Requirement analysis of international wholesale telecommunications for Carrier Ethernet services

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Abstract

The development of Internet applications, as well as new technologies to provide Internet access to users, has caused a massive increase in the amount of data traffic in networks and the need of cost-efficient solutions for various networks. This motivated the development of such technologies as Internet Protocol (IP) and Ethernet.

Ethernet originally aimed to serve the needs of Local Area Networks. The deployment of Ethernet in metropolitan area networks worldwide (also known as Carrier Ethernet) has made it both a competitive and preferable technology in comparison to technologies such as SONET/SDH and wavelength division multiplexing (WDM).

This thesis research investigates the requirement of various stakeholders to Carrier Ethernet technology. The following stakeholders were identified during the research: customers, standardization bodies, vendors, and providers. Each stakeholder was closely investigated and its needs, requirements and interconnection with other target groups were analysed and gathered into one communication map called Carrier Ethernet eco-system.

Moreover this thesis identifies more specific recommendations to each stakeholder that could improve the development of Carrier Ethernet technology in general and ensure the satisfaction of the customer and leave more space for future innovation.

Key words: Carrier Ethernet, requirements, standardization bodies, service providers, customers

Sammanfattning

Internettillämpningars utveckling har framkallat en massiv ökning av datatrafiken i näten och dess krav har drivit fram införande av Internet Protocol (IP) och Ethernet-teknologi i globala nätverk.

Ethernets teknologi har ursprungligen utvecklades för Local Area Networks. Ethernets spridning i globala näten (också känd som Carrier Ethernet) har gjort det till en både konkurrenskraftig och eftersökt teknologi i jämförelse med SONET/SDH och Våglängdsmultiplexering (WDM) tekniker.

Denna rapport utreder kraven på Carrier Ethernet som kommer från följande intressenter: kunder, standardiseringsorgan, telekommunikations företag, och leverantörer. Detta examensarbete undersöker varje intressent och identifierar vilka funktioner de behöver och hur de är i förbindelse med andra målgrupper. Resultatet av analysen samlades i en karta som kallades Carrier Ethernet ekosystem.

Dessutom kommer denna uppsats identifierar mer specifika rekommendationer för varje aktör som kan ge en förbättrad utveckling av Carrier Ethernet-teknik i allmänhet och motivera framtida innovationer i tekniken.

Nyckelord: Carrier Ethernet, krav, standardiseringsorgan, telekommunikations företag, kunder

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Table of Contents

List of Figures

List of Tables

List of Acronyms and Abbreviation

Acronym/ Abbreviation	Description
ANSI	American National Standards Institute
AP	Access Point
B-DA	Backbone Destination Address
B-SA	Backbone Source Address
B-Tag	Backbone VLAN tag
BGP	Border Gateway Protocol
BPDU	Bridge Protocol Data Unit
C-DA	Customer Destination Address
C-SA	Customer Source Address
C-Tag	Customer VLAN tag
CE	Customer Equipment
CES	Circuit Emulation Services
CEWC	Carrier Ethernet World Congress
CRM	Customer Relationship management
DOCSIS	Data Over Cable Service Interface Specification
DWDM	Dense wavelength division multiplexing
ENNI	External Network-Network Interface
EPL	Ethernet Private Line
EPLAN	Ethernet Private LAN
EPON	Ethernet Passive Optical Network
ETH	Ethernet MAC layer network (connectionless)
ETY	Ethernet PHY layer network (connection-oriented)
EVC	Ethernet Virtual Private Circuit
EVPL	Ethernet Virtual Private Line
EVPLAN	Ethernet Virtual Private LAN
FCS	Frame Check sequence
GARP	Generic Attribute Registration Protocol
Gb	Gigabit
GELS	GMPLS-controlled Ethernet Label Switching
HFC	Hybrid Fiber-Coaxial
I-Tag	Service Instance tag
IDSL	ISDN Digital Subscriber Line
ID	Identifier
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IP	Internet Protocol
ITIL	Information Technology Infrastructure Library
LAN	Local Area Network
LDP	Label Distribution Protocol
LSP	Label Switched Path
MAC	Media Access Control
MCA	Multiple Correspondence Analysis
Mb	Megabit
MEF	Metro Ethernet Forum
MEN	Metro Ethernet Network

MPLS	Multiprotocol Label Switching
MP-to-MP	Multipoint-to-multipoint
MRP	Metro Ring Protocol
MSTP	Multiple Spanning Tree Protocol
MTU	Maximum Transmission Unit
NMS	Network Management System
NNI	Network Node Interface
NI-NNI	Network Interworking Network-to-Network Interface
SI-NNI	Service Interworking Network-to-Network Interface
OAM	Operation, Administration, and Maintenance
OVC	Operator Virtual connection
PBB	Provider Backbone Bridge
PBB-TE	Provider Backbone Bridge Traffic Engineering
PHY	Ethernet Physical layer entity
PON	Passive Optical Network
P-to-P OVC	Point-to-point OVC
QoS	Quality of Service
RFC	Request for Comments
RMP	Rooted multi-point
RSTP	Rapid Spanning Tree protocol
s	Second
S-Tag	Service VLAN tag
SLA	Service Level Agreement
SDH	Synchronous Digital Hierarchy
STP	Spanning Tree Protocol
TE	Traffic Engineering
TRAN	Transport Services Layer
UNI	User Network Interface
UTA	User Network Interface Tunnel Access
VLAN-XC	Virtual Local Area Network Cross Connection
VPN	Virtual Private Network
VUNI	Virtual User Network Interface
WDM	Wavelength division multiplexing

1 Introduction

Since its creation, Ethernet has aimed to serve users in Local Area Networks (LANs); however, the rapid development of Internet and related services introduced new challenges and requirements for this technology. These changes were driven by the growth of bandwidth needs in metropolitan area networks of roughly 40% per year[1]. This growth was due to the so-called Web 2.0 driven end user applications and applications such as peer-to-peer file sharing.

Even though Ethernet faces competition from various technologies, such as multiprotocol label switching (MPLS), synchronous digital hierarchy (SDH), and wavelength division multiplexing (WDM), there are several advantages that make Ethernet even more attractive, these include: a standardized end-to-end header, a complete header, easier protection, and restoration[1]. Moreover, the lower costs of Ethernet equipment causes network operators to favor this technology.

Today Ethernet is used to connect various networks and providers aim not only to deliver best-effort service, but to fulfill certain additional requirements. Ethernet that meets these additional requirements is referred to as “Carrier Ethernet”.

The emerging Carrier Ethernet market has caused various players to discuss and agree upon common requirements, technologies, and performance indicators to facilitate their communication with customers and each other. A major achievement in this area was done by Metro Ethernet Forum (MEF) [2] when they introduced specifications and certifications for Carrier Ethernet providers and vendors of equipment in order to ensure the quality of service (QoS) provided to the customer.

Regardless of the specific standard, the variety of Internet based companies and services present certain requirements that need an individualized approach to the service presented by network operator and necessitate accurate measurement of the actual performance of this service.

This thesis presents an analysis of the various requirements that have been presented by the various players in the market for Carrier Ethernet services. The aim is to identify what functions, product options, and features need to be delivered in order to fulfill a wholesale customer’s needs, while taking into account the requirements of all of the various stakeholders.

This Master’s thesis starts with a general introduction to the term “Carrier Ethernet”. In order to understand the functionality of Carrier Ethernet, Chapter 2 gives some insights into the technical aspects of Carrier Ethernet. Chapter 3 presents the current status of existing Carrier Ethernet services. An insight into additional features related to Carrier Ethernet networks is given in Chapter 4. Chapter 5 serves as a foreword for the following chapters and introduces the Carrier Ethernet stakeholders. Chapter 6 focuses on standardization bodies. Chapter 7 is dedicated to Carrier Ethernet service providers. It is followed by Chapter 8 that is dedicated to Vendors. Additional insights into the players presented in this market, are given specifically for network providers and vendors. Chapter 9 focuses on target customers, their needs and criteria when selecting a solution. Finally, Chapter 10 summarizes the requirements and presents the interconnection of various stakeholders.

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[1] Protection means a recovery mechanism that includes implementation of a backup link in case of failure, while restoration refers to the process of bring the service back up when a failure happens.

2 Carrier Ethernet attributes

This chapter gives a background of Carrier Ethernet technology though an insight into the attributes of Carrier Ethernet networks. The chapter begins with a summary of the development Ethernet and Carrier Ethernet of technology. Following this a number of different types of Carrier Ethernet services are described. The next sections review some of the important Quality of Service (QoS) issues, including scalability and reliability. The chapter ends with a discussion of Carrier Ethernet service management.

2.1 Development of technology: Ethernet and Carrier Ethernet

Ethernet is a family of standardized network technologies originally developed to realize LANs. This work started in 1973 with a coaxial cable based implementation that offered a maximum data rate of 2.94 Mb/s[3]. Later (in 1983) the 10Mbps version was proposed in the IEEE 802.3 standard[3]. Early Ethernet standards had a clear division between the physical Ethernet layer (PHY) and the Media Access Control (MAC) sub-layer and standards were divided accordingly. In 1995, FastEthernet was standardized [3] and since then the maximum bit rate has continued to increase.

When the development of technology allowed extending an Ethernet from a LAN to a metropolitan area network, providers and researchers focused their effort on improvements in performance. This evolved into the so-called “Carrier Ethernet”.

Carrier Ethernet allows Ethernet connectivity on a large scale; specifically to extend traditional Ethernet communication across external networks and providing more reliable communication with the help of virtual links and operations, administration, and maintenance (OAM) functionality.

Carrier Ethernet technology is attractive for many networks since it can be implemented over various types of media and at the same time it structures parts of the network in a way that facilitates the use and integration of various technologies.

With the active participation of MEF [2], various new standards were introduced that facilitated the implementation of Carrier Ethernet and fostered its spread among providers. While initially the challenge was to define the technical capabilities of carrier Ethernet technology, later standards focus on introducing new services that meet the perceived demands, ensuring interoperability of various networks and providing high QoS.

In February 2012, the introduction of Carrier Ethernet 2.0 [4] introduced valuable additional specifications.

According to MEF, a Carrier Ethernet is a ubiquitous, standardized, carrier call service and network defined by 5 attributes that distinguish it from an Ethernet used for a LAN[36]:

- standardized services,
- quality of service,
- scalability,
- operator quality service management, and
- reliability.

These attributes reflect the requirements that are necessary in order to operate and manage complex networks while meeting specific Service Level Agreements (SLAs). Consequently, the carrier requirements apply especially to the areas of OAM; layered network architectures; and mechanisms for providing resilience. Fang, Zhang, and Taylor [5] outlined the connection between the MEF requirements and the standards of other organizations.

The following paragraphs give more detailed insight into these attributes, as well as other requirements listed by various researchers.

2.2 Types of Carrier Ethernet Services

In Carrier Ethernet 1.0, the Metro Ethernet Forum defined the three types of services[71] listed in Table 1.

Table 1: Types of Services specified by MEF[71]

E-line	A point-to-point Ethernet connection
E-LAN	A multipoint-to-multipoint Ethernet connection
E-TREE	A rooted multipoint Ethernet virtual connection

A specific User Network Interface (UNI) is an interconnection between the network of the service provider and customer network; further details are given in section 3.3.1. An access connection is a connection established between customer and provider equipment, further details are given in section 3.3.4.

The next iteration of the standard, Carrier Ethernet 2.0, extends the portfolio of services to 8 types of service, specifically:

1. *Ethernet Private Line (EPL)* – point-to-point services, configured for a specific UNI and a specific service. This service is shown in Figure 1. EVC stands for Ethernet Virtual Private Circuit.

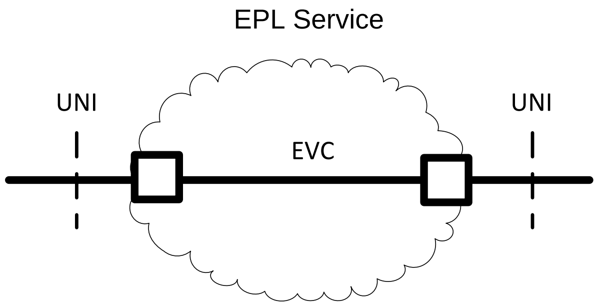

Figure 1 Ethernet Private Line (EPL)

2. *Ethernet Private Virtual Line (EVPL)* – point-to-point services connected to one UNI, but could terminate at various end-points and carry various services. In Carrier Ethernet 1.0, a Virtual Private Network (VPN) was needed for such connections. This service is shown in Figure 2

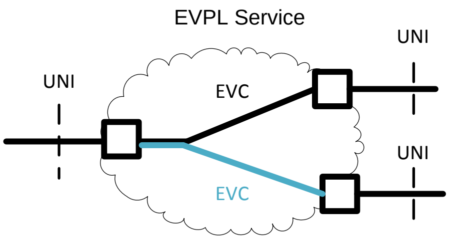

Figure 2 Ethernet Private Virtual Line (EVPL)

3. *Ethernet Private LAN* – Each UNI is dedicated to a service that simulates a LAN via the Carrier Ethernet network. This service is shown in Figure 3

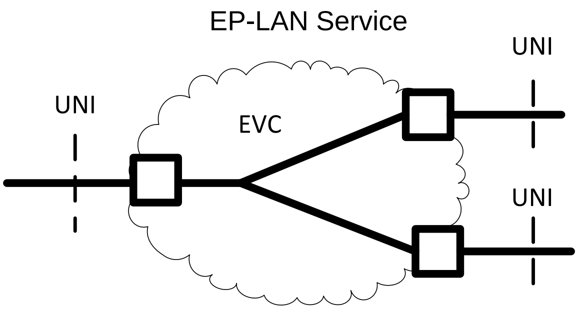

Figure 3: Ethernet Private LAN (E-LAN)

4. *Ethernet Virtual Private LAN* – One UNI connection could contain simulated LANs of various types. For example, simultaneous connection to a corporate network and to the public internet is possible. This service is shown in Figure 4. MP-to-MP EVC stands for multipoint-to-multipoint EVC, while P-to-P EVC stands for a point-to-point EVC.

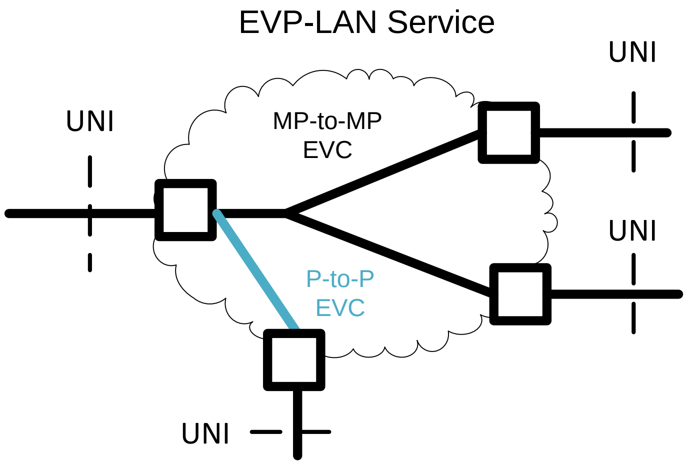

Figure 4: Ethernet Virtual Private LAN

5. *Ethernet Private Tree* – This service allows an exchange of traffic between a root node and end nodes, but not between end nodes. Therefore, a rooted multi-point (RMP) EVC is an EVC that has a single root to which each of the leaves can communication. Each UNI is assigned for a single type of service. This service is shown in Figure 5.

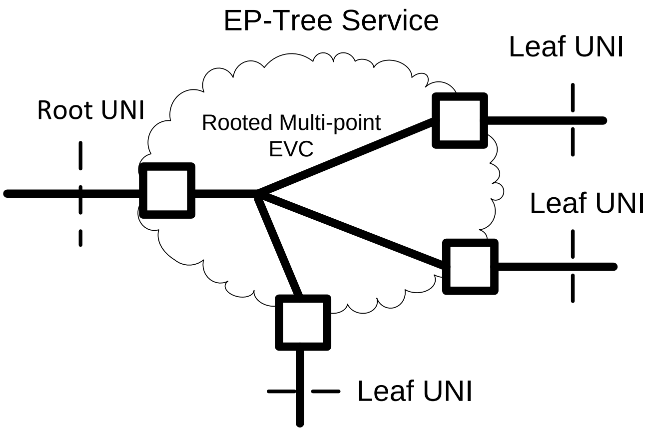

Figure 5: Ethernet Private Tree

6. *Ethernet Virtual Private Tree* – One UNI can support several tree connections of various types. This service is shown in Figure 6.

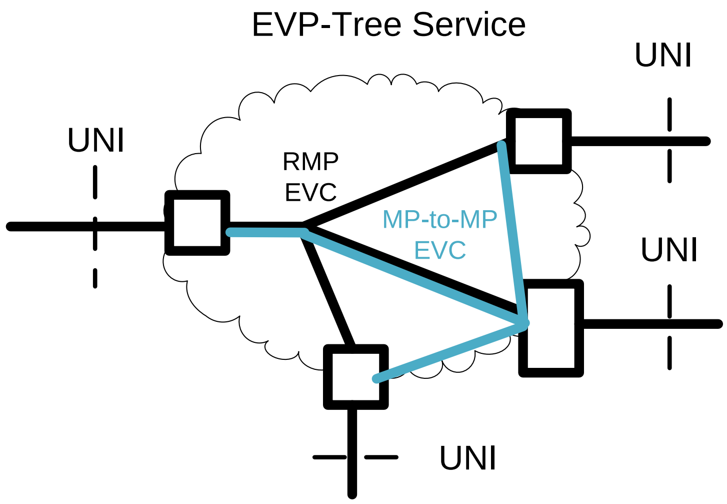

Figure 6: Ethernet Virtual Private Tree

7. *Ethernet Private Access* – A new type of service that allows connectivity to remote end points. The provider offers access through their own network and then organizes the connectivity via other providers so that the client has point-to-point connectivity with each UNI assigned to one service. This service is shown in Figure 7. In this approach the operator provides a point-point (P-to-P) Operator Virtual connection (OVC) EVC.

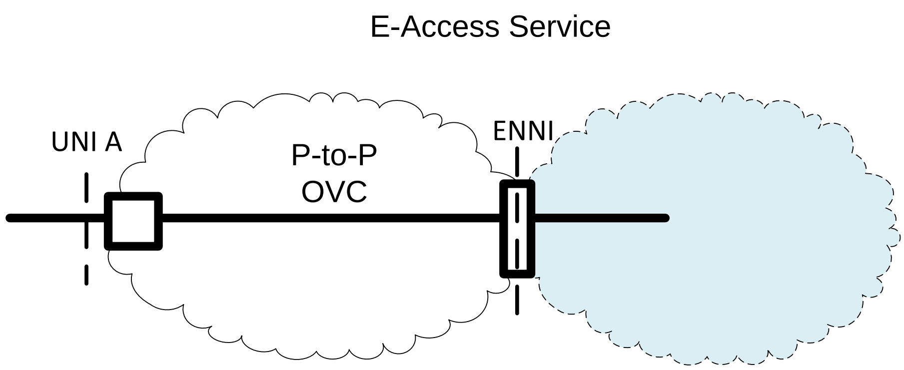

Figure 7: Ethernet Private Access

8. *Ethernet Virtual Private Access* - one UNI can support several access connections of various types. This service is shown in Figure 8.

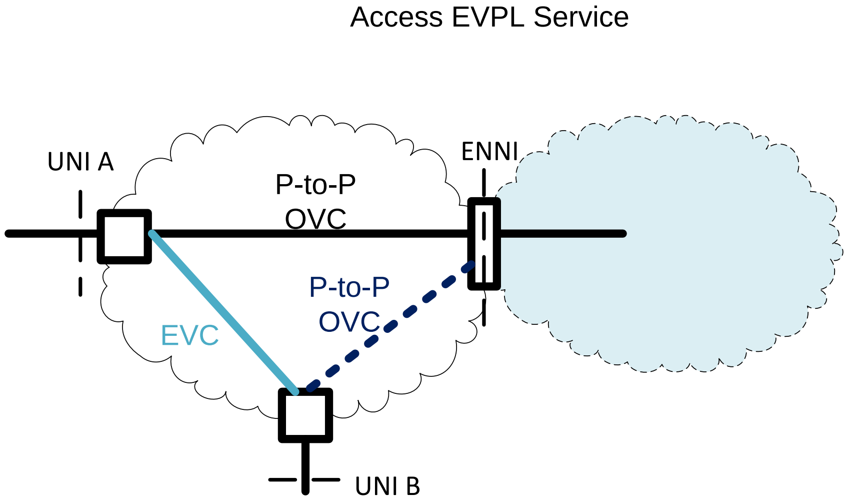

Figure 8: Ethernet Virtual Private Access

2.3 Quality of Service

The requirement for specific levels of QoS forces the telecommunication provider to support delivery of services while taking into consideration the shared aspects of the network (for example, sharing of bandwidth and switching capacity)

The performance that is to be provided by the network operator to the customer is specified in a Service Level Agreement (SLA) with SLA parameters. The SLA is a legal agreement between the provider and the customer that specifies the *expected* performance of the network. A set of parameters are defined for each specific service and must be supported by the underlying network infrastructure. SLAs became more important with the transition from LAN to Carrier Ethernet due to the number of different customers connected to shared resources.

The next generation of Carrier Ethernet introduced Multi-QoS that includes enhanced QoS functions. Moreover, service performance needs to be maintained across various networks and probably across the globe while making new services available for customers.[4]

2.4 Scalability

Carrier Ethernet services could be scalable in the following dimensions:

- users/endpoints;
- geographical reach: due to specifications and standards that have been developed, the desired QoS is maintained even when communication passes through several networks;
- applications: support of multiple technologies both from the network implementation point of view and from adapted QoS point of view ;
- bandwidth: allowing granular bandwidth increments; and
- extended interconnections: Carrier Ethernet 2.0 offers standards for multi-carrier, multi-vendor and multi-network service availability though External Network-Network Interface (ENNI) and E-access services.

2.5 Reliability

The following aspects are addressed by the reliability parameters:

Service resiliency	The troubleshooting and recovery process is rapid and involves minimum impact on the end users; moreover failures should be localized and should not affect other users.
Protection	Carrier Ethernet provides end-to-end service protection that takes into consideration any failure that is possible to predict.
Restoration	Recovery should be similar to or better than SONET networks. Meeting this prerequisite enables latency-sensitive traffic to be transported over carrier Ethernet.

2.6 Service Management

Carrier Ethernet services are often provided to geographically distributed customers. This requires the utilization of multiple networks and various types of equipment. Therefore proper organization of the service is crucial to ensure its functionality. There are three primary aspects of service management that we will consider in this thesis project:

Unified management	This feature requires that each vendor include a standardized means to monitor, diagnose, and manage the infrastructure.
Carrier-Class Operational, Administration and Maintenance (OAM)	There are two main areas of OAM: fault management and performance monitoring. Both of these areas need suitable support.
Rapid Provisioning	Rapid provisioning brings an added value by reducing the provisioning time as compare to TDM. The high flexibility of the service allows faster delivery of a new service as well as faster upgrades of functionality.

These requirements to service management might decrease the diversification among the offers of the providers and motivate the providers to search for innovative approaches to bring an added value to their customer. For example, through features described in Chapter 4

3 Functionality

In this chapter we consider the basic functionality underlying Carrier Ethernetin order to give more in-depth background for the thesis research. We begin by reviewing the logical link layer frame format. This is followed by a summary of related networking technologies. The chapter concludes with a discussion of the principle network elements.

3.1 Logical link layer frame format

The logical link layer frame format is defined in the series of IEEE 802.1 standards [6]. This frame format was gradually modified when new standards and technologies were released. The initial frame structure was focused on LAN implementation and therefore consisted of source address (in Figure 9 this is indicate as Customer Source Address – C-SA), destination address (Customer Destination Address), Ethertype, payload, and frame check sequence (FCS).

Later the IEEE 802.1 working group added a virtual LAN ID (VLAN ID) in the IEEE 802.1Q standard. This is indicated by the Customer VLAN tag (C-tag) in Figure 9. This tag enables various links to share the same physical media, while maintaining isolation between logical networks.

The IEEE 802.1ad standard enables multiple VLAN tags (for the provider and customer) through the standardized Ethernet architecture and bridged protocols. This enables MAC bridging of services to multiple customers in a bridged network. Bridging allows encapsulation of customer frames for transmission across one or more providers' networks.

Later the IEEE 802.1ah standard defined the interconnection of multiple providers' bridged networks. The service instance contains a customer addresses and is defined on the S-tag in the frame header at the edge of the provider's backbone bridge (PBB) network. The frame is forwarded in the PBB network according to the Backbone Source Address (B-SA), Backbone Destination Address (B-DA), and Backbone VLAN tag (B-tag).

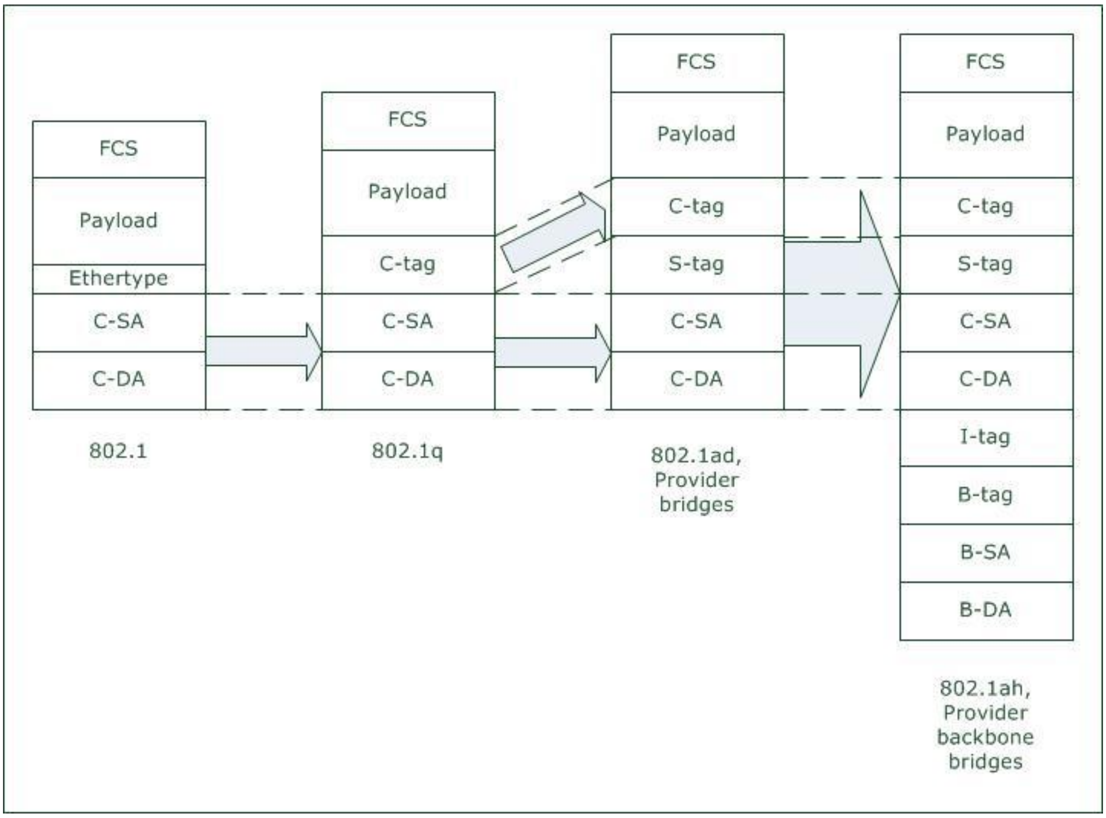

Figure 9: Evolution of the logical link layer frame in IEEE 802.1 [7]

3.2 Network technologies

In order to better handle a constantly growing network, carrier networks separated switching from transmission.

According to Reid et al.[8] switching has focused on service-oriented features using signaling systems, whilst transmission has concentrated on the cost effective management of bandwidth based upon the assumption that the managed capacity is largely static (i.e., that the configuration of the transmission paths lasts months or even years).

The access and aggregation part of the network tend to be expensive and requires long planning lead times to deploy. The use of carrier Ethernet technology in this part of the network is potentially attractive as it provides a cost-effective way of bringing traffic to more central points using a technology that should outlast currently foreseen service requirements.

Reid et al. [8] describe a number of technologies that can be used to enable Carrier Ethernet in metropolitan networks. Each of these technologies will be briefly described in one of the following subsections.

3.2.1 IP/MPLS

An Ethernet service could be enabled across an IP/MPLS network using layer 2 VPN services. In this case a pseudowire is used that emulates a point-to-point virtual link that consists of two unidirectional Label Switched Paths (LSPs)[9]. This technology has an obvious benefit in that it can use control protocols developed for IP and Multi-Protocol Label Switching (MPLS)[9].

3.2.2 Transport Multi-Protocol Label Switching (T-MPLS)

Transport Multi-Protocol Label Switching (T-MPLS) is an adaptation of MPLS (defined in ITU-T standard G.8110.1/Y.1370.1 [10]) that aims to be implemented on the media transport layer. It uses pre-established tunnels.

Technically T-MPLS is implemented through an additional MPLS header pushed in front of the client traffic that is transported transparently inside the backbone network.

3.2.3 Provider Backbone Bridge Traffic Engineering (PBB-TE)

The initial design of Ethernet as a LAN technology did not isolate customer traffic when crossing a provider's network. Several significant steps were made in order to enable this isolation.

The IEEE 802.1Q standard describes a virtual LAN (VLAN). Each VLAN is identified by a Q-tag (also known as a VLAN tag or VLAN ID) that identifies a logical partition of the network that isolates the different communities of interest.

Another important feature was the introduction of an additional tag that separates the VLAN ID in the provider's network from the VLAN ID in the customer's network. To do this the S-tag was added to the customer's Ethernet frame.

However, these tags did not ensure the desired scalability (as each tag is 12 bits, a provider can only support 4094 service instances). Moreover, if the provider's equipment learns the MAC addresses of the customer's network this information could overload the forwarding device's address table [9].

The IEEE standard 802.1ah aims to resolve this scalability problem and to solve the MAC learning problem through the introduction of a hierarchical network model and by introducing encapsulation for this MAC (sub-)layer tunneling.

3.2.4 VLAN Cross connect

A VLAN Cross-Connect (VLAN-XC) enables frames to be forward through tunnels between edge switches of a network. The forwarding decision is made based on the label (contained in the VLAN-XC tag) in the Ethernet header rather than based upon the destination MAC address. An ingress router analyses the Ethernet frame's header and chooses a pre-configured tunnel accordingly. Each intermediate router can change the tunnel information and the egress router removes the label. This technology enables traffic engineering and QoS. VLAN-XC uses the bits reserved for VLAN-IDs in IEEE 802.1Q and IEEE 802.1ad to encode the tunnels[11].

3.2.5 GMPLS-controlled Ethernet label switching (GELS)

The introduction of PBB-TE standards and the need to ensure the control of the network motivated research on GMPLS-controlled Label Switching. According to K. Ogaki and T. Otani, this research aims to "focus on the signaling extension for PBB-TE ESP (Ethernet Switched Path) setup by extending the generalized label for an Ethernet label including ESP-VID and ESP-MAC, and for the ESP maintenance by extending LSP attributes to control Ethernet OAM(802.1ag) function" [12]. The ESP is the Ethernet Switched Path – meaning an unidirectional label switched path that logical Ethernet packets are forwarded over, while the ESP VID is VLAN ID uniquely identifying ESP in combination with ESP MAC - is a backbone fixed MAC address that has global significance.

3.3 Network elements

A Carrier Ethernet network could be divided into several domains that use distinct technologies to organize the underlying data transmission: User Network Interface (UNI), Access network, Aggregation network, Core network, and External Network to Network interface (ENNI). The position of these elements is shown on figure below:

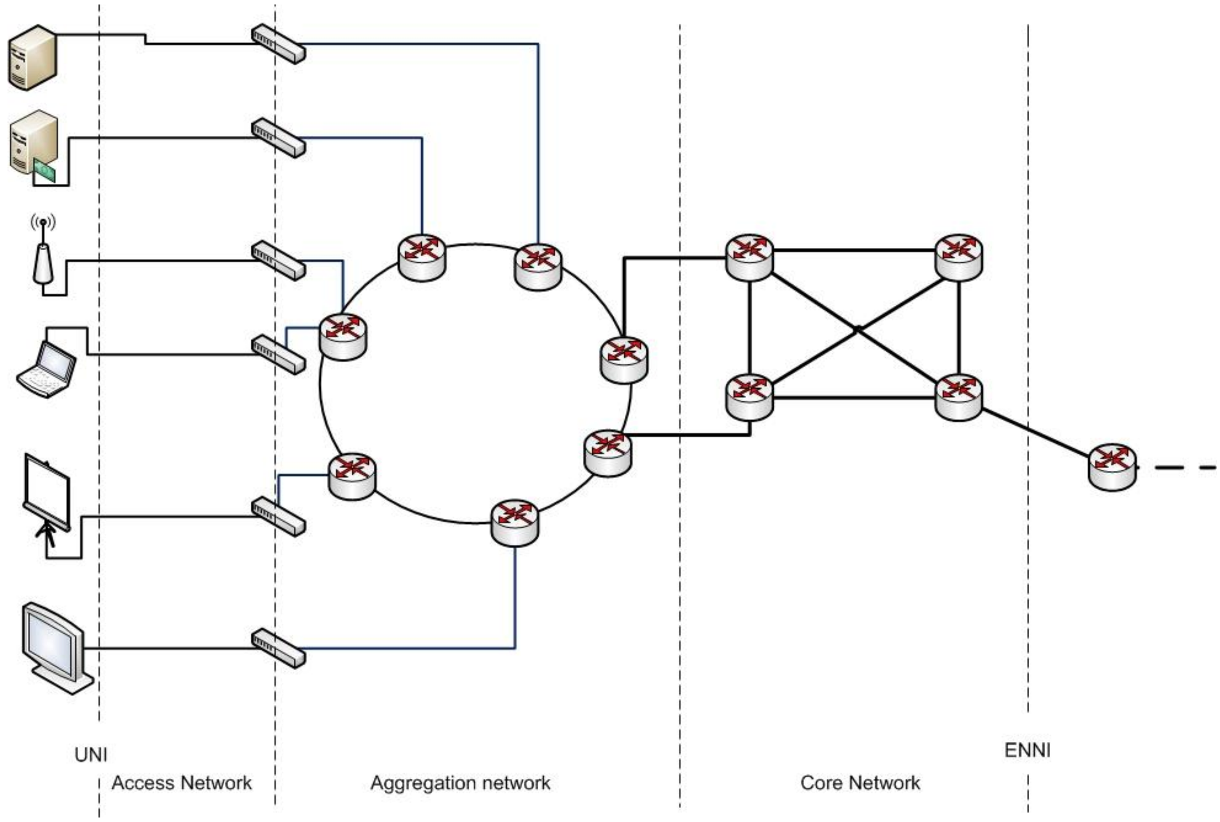

Figure 10: Carrier Ethernet Network

3.3.1 User Network Interface (UNI)

The interconnection between the network of the service provider and customer network is called the User Network Interface according to MEF [13]. The term UNI is used to describe the two elements that form a connection between the customer equipment and the network. Additionally, the term UNI refers to the functions associated with these two elements [13]. The networks that this point connects have separated operational, administrative, maintenance, and provisioning aspects. Moreover, the provider and subscriber each carry the responsibility for their part.

The physical implementation is done over a bidirectional Ethernet link (ETH layer) and the Customer side is always connected by IEEE 802.3 PHY[37]

The UNI reference model proposes 3 layers:

- Data plane: is used to transport various frames: signaling, management, and data.
- Control plane: defines a communication mechanism that allows the customer to use one or more Ethernet services. It might also include dynamic connection setup function that increases configuration flexibility and manageability.

- Management plane: configures and monitors the operation of the control and data planes. The management plane is also responsible for OAM, protection, and restoration setup.

Various types of UNIs allow manual configuration (type 1), as well as partially automatic negotiation; i.e. the customer can retrieve EVC status and configuration information from the provider's side, moreover fault management and protection functionalities are added (type 2). Standards MEF 13[74] and MEF 20[75] provide implementation agreements for various types of networks.

An important extension for Carrier Ethernet 2.0 is UNI Tunnel Access (UTA). UTA helps providers to reach their customers outside of their immediate service area. This connectivity could be implemented by a partner provider's network with an Operator Virtual connection (OVC) between the remote UNI and the ENNI to create a Virtual UNI (VUNI) directly connected to provider's network.

The UNI could be assigned to be in one of 3 positions [13]:

- At the port of the service provider's equipment,
- At the port of the customer's equipment, and
- In the middle of the wire between the customer and the service provider.

3.3.2 External Network-Network interface (ENNI)

The External Network-Network Interface (ENNI) is an interface between two Metro Ethernet Networks where each operator is under the control of a different administrative authority [38].

The definition and specification of this point is important since the customer might buy the service from one provider and then it is the responsibility of this provider to ensure relevant contracts with the networks of other Carrier Ethernet operators.

MEF specifies technical requirements for two types of connections:

- Interconnection interface between two networks of different providers and
- Operator service attributes that ensure transparency and quality of service of the connection for the customer, even if it requires several providers to deliver the service.

The deployment of the interconnection is done with an OVC that has a direct connection with a customer's EVC and should be configured accordingly. Moreover, similar to a UNI, an ENNI is composed of two sides (Operator 1 and Operator 2).

The following MEF standards address ENNI: MEF 26.1[38], MEF 28[76] (specifications and definition of UNI Tunnel Access), and MEF 10.2. The later complements these two other standards with a specification of the requirements for customer connectivity UNI to UNI in the provider's network.

3.3.3 Distribution (aggregation) network

The aggregation network aims to ensure scalability of an Ethernet network and it connects subscribers (through the access network) to the core Metro Ethernet Network. This aggregation network aggregates several links into a logical link that behaves as a single link.

In order to ensure the quality of service (QoS) promised by Carrier Ethernet in aggregation networks, the prevention of *aggregation overflow* should be ensured. Overflow could be caused by a large amount of traffic in flows with the same class of service, as well as by flows with different classes of services that occupy resources with prioritized traffic [14]. In order to resolve this problem a mechanism of resource requests and reservations should be used.

Ethernet supports service separation and prioritization by tagging, bridging, and admission control based upon subnet bandwidth management. However, admission control based upon subnet bandwidth management is considered to be complex and does not scale very well. Toelle and Knorr [14] introduce a method that involves assignment of vertical and horizontal potentials that take into consideration the capability of network, QoS, delays, and QoS for particular connections, then the resource allocation is done according to the outcome of a mathematical calculation. Their method has been evaluated with simple tests; however, no tests in large networks have been presented and the paper is missing an analysis of how the network assigns potentials and what parameters should be taken into consideration.

3.3.4 Access network

In the initial deployment of the Ethernet, the connectivity between the customer and the provider network was implemented by simple demarcation devices at the customer's location with no underlying transport, thus every customer appeared as a port on the network element and all interconnections between elements used dedicated optical fibers without any protection [15].

If the traffic to and from this customer grows, it becomes more and more essential to allow providers to deploy integrated Ethernet aggregation as this would allow better performance, lower costs, and greater scalability. This leads to the use of access networks rather than point-to-point links between the customers and service provider. The following underlying technologies can be used for access networks according to MEF's proposal that aims to improve the QoS through MEF- certified equipment and services [16]:

- Ethernet over Fiber (Active Fiber, Passive Optical Network (PON), SONET/SDH)
- Ethernet over PDH (T1/E1, DS3/E3)
- Ethernet over Copper
- Wireless Ethernet (WiMAX, Broadband Wireless, Microwave)
- Ethernet over HFC/DOCSIS

The following access possibilities were discussed at Ethernet Europe 2011 conference[17] and will be addressed in further research:

- Ethernet-over-bonded copper platform
- Ethernet-over-TDM access circuit platform
- Ethernet-over-fiber intelligent demarcation/switch platforms
- Ethernet-over-wireless platforms
- Ethernet-over-PON

3.3.5 Core

The deployment of Ethernet in the backbone networks has become a more and more attractive solution for operators due to its increased capacity and high data rates.

According to Schmid-Egger and Kirstadter there are two requirements for Core Ethernet networks [18]:

- Scalability is a concern as Ethernet moves from LAN to WAN. However, these two authors believe that this can be resolved using the IEEE standard for Provider Backbone Bridges (PBB) (see section3.2.3).

- A mechanism that enables utilization of meshed network structures. This mechanism could be implemented through additional features in the Spanning Tree Protocol (STP) or though the utilization of multiple VLANs across the network; however, both increase the complexity of network management

The technology used to implement Core networks is described in 3.2.

3.4 Underlying physical media

Ethernet is both a link-layer and a physical layer specification, therefore a variety of physical media can be utilized, including coaxial cable, copper wire, and fiber[8].

The following standards allow better performance of Ethernet through improvements to SONET/SDH[19]:

- Generic Framing procedure,
- Virtual Concatenation,
- Link Capacity Adjustment scheme, and
- Resilient Packet Rings.

The following types of Carrier Ethernet exist:[39]

– **Carrier Ethernet over Copper (EoCu)**

Allows expanding the fiber-based Carrier Ethernet network to the end customer without large additional investments. It serves telephony providers to deliver Ethernet services and could also be used within existing building to make multi-tenant access.

The standard that addresses the implementation of Ethernet at the First Mile is IEEE 802.3ah [80]

– **Carrier Ethernet over Hybrid Fiber Coax (HFC)**

The hybrid Fiber-coax architecture is composed of optical fiber that converts the signal from optical to electrical and vice-versa and connects operator equipment with customer devices. [39]

Initially this technology started to deliver the entertainment programs by cable television operators; however later a transition to full provisioning of video, voice and data services available both for residential and business customers happened.

– **Carrier Ethernet over Passive Optical Networks (PON)**

Passive Optical Networks are utilised in Access networks and thus extend the connectivity from Metro networks to the end customer inherently using the Ethernet equipment and optical fibers.

– **Carrier Ethernet over Fiber and Wave division multiplexing (WDM)**

The rapid growth of Ethernet deployment as well as the growth in data-traffic volumes motivated a development of Wavelength Division Multiplexing optical networking that provides effective operational and scalable solutions.

WDM technology multiplexes multiple channels (called wavelength) of laser light into one Single-mode fiber. [39]

– **Carrier Ethernet over Optical wireless mesh/Free Space Optics (FSO)**

This technology uses the method of data transmission and reception using light signals over free space medium. Most FSO systems use the infrared spectrum (IR) with wavelength between 785 nm and 850 mn. [39]

This technology could be, for example, used in urban commercial environment where the integration of other technologies is not possible.

– **Carrier Ethernet over Time Division Multiplexing (TDM)**

TDM networks were designed to support voice services and a robust manner; however the development of data traffic has introduced different requirements to the network.

In order to support Ethernet, TDM networks implement Circuit bonding technology that allows “uniting” many links into one single virtual link. [39]

– **Carrier Ethernet over SONET**

SONET represents Synchronous Optical Network and originates in voice telephony. It is a wide-spread technology due to good protection mechanisms, OAM capabilities and advantages compare to plesiochronous technology. The request to combine both technologies (Ethernet and SONET) was raised by providers that were looking for cost-efficient solutions.

– **Carrier Ethernet over Resilient Packet Ring (RPR)**

Resil3.2.3ient Packet Ring standard allows having efficient transfer of data at high rates and could be implemented in MAN and WAN networks.

The service attributes of Carrier Ethernet required new approaches in the underlying physical networks and the IEEE 802.17 Resilient Packet Ring working group responded to these needs with the standard concerning RPR technology [79]

– **Carrier Ethernet over Bridging/Switching**

The implementation of this technology was addressed in chapter 3.2.3

– **Carrier Ethernet over Multi-Protocol Label Switching (MPLS)**

The enhancement of this technology was addressed in chapter 3.2.2

– **Carrier Ethernet over WiMax**

WiMax is a shared medium point-to-multipoint communication technology that serves the needs of multiple users. It uses Multiple Access Control protocol for the access of multiple devices to the shared medium. WiMax uses a central controller as a Base Station which coordinates the access to the shared medium. [39]

This technology is implemented in the variety of environments where other technologies have limitations.

The underlying technology for the core network differs from the underlying technology for access networks, since the core network requires greater bandwidth and better performance than an access network.

4 Additional features that can make an operator attractive to customers

This chapter describes a number of features that can make an operator more attractive to customers and that complement the background given in Chapter 2and 3 for this thesis research. The chapter begins by describing some of the network parameters that are relevant to a customer when selecting an operator. This is followed by a discussion of various aspects of the operator’s service support system.

4.1 Network parameters

MEF define that an Ethernet service utilizes a set of Ethernet Service Attributes that define the service’s characteristics. These attributes include a set of parameters that further specify the requirements. In order to fulfill these requirements, the network settings of the provider should be configured according to various recommendations. The following parameters are specified by the MEF [40]:

- Speed (i.e., data rate)
- MAC Layer
- UNI MTU size
- Bandwidth profile (including parameters of the burst size as well as traffic shaping procedure that reduced the burstiness of traffic)
- Frame delay – this parameter is defined by the time from the moment of the reception at the ingress UNI of the first bit of the corresponding ingress Service Frame until the moment of the completed transmission of the last bit of the Service Frame at the egress UNI.
- Inter-frame Delay – according to MEF 10.2 standard [40]: “the difference between the one-way delays of a pair of selected Service Frames.”
- Frame loss ratio – the frame loss parameter is defined over a period of time for a specific pair of UNI.
- Availability performance – is expressed through a percentage of time over an interval of time when the frame loss ratio performance is low.
- Bursting possibilities

These parameters form the basis of a Service Level Agreement (SLA) that describes the service, its parameters, and regulates the relationship between the network provider and the customer.[41] Furthermore these parameters could serve as a basis for a Customer when comparing different providers and their performance; however they might not give a final answer to the Customer since the needs of customers include wider range of network qualities that need to be verified. An example of a company that makes SLA available in public access is Verizon [43]

Unfortunately, a potential customer rarely can find SLA and other information about the network in public access (except for a few of providers) and together with the lack of standardised set of comparison parameters makes impossible an in-depth pre-sales evaluation of various network providers.

4.2 Service Support system

The service obtained by the customer becomes more valuable through the service support system that becomes an interface between the customer and the provider.

Today the competition in the Carrier Ethernet market is very high and the support system is an additional value that may bring more customers to the provider and it ensures the satisfaction of the customer.

Within the frame of this thesis, the Service Support system includes: Customer Care, Online interface with customer, and delivery of a new service.

4.2.1 Customer focus

Customer service focus has shifted in past 20 years with the development of Customer Relationship management (CRM) to provide high quality customer experience and increase customer loyalty that positively affects the operator's profitability.[42]

Loyal customers are more likely to spread positive information regarding the company and to buy additional products, while dissatisfied customers might seriously damage the image of the company by expressing their negative opinions.

A large amount of theories and many models have been developed in the past that concentrate on improvements in customer satisfaction and profitability, as well as on the recognition of the contribution of employees and on the value derived from a specific approach.

Taking into consideration these factors, a customer-centric approach to organisations can developed when all employees consider their plans or actions not only from the viewpoint of their department, but also from the perspective of the service offered by the whole company to the customer. Therefore, employees play an important role in delivering customer service. Their contribution, involvement, knowledge, and dedication are vital.

The following knowledge is required of a customer support specialist:

- Products,
- Customers, and
- Processes.

This leads to changes in a firm's human resources practices, focusing on two steps: selectively hiring very good employees with high general skills and then investing in continual training to retain and improve the performance of these employees. The goal is to properly manage the human capital within the company.

One effort in this direction is certification of specialists. Two mechanisms for certification are:

- Professional certification in the field of the company (Network, IT)
- Productivity and efficiency certification (Six sigma, lean management)

With time, a shift in customer care functions happened in the telecommunications industry. Today the customer care part of the operator is expected to:

- provide timely information,
- determine the root cause of the problem,
- proactive collect provisioning information, and

– ensure communication of the relevant customer information within the company.

Companies provide different levels of service to their customers. These levels are listed in Table 2.

An important tool for improvement when using a customer-centric approach is the feedback given by the customer to the company as this allows not only improving individual characteristics of the support given to the customer, but enables a review of service elements, the general approach, and improvement of general performance.

Table 2: Levels of service

Basic level	In reactive support by customer service changes needed to be requested by the account manager.
Extended	In proactive support there are defined deliverables, a dedicated service manager, and phone access to level 2 specialists.
Customized	With customized customer service there is a dedicated team that works with the service. There is a service manager who has good knowledge of the products and the customer's needs, and is responsible for any third party equipment. Additionally, there is a dedicated helpdesk.

4.2.2 Online interface with customer

The development of internet technologies as well as cross-border provisioning of the service motivated the development of an online interface with the customer that facilitates communication as well as stores historical data. This interface is expected to provide the following possibilities:

- software tools that help to visualize services across different layers (Ethernet, WDM, TDM),
- relevant views for the service, for example, a real world understanding of the footprint and a market level view with SLA compliance roll-ups,
- historic and real-life SLA support, and
- edge-to-edge monitoring according to ITU-T's Y.1731 standard [44]: delay, delay variation; frame loss, etc.

This tool from the customer's perspective should have a secure login and availability from any device.

4.2.3 Delivery of new services and changes in existing services

ITIL[41] gives an in-depth description of the process of new service design. In the application to Carrier Ethernet, the delivery process is show on Figure 11.

The process of delivery starts with the identification of customer requirements and verification of whether existing solutions could satisfy the customer's needs [a] (more about solution portfolios will be mentioned in chapter 7.1) If the customer needs a special solution or modifications in an existing service offer, the relevant development will take place during stage [b]. Stage [b] also requires verification that the network parameters can support the developed solution.

After the solution is developed, the preparation of procurement is done including the ENNI or Access network solution coordination with one or more partner network provider(s) [d].

The next step includes physical delivery of the circuit including equipment and physical link installations [e] and then the configuration of the connectivity between UNIs, from the UNI to customer premises, ENNI, access network, and monitoring settings [f].

Delivery is completed after the verification and testing are done successfully and confirmed by all the stakeholders [h]

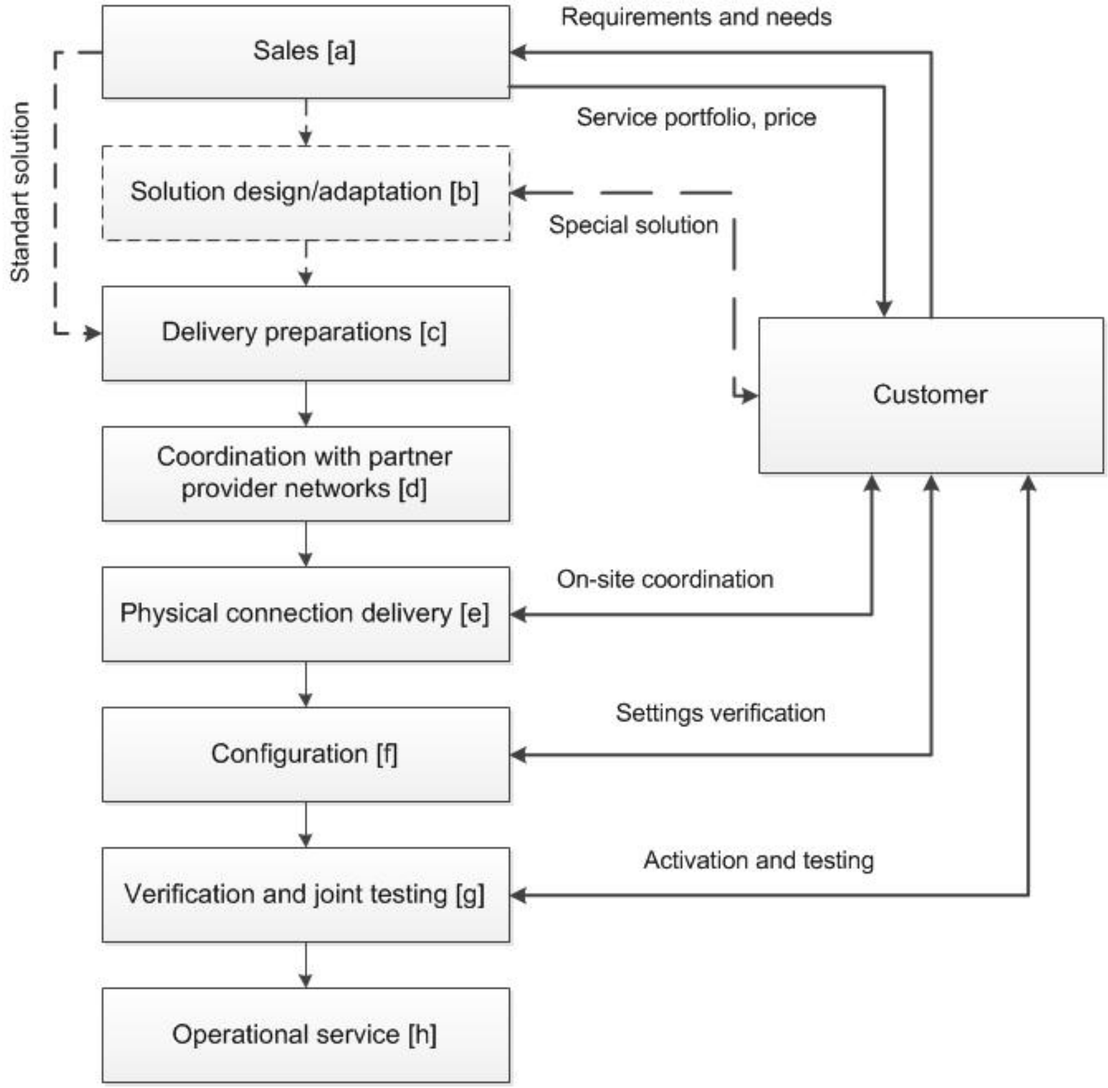

Figure 11: Overview of the delivery process

Changes in existing services follow same procedure; however, change requests might skip several stages depending on the particular request.

Both the delivery and the service change processes require coordination and communication both within the service provider and externally with the customer and partner network providers. Moreover, responses require strict adherence to a timeframe that many customers are very sensitive about.

Another requirement related to both delivery and service changes concerns technical configuration and interoperability. Carrier Ethernet is an attractive solution since Transport Services Layer (TRAN) supports various network technologies and interconnects approaches [45]; however the coordination of the various involved stakeholders requires clear agreements on the solution and interoperability.

5 Introduction to the requirements for Carrier Ethernet

In order to investigate the requirements on Carrier Ethernet from various bodies, four target groups were identified: standardization bodies, vendors of carrier Ethernet equipment, telecommunication providers, and customers - the companies that buy Carrier Ethernet services.

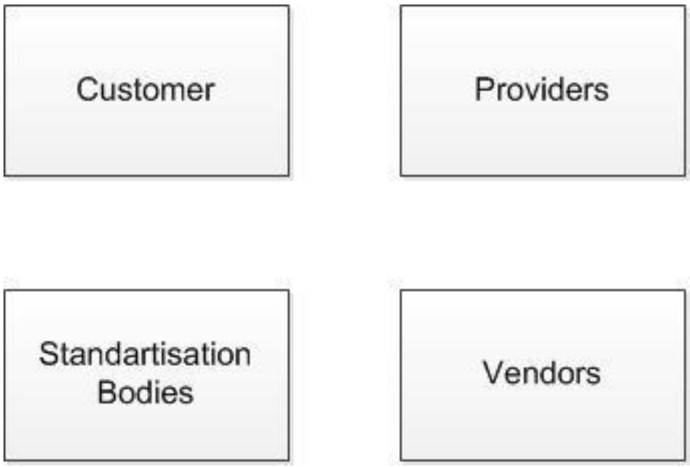

Figure 12: Carrier Ethernet Stakeholders

To examine each target group a customized approach was selected. The requirements of standardization bodies were investigated through published materials. The requirements of telecommunication providers were evaluated based upon available public information. Research regarding the requirements of the vendors of carrier Ethernet equipment required both theoretical research and the advice of specialists. Finally, the requirements of customers were investigated with the help of a survey.

One of these target groups is consider in each of the following four chapters. It should be noted that in each of the chapters we have only focused on topics which are relevant to Carrier Ethernet.

6 Standardization

This Chapter investigates the requirements of Standartisation bodies to Carrier Ethernet technology.

The development of Carrier Ethernet brought up the need to unite standardization efforts and to create standards for this technology. Some of the bodies that define the Ethernet standards are: the Institute of Electrical and Electronics Engineers (IEEE) investigated in 6.1, International Telecommunication Union (ITU) described in chapter 6.2, and the Internet Engineering Task Force (IETF) addressed in chapter 6.4.

Moreover there are several member-driven organizations of Ethernet end users, system and component vendors, industry experts, and university and government professionals who are committed to the continued success and expansion of Ethernet, for example, Metro Ethernet Forum (MEF) addressed in 6.3 and Ethernet Alliance described in 6.5

More details on each organization and existing standards are provided in the sections that follow.

Following this discussion of the standardization groups and interest groups, this chapter briefly looks at the relationships between the relevant standards.

6.1 Institute of Electrical and Electronics Engineers (IEEE)

IEEE is the world's largest professional association dedicated to advancing technological innovation and excellence for the benefit of humanity [77]

The IEEE 802.3 working groups[37] examined all the issues related to Ethernet. The website of the working group gives a good overview of the existing standards and the current developments being pursued within this working group.

Standards developed by two IEEE groups have contributed to the development of Carrier Ethernet: 802.1 (Bridging and management)[6] and 802.3 (Ethernet) [37]

Some of the standards are active at the moment; however some were included into next editions of the standards, but were studied within this work for the research purposes.

Table 3 IEEE Carrier Ethernet standards

Area	IEEE standards
Architecture	802.1Q – VLAN tagging 802.1ah – Provider Backbone Bridges 802.1ad – Provider bridging (also known as stacked VLAN) 802.1ak - Multiple Registration protocol 802.1aj – Two-port MAC relay 802.1Qay – PBB-TE 802.3 – Group of standards defines physical layer and datalink layer's Media Access Control 802.3ar - Congestion management 802.17 Resilient Packet Ring (RPR) [79] 802.1aq - Shortest Path Bridging 802.1AC - Media Access Control Service revision 802.3ah – Ethernet in the First Mile [80]

Survivability	802.1ag – Connectivity Fault Management 802.1Qay – PBB-TE 802.1aq - Shortest Path Bridging
Traffic Engineering, QoS and service specifications	802.1Qay – PBB-TE
OAM and network specifications	802.1ag - Connectivity Fault Management 802.1ah - Ethernet in first mile 802.1AB – Link Layer Discovery Protocol 802.1Qau – Congestion notification 802.1ap - VLAN Bridge MIB
Security	802.1AE/af - MAC/key security 802.1ar - Secure device identity
LAN/MAN management	802.1B – LAN/MAN administration 802.1X – authentication mechanisms for devices wishing to attach to LAN/WAN
Remote Media Access Control (MAC) bridging	802.1D – MAC bridges
Interfaces	802.3 - PHY 802.3as - Frame Expansion

6.2 International Telecommunication Union Standardization Unit (ITU-T)

International Telecommunication Union Standardization Unit develops standards in the telecommunication area (An overview of the standards could be found on the official website of the organization [46]). The ITU-T recommendations listed in Table 4 are relevant for Carrier Ethernet.

Table 4: ITU-T Carrier Ethernet standards

Area	ITU-T standards
Architecture	G.8010/Y.1306: Architecture of Ethernet layer networks [53] G.8012/Y.1308: Ethernet UNI and Ethernet over Transport NNI [55]
Protection	G.8031: Ethernet Linear Protection Switching [57] G.8032: Ethernet ring protection switching [58]
TE, QoS and service specifications	G.8011/Y.1307: Ethernet over Transport – Ethernet Service Characteristics [54]
OAM and network specifications	Y.1730: Requirements for OAM functions in Ethernet based networks;[66] G.8013/Y.1731: OAM functions and mechanisms for Ethernet based networks[67] G.8031: Ethernet Linear Protection Switching[57]
Ethernet Services	G.8011/Y.1307: Ethernet Services Framework. Including:[54] G.8011.1: EPL service G.8011.2: EVPL service
Synchronisation	G.8261/Y.1361: Timing and synchronization aspects in packet networks[63] G.8262 /Y.1362: Timing characteristics of a synchronous Ethernet equipment slave clock[64] G.8264 /Y.1364: Distribution of timing information through packet networks[65]
Equipment	G.8021/Y.1341: Characteristics of Ethernet transport network equipment functional blocks[61] G.8051/Y.1345: Management aspects of the Ethernet-over-Transport (EoT) capable network element[62]
Terminology	G.8001/Y.1354: Terms and definitions for Ethernet frames over Transport (EoT)[59]

6.3 Metro Ethernet Forum (MEF)

The Metro Ethernet Forum (MEF) is the defining body for Carrier Ethernet. MEF is a global industry alliance comprising more than 175 organizations, including telecommunications service providers, network equipment/software manufacturers, semiconductors vendors and testing organizations. MEF's mission is to accelerate the worldwide adoption of Carrier-class Ethernet networks and services. MEF develops Carrier Ethernet technical specifications and implementation agreements to promote interoperability and the worldwide deployment of Carrier Ethernet.

MEF has developed three types of specifications:

- Technical specifications: define architectural principles, mandatory elements and attributes that from Carrier Ethernet Network,
- Implementation agreements: provide evaluation of the parameters defined in technical specification in order to facilitate practical implementation of Carrier Ethernet network.
- Abstract test suites: define series of tests to evaluate the performance and compatibility of existing networks and elements.[78]

Carrier Ethernet Specifications are available to the public via the MEF website: http://metroethernetforum.org/. Moreover, MEF provides certification opportunities for providers, vendors, and specialists.

6.4 Internet Engineering Task Force (IETF)

The Internet Engineering Task Force (IETF) is a part of a bigger organization, the Internet Society. The IETF aims to improve the internet through the introduction of technical documents that facilitate design, usage, and management of the Internet as well as through giving researchers, industry representatives, network operators, and vendors the possibility to cooperate and discuss various questions.

The IETF official documents are called Requests for Comments (RFC). Not all of these RFCs are standards; some RFCs are simply informational documents. The following types of RFCs exist:

- Proposed Standard (PS);
- Draft Standard: next stage after proposed standard;
- Internet Standard: the final stage when the specifications and practices will be widely deployed.
- Best Current Practice (BCP) and informational documents are alternatives to standards.

IETF divides the work in several areas [47]: applications, general, Internet, Operations and management, Real-time Applications and Infrastructure, routing, security and transport. Documents that concern Carrier Ethernet mostly belong to Routing and Operations and Management areas.

IETF has developed a wide range of standards. A few examples of RFCs that concern Carrier Ethernet are:

- RFC 4762: Virtual Private LAN Service (VPLS) using Label Distribution protocol (LDP) signaling[20]

- RFC 4761: Virtual Private LAN Service (VPLS) using BGP for Auto-discovery and signaling [21]
- RFC 4447: Pseudowire setup and maintenance using the Label Distribution Protocol (LDP) [22]
- RFC 5641 Transport of Ethernet Frames over Layer 2 Tunneling Protocol Version 3 (L2TPv3) [23]
- RFC 4878: Definitions and Managed Objects for Operations, Administration, and Maintenance (OAM) Functions on Ethernet-Like Interfaces [24]
- RFC 5828: Generalized Multiprotocol Label Switching (GMPLS) Ethernet Label Switching Architecture and Framework[25]
- RFC 5994: Application of Ethernet Pseudowires to MPLS Transport Networks[26]
- RFC 6004: Generalized MPLS (GMPLS) Support for Metro Ethernet Forum and G.8011 Ethernet Service Switching [27]
- RFC 6005: Generalized MPLS (GMPLS) Support for Metro Ethernet Forum and G.8011 User Network Interface (UNI) [28]
- RFC 6060: Generalized Multiprotocol Label Switching (GMPLS) Control of Ethernet Provider Backbone Traffic Engineering (PBB-TE)[29]

The development of RFCs is done by *individuals* – these individuals do not represent vendors or providers (although they may of course be employed by vendors and providers).

6.5 Other organizations

There are several other telecommunication organisations that contribute to the development of Carrier Ethernet standards; however, their scope of work is significantly smaller in this domain. For example, the primary industrial standards body in the U.S. is the American National Standards Institute (ANSI, [49]). ANSI publishes software-related standards in conjunction with the IEEE and thus contributes to Carrier Ethernet development.

Many countries also have local standardisation bodies that adapt international standards for local application. In particular area such organisations have greater authority; however, in case of emerging technology, international industry-focused organisations are more innovative and quicker at development, so their standards are used as a reference.

6.6 Correlation between standards

Since all the organization aim the development of the technology, many of them have established cooperation on various questions or in the documentation there is a clear reference to the documentation of another organization.

For example, IETF established cooperation with ITU-T regarding the development of MPLS-TP technology [69]

Another example could be a reference in MEF documents to ITU and IEEE standards and clarification of the usage of different terms since ITU takes more a network view and MEF practices service view MEF 6[71]

6.7 Communication with other stakeholders

As mentioned in chapter 5, the four stakeholders of Carrier Ethernet technology were identified. Standardisation bodies were reviewed in this chapter and their interconnection with other stakeholders are presented on Figure 13

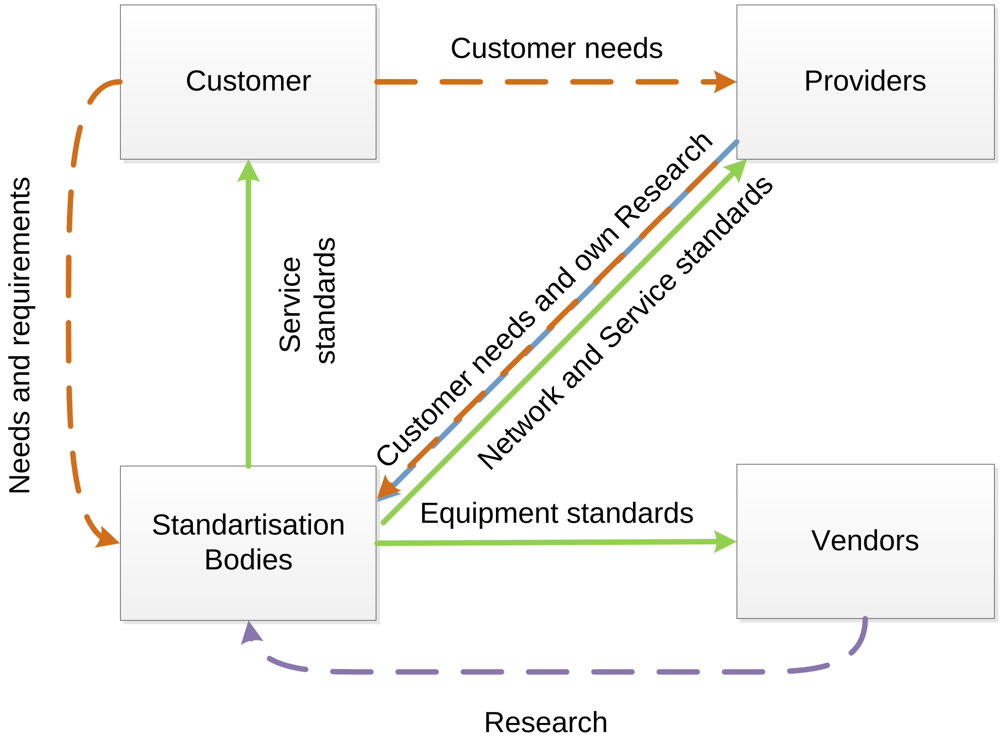

Figure 13: Communication of standardisation bodies with other stakeholders

Research on the operations of standardisation bodies showed that there are interconnections with the three other stakeholders: customers, providers, and vendors through provisioning of specifications and standards for services, networks, and equipment (respectively).

In their turn, customers, providers, and vendors contribute to the work done by standardisation bodies: customers provide their needs and requirements which shape research activities, and providers and vendors participate in the development of the standards. The needs of Carrier Ethernet customer might reach standardisation bodies through different channels: it could be direct feedback and contribution, but the could be also expressed through providers.

7 Telecommunication providers

This chapter presents another Carrier Ethernet stakeholder, Telecommunication providers, and its interconnection with other stankeholders.

The development of Carrier Ethernet technologies brought to the market many operators that offer various services related to this technology. Telecommunication operators want to ensure the quality of Carrier Ethernet Service, thus MEF has made public a list of certified Carrier Ethernet providers on their website [30]. However, in the actual market there are many more providers of Ethernet service than those who have announced publically that they provide Carrier Ethernet.

On the IP level there is a common practice to classify Internet service providers into: Tier 1 (having only peering connections and customers), Tier 2 (having customers while being a customer to another ISP), and Tier 3 (does not have ISPs as customers and is a customer of another ISP). In the case of Carrier Ethernet there is no commonly accepted classification of the providers; however, a few parameters could be used to distinguish the service providers:

- Infrastructure and network capabilities (defines the portfolio of services provided by the provider),
- Geographical presence, and
- Service portfolio

Even though these parameters might vary and thus identify distinct groups of potential customers, the survey conducted by Carrier Ethernet news [50] shows that most of provider representatives evaluate their operational environment as competitive or very competitive. This leads to the need to differentiate their service offerings in order to give additional value to the service.

This chapter addresses various aspects of network provider operations in the Carrier Ethernet market.

7.1 Service portfolio

Selling a product to a customer could take one of two opposite approaches: a standartised product offer and an individual offer that is designed according to a customer's specific needs.

The first approach gives a strict frame for the solution and has advantages in configuration and pricing simplicity, whereas the disadvantage is that it might not fit the customer's needs or requirements. The second approach gives the operator the possibility to design a solution that completely matches a customer's needs; however, it often leads to too many possible choices for the customer (which could be confusing to the customer) as well as increasing the complexity of managing and maintaining a large number of different services for the provider.

The best approach may be a standard service that can be adapted to fit the profile of the customer. This can be combined with the possibility for further adaptation to a particular customer's needs.

MEF specifies 8 types of Carrier Ethernet services in their latest standards [4]. These types provide a base for telecommunication providers to construct their service offers. The profile of the customer could be identified based on their business or geographical presence in combination with the customer's business strategy. The identified profile could help to prioritize specific types of services and network parameters that could be combined in an offer adapted to a certain profile.

A profile adapted service portfolio could help the network provider to approach a potential customer with an offer that would show that the network provider understands the needs of the business without limiting the possibility of adapting the offered service according to the customer's specific requirements. During later stages parameters such as architectural requirements, bandwidth and scalability, integration and interoperability, management of the service and security could require customer tailored solution.

Another advantage of having a profile adapted service portfolio is the possibility to assign classes of service in the network and create clear (and simple) schemes of prioritization for customer traffic. The network provider could profit from utilizing the tools that Carrier Ethernet 2.0 provides (color-awareness, ingress-egress bandwidth profiles, and burst possibility on a per-use basis) and to allocate bandwidth unused by delay-sensitive applications to best effort services.

7.2 Service solutions

A customer profile adapted service portfolio could be empowered by the network solutions and application of Carrier Ethernet that are already addressed by standardisation bodies and network providers. These will be described in this section.

7.2.1 Mobile backhaul

The development of mobile devices (including the introduction of 2.5G, 3G, and now 4G data services) and mobile networks brought a growing need for backhaul bandwidth. The backhaul link connects local sub-networks with the operator's backbone or core network.

Metro Ethernet Forum has proposed an initiative for the usage of Carrier Ethernet for mobile backhaul. This is in contrast to the Time Division Multiplexed (TDM) circuits from third party providers that are currently widely used for connecting mobile base stations. The growth of Carrier Ethernet has made it possible to have a leased Ethernet Virtual connection that fulfills the same objectives as a TDM circuit. The latest standards introduced by the Metro Ethernet Forum allow an access connection (which might use a third party network) to connect the mobile base station; moreover the SLA and the QoS would be ensured by the Carrier Ethernet provider.

MEF has described the advantage of having multiple QoS classes of service as compared to a single QoS [72] Multiple classes of services would allow prioritising traffic and having two lanes: high-priority (for delay sensitive traffic) and low-priority (for bursty delay tolerant traffic) which would allow prioritising network control, signaling, and delay-sensitive traffic and at the same time maximize profitability and reduce costs.

An important issue that providers face is synchronization for packet technologies such as Ethernet. This will be described in section 8.2.

7.2.2 The emulation of TDM circuits

The emulation of TDM circuits is also known as Pseudowire or Circuit Emulation Services (CES).This emulation enables a transition to Carrier Ethernet and allow MEN providers to offer TDM equivalent services to customers. MEF 3 [70] provides a set of service definitions, descriptions of issues arising with such services, and a set of requirements for Metro Ethernet Networks needed to provide CES.

Emulation services use a Carrier Ethernet standardized service: EVC. There are three possible modes of operation that allow point-to-point connections and multipoint-to-multipoint connections. Pseudowire allows Carrier Ethernet providers to reach a wider range of customers, for example to carry voice traffic alongside with data traffic.

7.2.3 Cloud connectivity

The development of cloud computing has significant implications to today's network, as the shift of computing to the cloud requires both networking from the user to the cloud and connectivity within the cloud.

The complete cloud solution is made up of the following components [35]:

- Physical Server infrastructure or Infrastructure as a service (IaaS): allows the customer to obtain computer storage resources (for example, server) together with the connectivity and thus eliminate dedicated servers per user;
- Operating System foundation or Platform as a service (PaaS):allows the customer to have virtualized computing platform on multiple servers across the cloud;
- Application layer or Software as a service (SaaS): allows the customer to have application software running in the cloud;
- Networking: to and from the cloud as well as within the cloud.

Interconnection of Cloud servers and connection of customers to cloud servers becomes crucial for many businesses and leads to the following requirements on the network technology:

- Scalable bandwidth;
- Service differentiation is required to enable many customers with various types of service;
- End-to-end performance assurance; and
- Resiliency.

Carrier Ethernet features support the above requirements and offers cost effective solutions that have some advantages over alternative technologies (for example, bandwidth scalability, service differentiation). One specific type of services, E-access, introduced within the Carrier Ethernet 2.0 framework makes Carrier Ethernet even more attractive solution since it enables connectivity to a remote location across partner networks while supporting the performance and resilience qualities of the original provider's network.

7.2.4 Other services offered by the provider

Telecommunication providers are not limiting their offers to Carrier Ethernet services, but they also provide connectivity on different OSI levels (for example, WDM, TDM links, and IP connectivity). Moreover, the latest generation of Carrier Ethernet includes the possibility for the UNI to handle connections of different types (more details are provided in section 2.2) and multi-QoS enables the prioritization of traffic and efficient utilization of network resources.

Another type of service that network providers can offer and that could complement their Carrier Ethernet portfolio is a datacenter offer or a managed equipment offer. The datacenter provides space, power, and connectivity. A datacenter offer can be attractive to some customers since it reduces the amount of capital expense (CAPEX), as well as providing a highly scalable solution. Such a service complements Carrier Ethernet since the datacenter or managed equipment (similar to a datacenter but with the customer owning the equipment) could be used for various purposes:

- To host cloud computing servers while Carrier Ethernet ensures the connectivity as was described in section 7.2.3 and
- To ensure interconnection with various technologies and applications (both on the same OSI level and with different upper layer protocols).

The combination of various services could help a network provider to create the most suitable offer for a potential customer.

7.3 Factors to consider when choosing a telecommunication provider

Fang, et al. have said that the following factors should be taken into consideration when choosing a Carrier Ethernet provider [5]:

- Capital expenses and operational expenses
- Is the deployment a new network or an expansion of an existing network?
- What existing technologies are already deployed in the network?
- Operational staff experience
- Portfolio of desired services
- Availability and maturity of the desired technologies
- Operation Support Systems to be used

7.4 Communication with other stakeholders

This chapter focused on the operations of service providers that are related to Carrier Ethernet technology. According to the portfolio of services that was investigated earlier in the chapter, these service providers address their requirements not only using Carrier Ethernet technology, but by communicating with the other stakeholders. An overview of this communication is presented in Figure 14

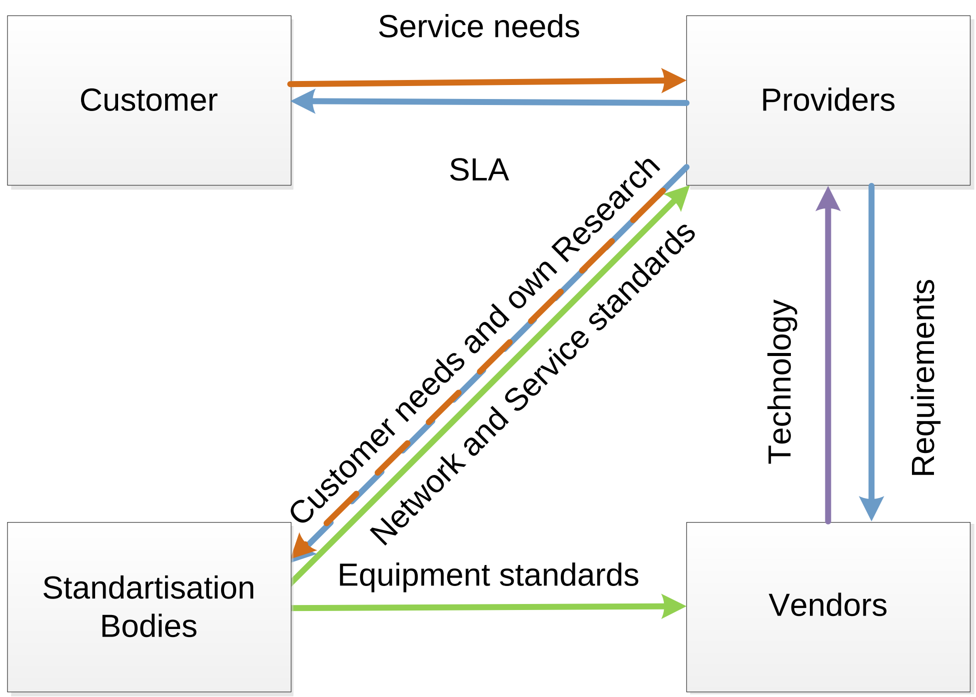

Figure 14: Communication of providers with other Carrier Ethernet stakeholders

Carrier Ethernet providers build their services based on the needs presented by their customers and support a level of performance specified by a SLA. However, the operation of the network would not be possible without the equipment and technology solutions provided by vendors nor without network standards issued by standardisation bodies. Telecommunication providers, in their turn, contribute to the development of the technology with their research and active participation in the Carrier Ethernet community.

8 Vendors

Another stakeholder in Carrier Ethernet technology is equipment vendors that producing products and solutions for Carrier Ethernet networks. This chaptet gives an insight to the needs and requirements of this stakeholder.

MEF offers certification programs[30] for vendors in order to validate their compliance with the MEF standards and to strengthen their presence in the market. The certification covers compliance with MEF standards regarding Ethernet Service functionality, Ethernet service performance, TDM over Ethernet, and link OAM.

Vendors and their products play a crucial role in enabling the providers to support offered services and their SLA with their customer, while at the same time implementing and operating cost-efficient networks. For these many reasons the vendors' products and solutions should match the requirements described in this chapter.

8.1 Interoperability between various vendors: tests and certification

The functionality of the network depends on the network's infrastructure. This infrastructure includes the various devices that not only need to follow the standards, but must be technically compatible with each other in order to ensure the announced functionality and QoS. For test purposes interoperability events, such as the Carrier Ethernet World Congress (CEWC), unite vendors and providers. In 2008 such an interoperability event was dedicated to the future of Carrier Ethernet Services [31]. The tests aimed to interconnect equipment from each vendor with equipment from every other vendor and to test all the possible network configurations.

Vendors, being commercial companies operating in a competitive market, aim to create attractive individual solutions that would require a provider to remain their customer and be committed to the vendor's solution. At the same time, network providers struggle for diversity in their network and the utilized equipment, thus network providers try to avoid solutions that cannot be combined with equipment offered by other vendors. Thus certification programs and interoperability tests play an important role in supporting the needs of these providers.

8.2 Synchronisation

Two applications of Carrier Ethernet that require special attention to synchronisation are: mobile backhaul and time-division multiplexing circuit simulation. Other applications which might benefit from synchronization are audio/video applications.

Synchronisation includes both synchronisation in time and frequency, where a frequency reference is used to derive transmission frequencies at the mobile station and a time reference is needed to recover transmitted bits at the edge TDM emulation points and to ensure the global clock synchronization of circuit switched networks.

Earlier technologies, such as SONET/SDH, naturally disseminated synchronisation as the whole network was synchronized to a single global clock. In Ethernet synchronisation of the receiver with the incoming frame is done on per-frame basis. In order to resolve this problem several initiatives were introduced by the standardisation bodies that concern various layers. For Layer 2 and Layer 3 synchronisation is based on multicasting of synchronisation frames or packets with time stamps. The latest standards include IEEE 802.1AS, 802.1Qat, and 802.1Qav (from the IEEE Audio/Video Bridging Task group [48]). Other developments in this domain were made by the IETF Network Time protocol (NTP) and the Simple Network Time Protocol (SNTP). Additionally, there is an IEEE working group developing the IEEE 1588 Precision Time Protocol [68].

The drawback of the higher layer synchronisation is the possible dependence on the traffic load and the packet-delay variation. Therefore, other proposed solutions (that form the basis of Synchronous Ethernet) use the physical layer for synchronisation similar to SONET/SDH. ITU-T standards address minimum requirements for jitter and wander network equipment in G.8261/Y.1361 [63], distribution of timing information through packet networks in G.8264/Y.1364 [65], and Synchronous Ethernet in G.8262/Y.1362 [64].

8.3 High data rate support

Through the continuing development of Ethernet the peak data rate has reached 10 Gbit/s from the initial 2.94 Mbit/s. These days the new highs are being targeted by developers and vendors to provide 100Gbit/s.

In 2010 Facebook officially remarked [37] that 100Gbit/s links are needed for the successful functionality of their service and these days various newspapers and network journals address this functionality. Tests in this domain have shown positive results [36]. Moreover, 1 Terabit/s links are expected to be developed by 2015 [38].

Achieving these desired data rates not depends upon on the motivation of providers and the needs of their customers, but also on the research done by specialists from various fields, including material science. At the moment researchers are investigating the qualities of the material that can transmit such high data rates at low costs.

IEEE Ethernet working group 802.3 [37] investigates the bandwidth needs of the other stakeholders through the creation of specialized study groups and develops various standards in this domain. For example, 802.3ba-2010 provides in-depth information regarding 40 Gbit/s and 100 Gbit/s Ethernet.

8.4 Energy efficient solutions

Energy efficient Ethernet reduces the energy consumption of an Ethernet interface. This not only decreases the interface's power consumption, but also reduces the cooling requirements for the equipment [52].

Moreover, the Energy efficient Ethernet initiative is part of a project that targets Ethernet networks and foster research into low energy consuming equipment. This initiative is also investigating the adaptation of links to traffic levels and exploiting sleep mode when the conditions are fulfilled by the connected equipment. This project also targets consumer electronics and energy efficiency [51].

8.5 Communication with other stakeholders

The research on vendor requirements for Carrier Ethernet technology showed an interesting result: Vendors receive their requirements from other stakeholders (service providers and standardisation bodies) and respond with technology development, research, and solutions supporting these requirements. The research done by the vendors plays crucial role since it has direct practical implementation and thus enable innovation. Often standardisation bodies are reproached in this case for being inert and not respond with relevant documentation on time.

The communication scheme is provided in Figure 15

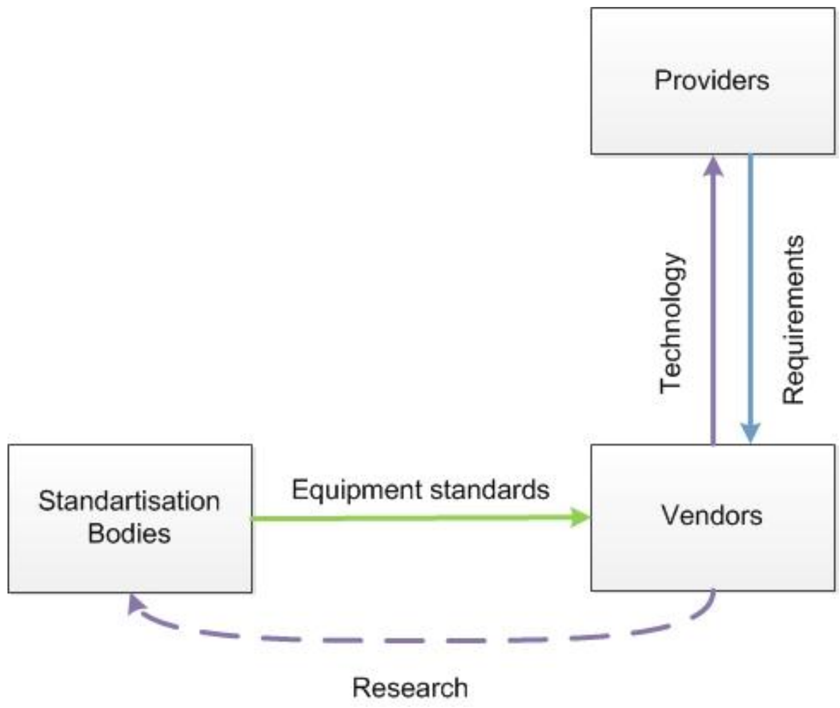

Figure 15: Communication of vendors with other Carrier Ethernet stakeholders

9 Customers

This chapter finalises the presentation of various stakeholders and presents the needs and requirements of Carrier Ethernet customers.

The performance that is ensured by Carrier Ethernet aims to satisfy the needs of the customers, who are companies and organizations from different businesses. Due to the large number and wide variety of potential customers, the offers and services are only partly standardized, thus allowing some adaptation according to the needs of each specific customer.

Providers' websites generally describe which types of customers they are targeting and thus give us an overview of some of the potential customers who might be interested in Carrier Ethernet Services. Based upon reading the information at many of these sites, the set of potential customers seems to include:

- Gaming companies,
- Governmental organizations,
- Medical organizations,
- Businesses that need to connect remotely located offices,
- Social network and media content providers,
- IPTV (i.e., Internet Television),
- Banks and financial businesses,
- Internet Service Providers (ISPs), and
- Mobile operators who want backhaul connections from their base stations.

Moreover, Carrier Ethernet empowers cloud computing through provisioning of network infrastructure and providing connectivity to the cloud datacenter. Carrier Ethernet is considered by some to be the optimal solution for cloud computing[32].

The requirements of Carrier Ethernet customers were gathered through a survey. This survey and its results will be further described in the following sections.

9.1 Carrier Ethernet Survey

The goal of the survey was to obtain the opinion of companies that already use Carrier Ethernet or to analyze the reasons why a company does not yet use Carrier Ethernet. An English version of the questions asked of the respondents is provided in the Appendix A (Russian and Spanish versions were also available to facilitate the survey process in different regions of the world and cover the largest language and geographical groups).

The target group for the survey was companies that buy telecommunication services from operators, for example:

- Telecom providers (ISPs, mobile),
- Large companies from all industries using internal networks,
- Governmental and health care organisations,
- Educational and research institutions,
- Financial institutions, and
- Companies providing online services.

The target audiences for the results of this survey were network and IT managers, network architects, and network engineers.

Respondents were asked to evaluate the importance of the criteria when choosing a Carrier Ethernet Provider using the scale shown in Table 5.

Table 5: Scale to be used by respondents

1	Not important (Do not take into consideration)
2	Take into consideration when making the choice but is not important
3	Important
4	Extremely important

In order to see what criteria were determined by the respondents to be relevant and to determine how important each criterion was, the survey proposed the following list of criteria:

3.1 Availability of different classes depending on network performance guarantees (packet loss, availability, frame delay)
3.2 Access technology
3.3 Support of standards (For example, IEEE, MEF)
3.4 Guarantees on SLA with penalties for not-compliance
3.5 Bandwidth profile parameters in the provider network (including bursting possibilities)
3.6 OAM functions and mechanisms of provider network
3.7 Collocation of Customer equipment offered by provider
3.8 Services other than Ethernet offered by provider (please specify in "Comments" field)
3.9 Ubiquitous service coverage within your region
3.10 Possibility for a custom tailored solution
3.11 Make adjustments to the service quickly
3.12 Delivery: how easy is it to connect to the provider’s network
3.13 Delivery: time required to connect new service
3.14 24 hours/7days Customer Support available
3.15 Possibility for you to access the monitoring information of the service
3.16 The price of the service
3.17 Visibility of the provider: participation in conferences, information in news, awards
3.18 Reputation of the provider: testimonials from other customers

9.2 Survey results

The survey gave a number of results. The first aspect that we will consider is the number of surveys sent out and the number of responses that we received. The total of indirectly contacted people was counted through the approximation of the number of users of public specialised forums and mailing lists where the survey was sent. These numbers are given in Table 6.

Table 6: Overall results of the survey

Total directly contacted, people	Total indirectly contacted, people	Answers received	Answers accepted
110	~ 500	29	24

The difference between the numbers of answered received and the number accepted is due to the fact that 5 responses were not accepted for the following reasons: the answers in question 2 (Is your company currently using Carrier Ethernet services?) showed that the respondent does not know what Carrier Ethernet is (thus the respondent does not have sufficient insight into the subject) caused the rejection of 4 responses and one of the responses was identical to another response and submitted within approximately one hour of the first response (thus the second response was judged to be a duplication submission).

The survey was conducted all around the world and the distribution of responses representing various geographical areas with the distribution shown in Figure 16 (the number associated with the region was assigned according to the information filled in as free text on the survey form).

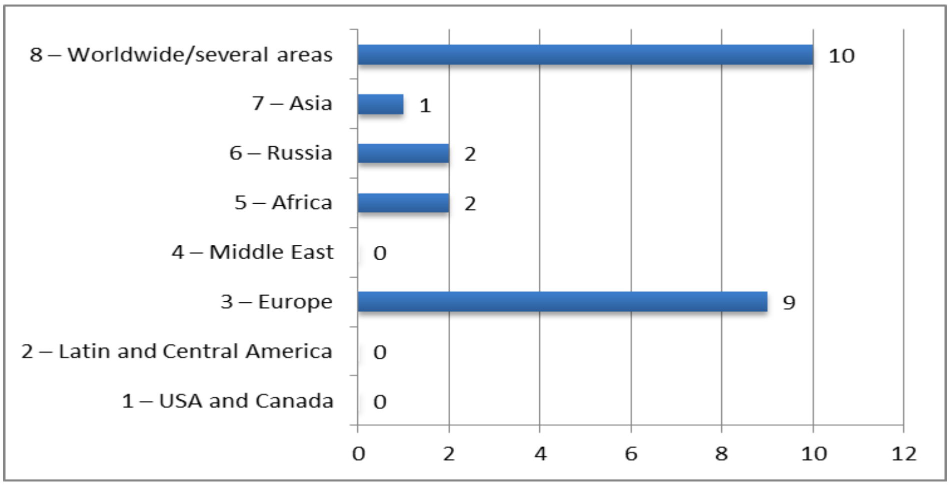

Figure 16: Division of answers by geographical area

The responses received for the survey were provided by employees of companies that represent the business sectors presented in Figure 17 (the number associated with the business domain was assigned according to the information filled in as free text on the survey form.)

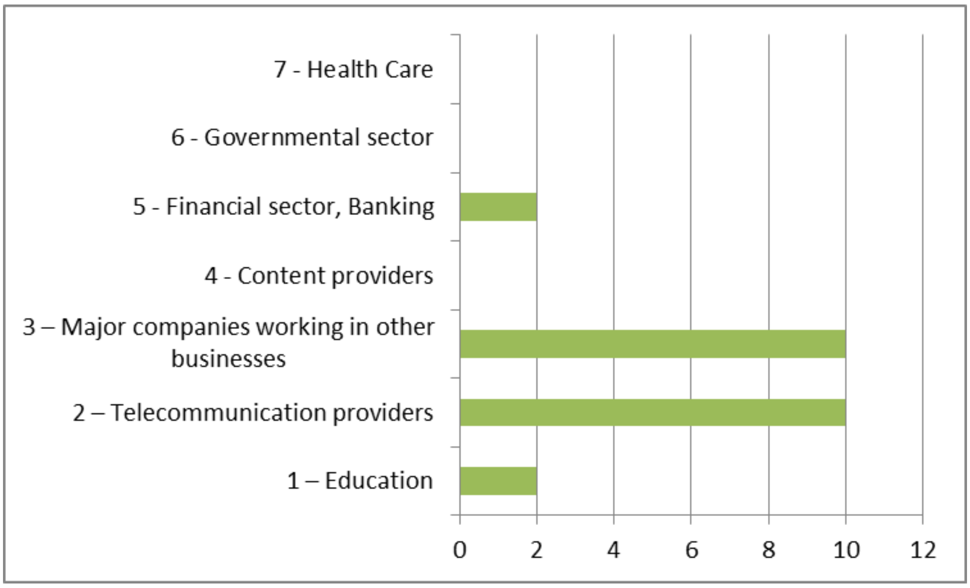

Figure 17: Division of answers by business domain

9.2.1 Multiple Correspondence Analysis (MCA)

The analysis of the responses was done with Multiple Correspondence Analysis that allows analysing a pattern of relationships in a group of variables and presenting the profiles of the variables on a low-dimensional map (with only two or three dimensions).

This method was selected since it requires no *a priori* hypothesis about the nature of the underlying patterns and it is applicable to the available data. The software used to perform this analysis was the XLSTAT Microsoft Excel extension [73].

These computations generated several results:

- disjunctive table: an intermediary table that displays how the input data corresponds to an observation;
- burst table: an symmetric indicator matrix of all two-way cross-tabulations formed from variables
- total inertia: integral of mass times the squared distance to the centroid, it is used to access the quality of graphical representation in correspondence analysis;
- eigenvalues and percentages of inertia: non-zero vectors that, after being multiplied by the matrix, remain parallel to the original vector (these are shown in Figure 18);

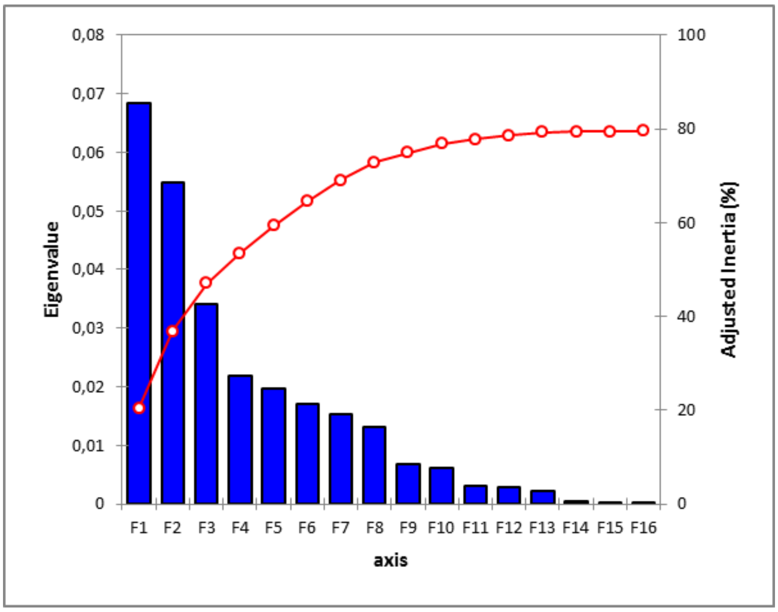

Figure 18: Eigenvalues and percentages of inertia

- principal coordinates table: displays the principal coordinates which are used later to represent projections of profile points in symmetric and asymmetric plots.
- symmetric plot: these plots are based on principal coordinates.
- asymmetric plot: uses the principal coordinates for the categories of the variables and the standard coordinates for the observations and vice versa.

In the presentation below, the symmetric plot was selected since the analysis is done based on the variables that describe both the type of the customer (using the information in "Geographical location" and "Type of business" categories) and the requirements for Carrier Ethernet service (the information in the rest of categories). The generated symmetric plot is displayed in Figure 19.

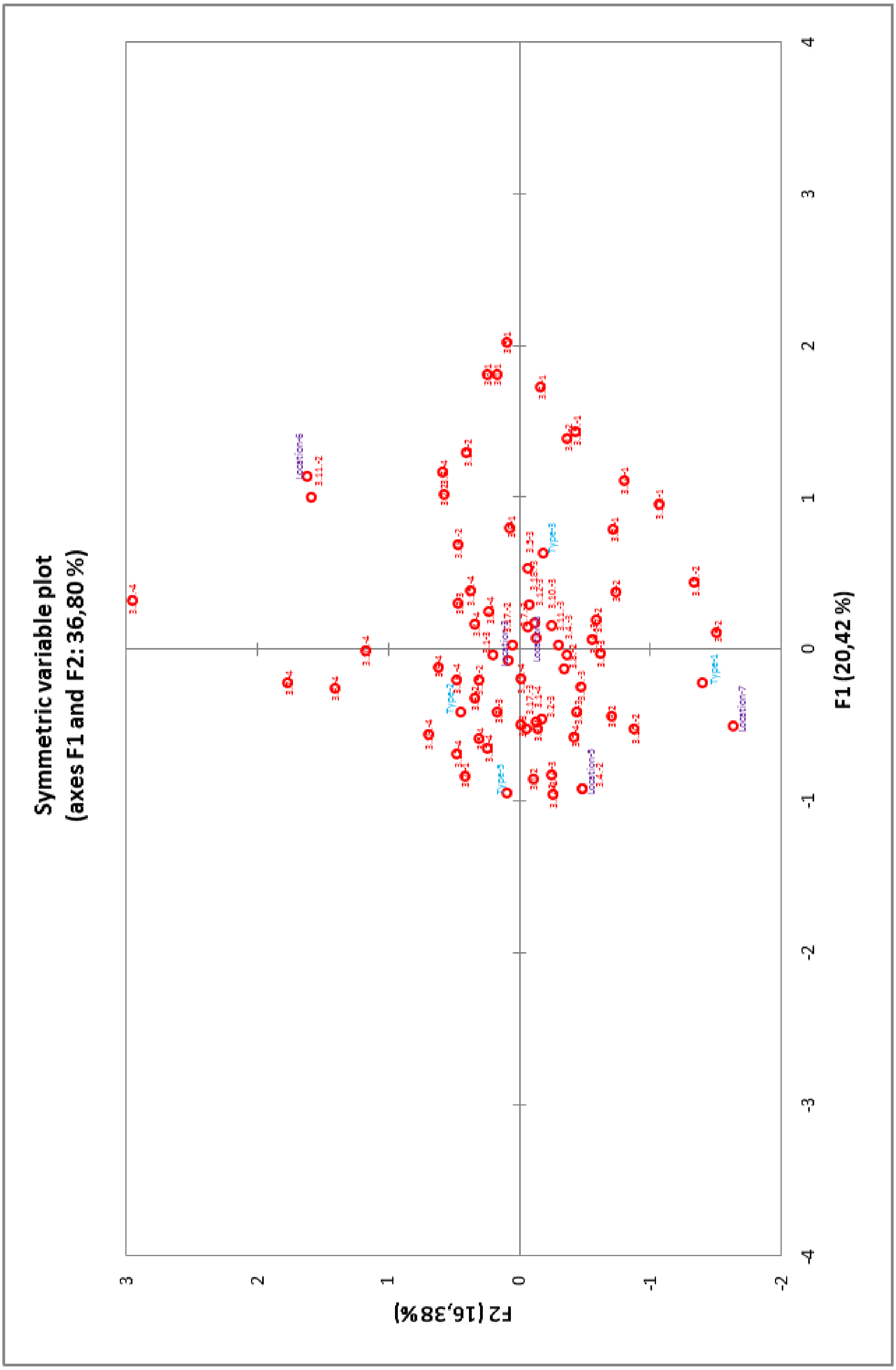

Figure 19: Graphical MCA representation of variables obtained through the thesis survey

For this plot the axes F1 and F2 were selected since they give the best representation of the results in a two-dimensional space. Each point on the graph represents a certain value (For example, 1, 2, 3, 4 in the case of requirements evaluation) of the category of variable (type of the requirement: 3.1, 3.2, etc.) and the coordinates were defined by a single value decomposition of the row score (coordinates of the points in a high-dimensional space). The center of the graph is the origin of the plot or the “average” row.

To identify possible correlations between variables, a visual analysis was conducted and a grouping of points was marked taking into consideration the following observations:

- if two shapes are located in close proximity on the same side of the graph, they have a strong correlation;
- dimension F1 is the most reliable indicator of the association with a calculated inertia; and
- if a particular point is near to the origin, it is an average profile.

Existing analysis methods allow the application of scientific algorithmic approaches to identify groups of variables in MCA graph. This thesis research had in focus a bigger picture of communication between various stakeholders, therefore a visual analysis was implemented as an example and a catalyser for future research.

Correlations identified in the plot are marked in Figure 20 and analysed further in section 9.2.2.

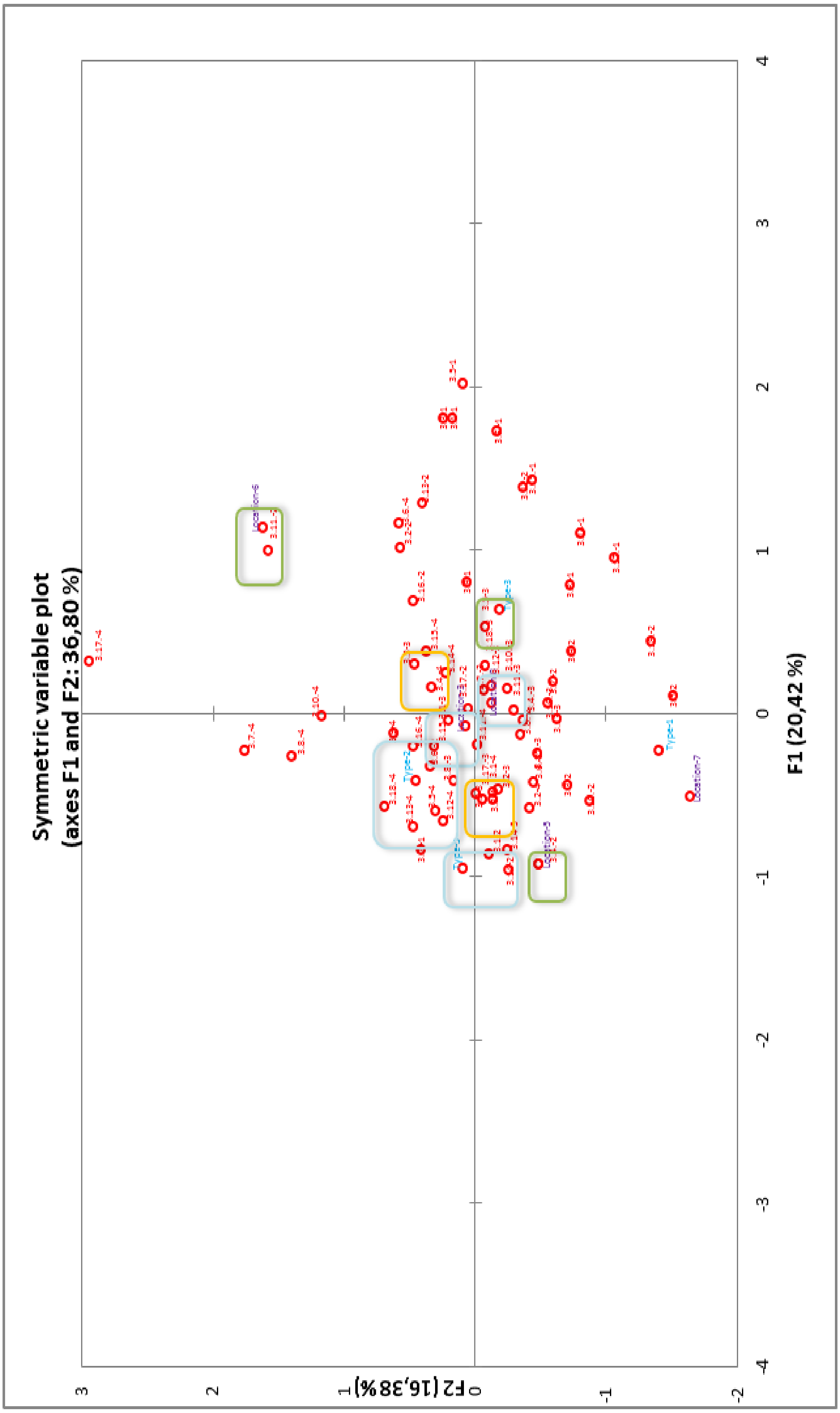

Figure 20: Identification of correlations among variables

9.2.2 Conclusions

The MCA graphical representation shows that the answers do not directly reveal any obvious groups that match customer profiles according to the business type and geographical position, however some grouping is possible.

According to the Figure 20 the variable Location-3(Europe) and Location-8 (Worldwide) are located in proximity of the center - this could be explained by the fact that the majority of responses were received from these two geographical areas and thus they have a strong influence on the average profile. Even though the business type category also the majority of answers in two categories (2- Telecommunication providers and 3- Major companies working in other businesses), only the Business type-2 is located in proximity of the center (this could be explained by the similarity of these customers' requirements), but not business type-3 (this could be explained by the fact that the major companies working in other businesses have a very diverse set of needs concerning Carrier Ethernet).

Dimension F1 is the most reliable indicator of the association with an calculated inertia, along this axis the requirements 3.5 (Bandwidth profile parameters in the provider network (including bursting possibilities)) is located on the further positive end of the axis with no customer profiles located next to it which shows that this criteria has insignificant influence on the average profile and will not be taken into consideration due to its low grade (1).

Along the F2 axis the points are spread further in the bottom part. However, the data is balanced with more variables located closer to the center on the positive part of axis F2. The points located far from the center of the graph demonstrate that this variable is least correlated with the average profile. For example, Location 7 (Asia) is located at about F2 = -1,6 and there are no other variables close to it. This illustrates the fact that there was only one answer submitted from this geographical location and it is not possible to identify any requirement trend matching it. Similarly the variable 3.17-4 (Visibility of the provider: participation in conferences, information in news, awards – Very important) is not supported by other variables and is located remote from the center which means that there are no customer profiles matching this criteria.

It is important to mention that in case of this survey it is important to take into consideration the grading system described in Table 6. The requirements that have grade 4 should be prioritized, the ones with a grade 3 are recommended to be taken into consideration, and the ones with grades 2 and 1 have less importance.

The analysis of Figure 20 identified the following groups of requirements that have a correlation to certain profiles of the companies (the profile of the company could be identified by the information in the category "Type of business" or "Geographical position")

a. Geographical location: Worldwide/several areas (Location-8)

This group is placed in the lower right quadrant of Figure 20 close to the centroid and its requirements are presented in Table 7.

Table 7: Group of requirements for the "Worldwide/several areas" customer profile

Requirements	Requirement evaluation score
3.7. Colocation of Customer equipment offered by provider	3
3.12. Delivery : how easy is it to connect to the provider network	3
3.10. Possibility for a custom tailored solution	3
3.11. Make adjustment to the service quickly	3
3.18. Reputation of the provider: testimonials from other customers	3

In this group all the criteria were evaluated as important and affect various areas of the provider's operations. The requirement for simplicity in the connection between the customer and the provider could include both standardised UNIs and multiple points of presence that would not require additional stretches to have the desired connectivity. The possibility to design a tailored solution, as well as quick changes to the existing solution should affect corporate processes practiced in the provider's organization.

The presence of the requirement concerning colocation could confirm the cloud computing trend and the need of customers to have quick access to servers in various locations or to use Carrier Ethernet as an interconnection for their datacenter infrastructure.

The reputation of the provider is important since it is difficult to evaluate the performance of the providers operating worldwide and the testimonials from other customers could serve as a reference for such evaluation.

b. Geographical location: Europe (Location-3)

This group is placed in the upper half of F2 axis of Figure 20 close to the centroid and the requirements are presented in Table 8.

Table 8: Group of requirements for "Europe" customer profile

Requirements	Requirement evaluation score
3.11. Make adjustment to the service quickly	4
3.1 Availability of different classes depending on network performance guarantees (packet loss, availability, frame delay)	3
3.17. Visibility of the provider: participation in conferences, information in news, awards	2
3.15. Possibility for you to access the monitoring information of the service	2

A group of customers that operate on a European scale evaluate the possibility of making a quick adjustment as very important. This could be based on the business dynamics existing in the Internet industry and scalability of their business. It could also be motivated by the loyalty of customers who prefer to work with a certain provider; however, they need to have their services adapted when their needs change.

The availability of different classes of service is evaluated as important since it allows having multiple services over one network provider.

Two remaining requirements (visibility of the provider and the access to the monitoring information) are taken into consideration by the customer and could be used during the sales process as an additional selling point.

c. Business type: Telecommunication providers (Type-2)

This group is placed in the upper left quadrant of Figure 20 close to the centroid and the requirements are presented in Table 9Table 7.

Table 9: Group of requirements for "Telecommunication providers" customer profile

Requirements	Requirement evaluation score
3.18. Reputation of the provider: testimonials from other customers	4
3.9. Ubiquitous service coverage within your region	4
3.13. Delivery : time required to connect new service	4
3.5. Bandwidth profile parameters in the provider network (including bursting possibilities)	4
3.12. Delivery : how easy is it to connect to the provider network	4
3.8. Services other than Ethernet offered by provider	3
3.6. OAM functions and mechanisms of provider network	2
3.15. Possibility for you to access the monitoring information of the service	2
3.16. The price of the service	4

The group of requirements for Telecommunication providers is large and this might be explained by the fact that telecommunication providers vary and each could have a different focus. For this type of business delivery is very important both for speed and simplicity, as well as the bandwidth profile in the provider's network, the coverage within the region, the price of the service, and the reputation of the provider. Other services offered by the provider play less important roles and OAM functions and monitoring information need to be taken into consideration.

Such choices of requirements might be explained by the fact that telecommunication providers are interested in Carrier Ethernet to extend their network or the services that they provide to their customers. This motivates the need for bandwidth, as well as coverage in a region. The importance of delivery could be explained by the boundary of the delivery of the service to the end customer delivered with the Carrier Ethernet service (this would mean that the end customer has to accept a long delivery time and might face compatibility problems with both providers). The price of the service affects the profit of the Carrier Ethernet customer from the end product sales point of view and therefore plays an important role.

d. Business type: Financial sector, banking

This group is placed along the horizontal axis at F1≈-0,95 in Figure 20. The requirements are presented in Table 10

Table 10: Group of requirements for "Financial sector, banking" customer profile

Requirements	Requirement evaluation score
3.1 Availability of different classes depending on network performance guarantees (packet loss, availability, frame delay)	2
3.14. 24 hours/7days Customer Support available	3
3.14. 24 hours/7days Customer Support available	2

The requirement of support available 24h/7d was placed both as "important" and as "taken into consideration" parameters; this could be motivated by the lack of technical knowledge in the potential banking company and at the same time the need for 24h/7d availability. The availability of different classes of service is a requirement that is taken into consideration by the customer.

e. Individual requirements for customer profiles

There are also unique requirements that have a strong correlation to certain profiles of the companies, hence these could be taken into consideration when making a communication plan for this group of customers. These requirements are shown in Table 11.

Table 11: Individual requirements for customer profiles

Customer profile	Requirements	Requirement evaluation score
Major companies working in other businesses	3.5. Bandwidth profile parameters in the provider network (including bursting possibilities)	3
Africa	3.4. Guarantees on SLA with penalties for not-compliance	2
Russia	3.11. Make adjustment to the service quickly	2

f. Groups of requirements with high grade

Apart from the groups of requirements that are clustered in the proximity to certain customer profiles, the analysis of Figure 20 shows that there are grouped requirements with a high grade (3 or 4) that are not clustered around any particular customer profile. Moreover, these groups are located close to the centroid ($-1 \leq F1 \leq 1$ and $-1 \leq F2 \leq 1$) showing their influence on the average profile. The requirements clustered around $F1 \approx -0,5$ are listed in Table 12.

Table 12: Group 1 of requirements with a high grade

3.9. Ubiquitous service coverage within your region	3
3.17. Visibility of the provider: participation in conferences, information in news, awards	3
3.1 Availability of different classes depending on network performance guarantees (packet loss, availability, frame delay)	4
3.2 Access technology	3
3.3 Support of standards (For example, IEEE, MEF)	3

The requirements clustered in the upper right quadrant ($0 \leq F1 \leq 0,5$ and $0 \leq F2 \leq 0,5$) are listed in Table 13.

Table 13: Group 2 of requirements with high grade

3.4. Guarantees on SLA with penalties for not-compliance	4
3.14. 24 hours/7days Customer Support available	4
3.15 Possibility for you to access the monitoring information of the service	4
3.3 Support of standards (For example, IEEE, MEF)	3

These two groups mean that there was a significant group of customers that evaluated these requirements with the listed grade; however, they do not belong to a certain type of business or to a certain geographical location. The requirements could be used when developing general marketing and promotion materials and these selling points could be used for companies in general.

9.2.3 Comparison with service provider survey

In August 2010, Carrier Ethernet news conducted a survey of its service provider readers to understand the features and capabilities they believed important to differentiate their services from competitors.[50] The survey grouped the service differentiators into technology-oriented and business oriented categories and asked the respondents to identify how important each is to differentiate their particular offerings.

The technical differentiators that generated the most “Extremely important” votes were: high availability and low downtime. Support for a high degree of security was second and multipoint service came third.

The most important business-related feature was the company’s brand followed by: delivering services quickly; making adjustments and changes to service quickly, responsive customer service, and rapid troubleshooting of network problems.

The customer survey for this thesis research included similar options; however, there were fewer respondents (with 24 valid responses compare to 110 in the case of the Carrier Ethernet news report). Additionally, the survey responses had different distributions by geographical area. The result of the survey conducted for the current research showed a wider spread of priorities. High availability of service was taken as a default assumption within my survey. This requirement was highly valued and was placed close to the average profile. Both surveys identified the need to have multiple classes of services and this goes along with the Carrier Ethernet 2.0 strategy.

The features mentioned as “business-related” found similar high response rates in both surveys: quick delivery of the service and 24/7 customer service, as well as the possibility of quick changes in the service.

To summarise, the results of both surveys showed similar results; however, the customer survey conducted within this thesis research allowed us to focus the analysis on various groups of customers and thus to obtain individual preferences. A combination of this approach with the coverage of the Carrier Ethernet news survey could give more in-depth results in future research.

9.3 Communication with other stakeholders

The customer of Carrier Ethernet services is the origin of demand-driven Carrier Ethernet offers. Customers set requirements for the technology depending on their business needs and communicates these requirements to service providers and standardisation bodies. In addition, Standartisation bodies receive Customer requirements from Network providers.

These requirements are responded to with service offers by one or more providers and fins support in standards. Figure 21 illustrates the customer-focused communicated among stakeholders.

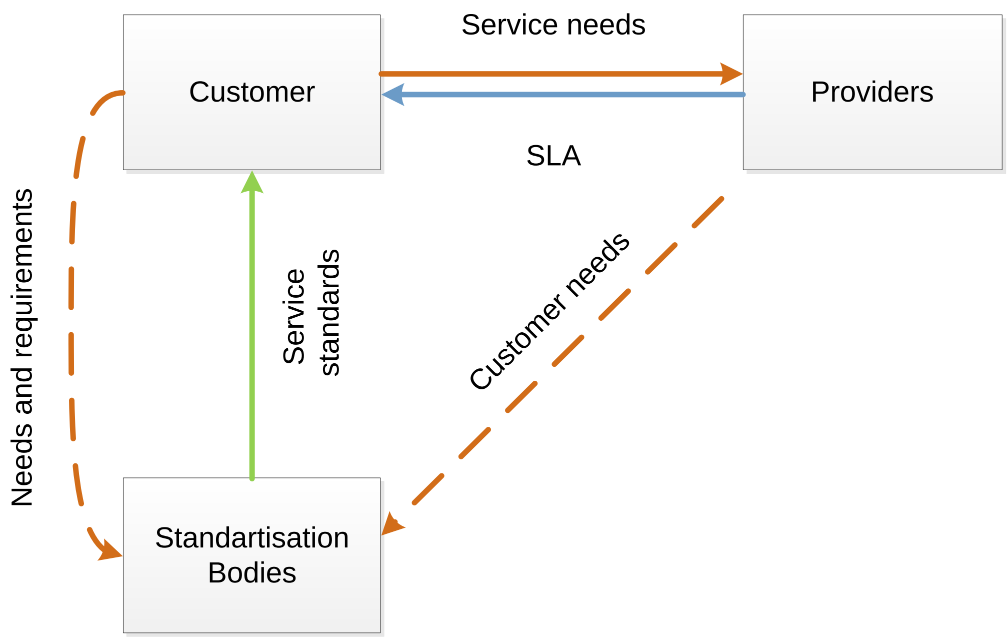

Figure 21: Communication of customers with other Carrier Ethernet stakeholders

10 Summary of recommendations and Conclusions

This chapter summarizes my recommendations based upon the analysis in previous chapter, and then some conclusions are drawn. Finally some required reflections concerning social, economic, environmental, and ethical aspects of this thesis are given.

10.1 Recommendations and analysis

The MCA analysis as well as the investigation conducted within the framework of this thesis research provides some recommendations for network providers that could be used to improve the performance and attractiveness of their Carrier Ethernet services.

First of all, it is recommended that the network provider create a profile adapted service portfolio based on the needs of companies with similar businesses (section 9.2.2 describes possible service offers). This would help the provider to have a more individually tailored approach to the potential customer and to show their understanding of the customer's needs, while at the same time give each customer the possibility to have a reference for their service request. This should enable the customer to avoid the problems associated with having to make too many choices.

Secondly, it is important for service providers to pay attention to the delivery and change order stage in their provider operations. Carrier Ethernet is a very dynamic domain of telecommunications and timely and flexible delivery of services should include simplicity in establishing a connection, while changing the parameters of this connection later. A practical implementation should facilitate close monitoring of the delivery process, leading to identification and improvements in time-consuming actions. Such improvements could include re-definition of responsibilities for changes in service agreements with all the relevant service providers and vendors.

Another recommendation that concerns not only telecommunication providers, but also their partners and other stakeholders is the importance of interoperability and scalability. The successful implementation of this recommendation would lead to trustworthy partnerships for the providers and higher availability of service for their customer. This cooperation should be supported by agreements with a clear SLA (that should support the SLA from the provider towards the customer) and the existence of well-defined and functional troubleshooting process. MEF standards with reference to Carrier Ethernet 2.0 provide technical details regarding possible implementations.

Furthermore, interoperability and scalability and the need of a clear SLA leads to the problem of the access to SLA information of different providers. At the moment only few providers make SLA publicly available and this leads to longer sales lead times as well as to the difficulties to compare network providers between each other. In this situation standardisation bodies could take initiative and how possibly the SLA information could become more available without interference to the internal information that is not supposed to be disclosed.

An advantage of cooperating with other providers is to be able to identify and satisfy customers' needs. For global providers this cooperation could help to reach local customers with global needs (and thus to identify services that would satisfy these needs). This is expected to be important since for the customer it is more convenient to approach a locally known-provider than to approach an unknown provider. For local providers this cooperation extends the reachability of their network and makes the solution more attractive for their potential customer.

A quality that supports this cooperation is the ability to be “Glocal”, i.e., local action with a global perspective. This quality could be expresses both in the approach to the customer and in the processes and routines that a company practices. In practice this could be done with an eye toward multi-cultural insights, combing international teams with local knowledge, as well as close communication with the customer.

Another quality that could improve the way large telecommunication providers work is the implementation of entrepreneurship practices (or encouragement of intrapreneurship). This would allow more dynamic development, leading the providers to be more responsive, innovative, and adaptive to market changes. These qualities could also be enhanced by standardising bodies that are often accused to be inert and to have slow response to market needs.

To conclude, all the qualities listed in this chapter lead to big changes in the processes and routines within the stakeholders and furthermore they challenge the mentality and general approach to the business. They might be difficult to be implemented all at the same time; however they will be rewarding on the long run for each stakeholder and for the technology in general.

10.2 Carrier Ethernet Eco-system

Our analysis of the requirements of international wholesale telecommunications for Carrier Ethernet services started by dividing the telecommunications into four stakeholders: customers, standardisation bodies, vendors, and providers.

The result of my research showed the variety of requirements that exist for Carrier Ethernet technology; however, it also demonstrated that these four stakeholders are tightly connected to each other in a Carrier Ethernet eco-system. Due to this tight interconnection there is a need for them to cooperate in order to ensure the functionality and success of Carrier Ethernet.

A customer or a company buying Carrier Ethernet presents their needs and requirements to a potential provider. At the same time these requirements motivate the activities of standardisation bodies and vendors.

A network provider provides service to the customer as defined in a SLA. This SLA is ensured by the requirements that the network provider places on the vendors.

In their turn vendors ensure the technology functions as per their product descriptions. In cooperation with network providers the vendors contribute to research in the domain.

Standardisation bodies provide standards that affect the service that a customer will be able to use, the network that each provider implements and maintains, and the equipment produced by vendors.

All together the eco-system built on the cooperation of these four stakeholders ensures the functionality of Carrier Ethernet and that this technology fulfils the requirements of its announced qualities.

Figure 22 shows the essence of the cooperation between the four stakeholders.

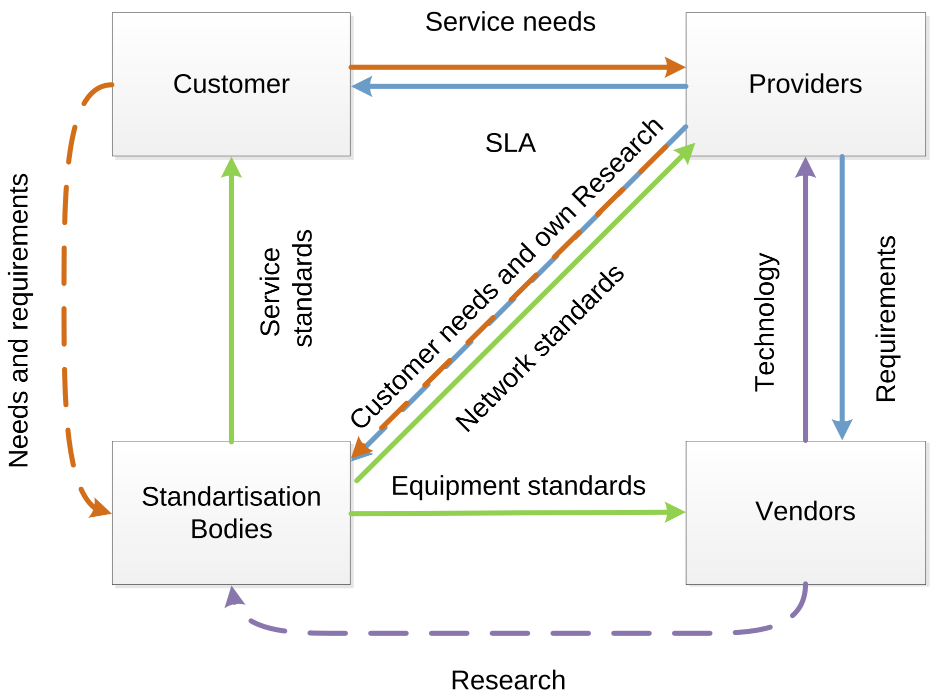

Figure 22: Interconnection of stakeholders of Carrier Ethernet

Services provided with Carrier Ethernet technology not only fulfill the needs of various groups of customers, but these services have also changed the approach to provisioning by telecommunication companies and how these companies ensure their network's performance.

The increase in the usage of mobile devices and the growth of trans-border businesses motivated the shift from TDM link to Carrier Ethernet reducing the costs for providers, while giving the customer the possibility to get more diverse and personalized services. This has increased the demand for speed, flexibility, cooperation, and innovation - that often takes time to develop in large companies. Improvements in these qualities bring increased satisfaction to customers, more efficient operations, and suggest a direction to achieve great success in the future.

10.3 Required reflections

This Master thesis addressed the problem of the definition of recommendations from the wholesale international telecommunication to the Carrier Ethernet. Conducted research identified four Carrier Ethernet stakeholders (standardising bodies, network providers, customers and vendors) and presented them as a united Carrier Ethernet eco-system that has strong interconnections through their requirements to the technology as well as through the provided services and agreements. The recommendations and conclusions of the research aim to bring closer attention of the stakeholders to each other's needs as well as to the means to meet these needs.

The cooperation and communication between Carrier Ethernet stakeholders play an important role for the future of the technology. Closer attention to Customer needs lead to the development of cost-effective solutions that would satisfy expectations and make all the stakeholders benefit from them.

Carrier Ethernet technology and the eco-system of its stakeholders goes along with the on-going innovation in telecommunication industry that used to be domain dominated by large governmental companies. The development of Internet and the growth of new players on the market forced telecommunication companies to be more opened, cost-effective, and modern and, in addition, respond to the customer needs. The globalisation of the services opens new markets for Network Providers, but it also requires adaptation of working methods and approaches within the company.

The idea of cooperation between competitors working in the same market (it could be vendors, network providers or even standardisation bodies) bring new focus and new possibilities for the whole industry.

For any domain it is challenging to make all the changes at the same time and this thesis outlines several directions that could be prioritised by Carrier Ethernet stakeholders and that could motivate further changes and improvements in the Telecommunication industry in general.

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Appendix 1. Customer Survey (English version)

The customer survey was done in 3 languages to facilitate the understanding and attract respondents. The online versions of the survey could be found:

English https://docs.google.com/spreadsheet/viewform?formkey=dDVlampkb2k2cmVDaGlOMlFCUUxnMkE6MQ#gid=0

Spanish https://docs.google.com/spreadsheet/viewform?formkey=dGluRnA3c1k2WmZYMzYtTVNyRTlDWVE6MQ#gid=0

Russian https://docs.google.com/spreadsheet/viewform?formkey=dDJIc2NfZnYwOEhxWWFSbVdjY25Odmc6MQ#gid=0

The list of questions, identical in all the versions, is presented below in English:

Table 14 List of survey questions

1.1	What type of business is your company in? (text field)
1.2	Location of your company (text field)
1.3	What is your position in the company? (text field)
2	Is your company currently using Carrier Ethernet services? (text field)
3 Please evaluate the importance of the following criteria when you choose your Carrier Ethernet Provider (questions 3.1-3.18 require scale evaluation) Scale: 1 - Not important (Do not take into consideration), 2 - Take into consideration when making the choice but is not important, 3 - Important, 4 - Extremely important	
3.1	Availability of different classes depending on network performance guarantees (packet loss, availability, frame delay)
3.2	Access technology
3.3	Support of standards (For example, IEEE, MEF)
3.4	Guarantees on SLA with penalties for not-compliance
3.5	Bandwidth profile parameters in the provider network (including bursting possibilities)
3.6	OAM functions and mechanisms of provider network
3.7	Collocation of Customer equipment offered by provider
3.8	Services other than Ethernet offered by provider (please specify in "Comments" field)
3.9	Ubiquitous service coverage within your region
3.10	Possibility for a custom tailored solution
3.11	Make adjustment to the service quickly
3.12	Delivery: how easy is it to connect to the provider network
3.13	Delivery: time required to connect new service
3.14	24 hours/7days Customer Support available
3.15	Possibility for you to access the monitoring information of the service
3.16	The price of the service
3.17	Visibility of the provider: participation in conferences, information in news, awards
3.18	Reputation of the provider: testimonials from other customers
Comments (text field)	

Appendix 2.Summary statistics of the survey responses

The statistics of responses to the survey questions is provided in Table 15.

Table 15 Summary statistics of the responses

Variable	**Categories**	**Frequencies**	**%**
Type	1 (Education)	2	8,333
	2 (Telecommunication providers)	10	41,667
	3 (Major companies working in other businesses)	10	41,667
	5 (Financial sector)	2	8,333
Location	3 (Europe)	9	37,500
	5 (Africa)	2	8,333
	6 (Russia)	2	8,333
	7 (Asia)	1	4,167
	8 (Worldwide)	10	41,667
3.1	1	4	16,667
	2	1	4,167
	3	6	25,000
	4	13	54,167
3.2	2	8	33,333
	3	9	37,500
	4	7	29,167
3.3	1	2	8,333
	2	5	20,833
	3	9	37,500
	4	8	33,333
3.4.	2	2	8,333

	3	9	37,500
	4	13	54,167
3.5	1	1	4,167
	2	2	8,333
	3	9	37,500
	4	12	50,000
3.6.	1	2	8,333
	2	9	37,500
	3	10	41,667
	4	3	12,500
3.7.	1	3	12,500
	2	10	41,667
	3	8	33,333
	4	3	12,500
3.8.	1	6	25,000
	2	7	29,167
	3	7	29,167
	4	4	16,667
3.9	1	3	12,500
	2	6	25,000
	3	8	33,333
	4	7	29,167
3.10.	2	4	16,667
	3	14	58,333
	4	6	25,000
3.11.	2	2	8,333

	3	10	41,667
	4	12	50,000
3.12	2	4	16,667
	3	9	37,500
	4	11	45,833
3.13	2	5	20,833
	3	10	41,667
	4	9	37,500
3.14	1	2	8,333
	2	2	8,333
	3	5	20,833
	4	15	62,500
3.15.	1	1	4,167
	2	8	33,333
	3	9	37,500
	4	6	25,000
3.16.	2	2	8,333
	3	11	45,833
	4	11	45,833
3.17.	1	3	12,500
	2	13	54,167
	3	7	29,167
	4	1	4,167
3.18.	2	4	16,667
	3	11	45,833
	4	9	37,500

TRITA-ICT-EX-2012:124