereb: "Network Reliability: Models, Measures and Analysis" 6^{th} IFIP ATM WS, Ilkley, UK, 1998

[12] Chi-Hung Kelvin Chu, Mohcene Mezhoudi, et al.: "Comprehensive End-to-End Reliability Assessment of Optical Network Transports", OFCC, Anaheim, CA, March, 2002
[13] L. Jereb, T. Jakab, F. Unghváry: "Availability Analysis of Multi-Layer Optical Networks" OPTNET, 2002
[14] Magyar Telekom: http://www.magyartelekom.hu

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