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Towards end-to-end integrated optical packet network: Empirical analysis

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ABSTRACT

Today, the overloaded networks increasingly entail high operational costs but may not generate new revenues accordingly. Legacy network elements are reaching end-of-life and packet-based transport networks are not efficiently optimized. Thus, an efficient migration plan towards an End-to-End Integrated-Optical-Packet-Network (E2-IOPN) is emerging for service providers in access, metro and core networks. This paper reviews various empirical challenges faced by a Service Provider (*SP*) during the transformation process towards E2-IOPN as well as in the implementation of an as-built plan and high-level design for migrating towards GPON, MPLS-TP, OTN and next-generation DWDM. Then, we propose a *SP* longer-term strategy based on SDN and NFV approach that will offer rapid end-to-end service provisioning and centralized network control. Such strategy helps *SP* maintain good profit margin and best customer experience. A cost comparative study shows the benefit and financial impact of introducing new low-cost packet-based technologies to carry legacy as well as new services traffic.

1. Introduction

The residential and enterprise customers require different kind of services in service providers networks [1]. In particular, mobile backhaul networks (2G/3G/4G) represent as well a big part of *SP* connectivity services. Different Service Level Agreements (SLAs) and traffic constraints (bandwidth, priority, latency and resiliency) need to be considered carefully by *SP* designers. Rapid time-to-market service requires dealing with legacy administrative processes based on manual provisioning [2]. North-Bound Interfaces (NBI) based end-to-end service management systems, like OSS/BSS (Operation Support System / Business Support System) applications might be a possible solution [3]. So far, they still need automatic resource optimization and programmable real-time monitoring [4,5]. While many current service provider networks already stopped being profitable [6,7], some others may still increase their costs by expanding pipe capacities to deal with the bandwidth requirements of new services. Only services with differentiated prices can generate new revenues and reverse the end-of-profit trend. Future networks need to be smart networks to serve next generation smart services [4]. Legacy networks are therefore required to be re-designed and dumb pipes control would have to be replaced by resources monetization and new innovative business models. We present in this paper a real service provider *SP* practical transformation experience towards an *End-to-End Integrated Optical Packet Network (E2-IOPN)* that represents the necessary infrastructure for next generation smart networks. Note that this transformation strategy was implemented in *SP* network after long literature studies and market analysis with various technology partners, solution suppliers and equipment manufacturers in the telecoms industry.

Recent research in the field proposed standard perspective to optimize resources planning by focusing on the contributions and the impact of the IEEE, ITU, and IETF standards in the lower layers of the telecommunications stack such as Wavelength Division Multiplexing (WDM), Carrier Grade Ethernet (CGE), Optical Transport Network (OTN), Multi-Protocol Label Switching (MPLS) and MPLS-Traffic Profile (MPLS-TP) [9,10]. However, they do not discuss challenges and solutions to achieve such transformation plan. In this paper, we address technical challenges that most service providers are facing to build their migration plan toward the E2-IOPN, in particular, to compensate the lack of detailed standardization. Criteria for network design (routing, propagation across the network and deployment of higher-layer protocols) are discussed in [11] including cost considerations. In reality, transforming all legacy network components and the way they are managed to an E2-IOPN is very challenging. While monitoring the compromise between transformation costs and new revenue streams, *SP* needs to deal also with classic design challenges such as traffic shaping, bandwidth optimization and network resiliency. New challenges related to the complexity of recent mobile technologies (coming 5G for instance), smart services requirements and user Quality of Experience (QoE) are making this design exercise more complicated task [12]. With the explosive migration towards All-IP services, legacy Time Division Multiplexing (TDM) technologies are phasing out as

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Nomenclature

Acronyms

ACR	Adaptive Clock Recovery
ACS	Auto-Configuration Server
ACL	Access Control List
APS	Automatic Protection Switching
ANSI	American National Standards Institute
BFD	Bidirectional Forward Detection
BoD	Bandwidth-on-Demand
BSS	Business Support System
BVT	Bandwidth-Variable Transponders
CAPEX	CApital EXPenditure
CAR	Committed Access Rate
CDC	Colorless, Directionless and Contention-less
CGE	Carrier Grade Ethernet
CIR	Committed Interface Rate
CO	Central Office
CoS	Class of Service
CORD	Central Office Re-architected as a Datacenter
CWDM	Coarse Wavelength Division Multiplexing
CPE	Customer Premise Equipment
CVLAN	Customer VLAN ID
DCI	Data Center Inter-connectivity
DCSP	Differentiated services Code Point
DEI-bit	Drop Eligible Indicator bit
DNI	Dual-Node Interconnection
DSLAM	Digital Subscriber Line Access Multiplexer
DWDM	Dense Wavelength Division Multiplexing
ePC	evolved Packet Core
EON	Elastic Optical Network
ETSI	European Telecommunications Standards Institute
FDT	Fiber Distribution Termination
FTTH	Fiber-To-The-Home
FTTC	Fiber-To-The-Curb
FM	Fault Monitoring
GACH	Generic Associated CHannel
Gbps	Giga Bit Per Second
GNSS	Global Networks Synchronization System
GUI	Graphical User Interface
HDPE	High-Density Polyethylene Pipe
HSI	High Speed Internet
IP	Internet Protocol
LACP	Link Aggregation Control Protocol
LAG	Link Aggregation
LSP	Label Switched Path
LTE	Long Term Evolution
MPLS-TP	MPLS - Transport Profile
MLO	Multi-Layer Optimization
MPLS	Multi-Protocol Label Switching
MSOH	Multiplexer Section OverHead
MSPP	Multi-Service Provisioning Platform
NBI	North-Bound Interfaces
NG-SDH	Next-Generation SDH
NFV	Network Functions Virtualization
NMS	Network Management Systems
NNI	Network Node Interface
ODU	Optical Data Unit
OAM	Opeartion, Administration and Maintenance
OD	Outer Diameter
OFDM	Orthogonal Frequency Division Multiplexing
OFMS	Optical Fiber Monitoring System
OMCI	ONU management and control interface
OLT	Optical Line Termination
OSI	open systems interconnection
OSP	Out-side Plant
OSS	Operation Support System
OTN	Optical Transport Network
PBB-TE	Provider Backbone Bridge / Traffic Engineering
PCE	Path Computation Engine
PCP	Priority Code Point
PDH	Plesiochronous Digital Hierarchy
PHP	Per-Hop Behaviors
PIR	Peak Interface Rate
PM	Performance Monitoring
PRC	Primary Reference Clock
PTP	Precise Time Protocol
PW	Pseudo-Wire
PWE3	Pseudo-Wire Edge-to-Edge Emulation
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RSA	Routing and Spectrum Assignment
RSOH	Regenerator Section OverHead
SDH	Synchronous Digital Hierarchy
SDN	Software-Defined Networks
SONET	Synchronous Optical NETwork
SLA	Service Level Agreements
SP	Service Provider
SSM	Synchronization Status Message
SSS	Spectrum Selective Switch
SSU	Synchronization Supply Units
STM-x	Synchronous Transport Module - Level x
SVLAN	Service VLAN ID
TCO	Total Cost of Ownership
TDM	Time Division Multiplexing
UNI	User Network Interface
VC-x	Virtual Container - Level x
VPN	Virtual Private Network
VNF	Virtual Network Function
VRRP	Virtual Router resilient Protocol
VLAN	Virtual Local Area Network
WFQ	Weighted Fair Queuing
WRR	Weighted Robin Round
WSON	Wavelentgh Switched Optical Network
WSS	Wavelength Selection Switching

their rigid pipes are no longer efficient for packet-based services [12,13].

Along with the increasing number of residential (and small business) applications, the bandwidth and Quality of Services (QoS) offered to current quadruple-play services by legacy Digital Subscriber Lines (DSL) solutions is not anymore sufficient. Copper cables in the last mile need to be re-placed by fiber. DSL technology needs to be migrated to GPON (Gigabit Passive Optical Network) based FTTH (Fiber-To-The-Home) networks [8,10,14,83]. In this paper, we investigate detailed FTTH design based on GPON technology and related Out-side Plant (OSP) part. To manage millions of Customer Premises Equipment (CPE) and to monitor the related millions of fiber optical cables, a network should be designed in a scalable fashion, for instance, using TR-069 Auto-Configuration Server (ACS) and Optical Time Domain Reflectometer (OTDR) based Optical Fiber Monitoring System (OFMS). TR-069 is a CPE management protocol offering GPON CPE auto-configuration, dynamic service provisioning, remote Software and firmware management as well as diagnostics, status and performance

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