The Next Generation Network: Issues and Trends

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Statement of Originality

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person or material which has been accepted for the qualification of any other degree or diploma of a university or other institute of higher learning."

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Abstract

The development and deployment of the Next Generation Network (NGN) is important for public network carriers as for them it could be an innovative and effective way to differentiate by offering a number of various value-added services at a lower cost, and consequently survive and even prosper in a highly competitive market.

It is predicted that the convergence of services, applications and networks will shape the future of the telecommunication industry; it may also force network carriers to update their existing network infrastructure towards an NGN platform, in order to meet the trend and satisfy the expected increase in demand.

Based on this premise and using results reported in the literatures, the dissertation explores NGN development from an exploratory perspective by studying the envisioned NGN architecture, and identifying the core technologies required for the NGN in the transport stratum; some NGN deployment related issues are also discussed.

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List of Abbreviations

ADSL: Asymmetric Digital Subscriber Line

ANI: Application to Network Interface

ASON: Automatically-Switched Optical Network

ATM: Asynchronous Transfer Mode

CPE: Customer Premises Equipment

DSL: Digital Subscriber Line

DWDM: Dense Wavelength Division Multiplexing

G-MPLS: Generalized - Multiprotocol Label Switch

IANA: the Internet Assigned Numbers Authority

IETF: Internet Engineering Task Force

IP: Internet Protocol

IPv4: Internet Protocol version 4

IPv6: Internet Protocol version 6

ISDN: Integrated Service Digital Network

ISP: Internet Service Provider

ITU-T: International Telecommunications Union – Telecommunication

KAREN: the Kiwi Advanced Research and Education Network

LLU: Local Loop Unbundling

MPLS: Multiprotocol Label Switch

NAPT: Network Address and Protocol Translation

NAT: Network Address Translator

NE: Network Equipment

NGN: Next Generation Network

NNI: Network to Network Interface

OSI: Open Systems Interconnection

OTN: Optical Transport Network

PSTN: Public Switched Telephone Network

PT: Protocol Translator

OADM: Optical Add-Drop Multiplexer

QoS: Quality of Service

ROADM: Reconfigurable Optical Add-Drop Multiplexer

SDH: Synchronous Digital Hierarchy

SONET: Synchronous Optical Network

TCP: Transport Control Protocol

TDM: Time Division Multiplex

UNI: User to Network Interface

VoIP: Voice over IP

WB: Wavelength Block

WDM: Wavelength Division Multiplexing

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Chapter 1: Introduction

Intense competition in the telecommunication market has emerged over the last decades and is expected to grow continuously and rapidly. Therefore it is essential for those network companies involved in the telecommunication market (i.e. network carriers or service providers) to gain advantage of their core competencies by adopting appropriate strategies or positioning themselves properly in the market. In particular network companies are forced to search for new solutions to reduce their operational costs, in order to eliminate the unnecessary expenditure on the existing infrastructure which often consists of multiple parallel and even overlapping networks, and to provide differentiated services with superior quality (Crimi, 2005).

The expected “network convergence” may offer a solution to the problem, as it will involve providing integrated services on a common network infrastructure. Network carriers have attempted to address network convergence by increasing the number of services and/or applications on existing networks. Examples include network carriers and service providers making a great effort in integrating residential broadband services, TV video services and voice services into the existing copper phone line network by adopting advanced network technology (IP phone and IP TV). Some network carriers are deploying a new type of transport networks - ASON/OTN in a small scale, to test its feasibility of replacing a variety of existing transport networks such as SDH/SONET, and ATM.

At the same time, the migration from traditional voice traffic and ATM data traffic to IP traffic in our networks has already become a prevailing trend in telecommunication network development: All-IP networks (Stiller, 2000).

Through these and similar efforts, over the last few years the concept of a new, integrated broadband network has been developed and labelled ‘next generation network’ (NGN). Conceptually, the NGN defines a new network architecture in which network convergence can be achieved through a stepwise upgrade from existing networks seamlessly from the edge to the core (as retaining compatibility with legacy networks is important to retain the value of existing investment). Through NGN traditional telephone networks (PSTN/ISDN) and computer networks (the Internet) will converge into a unified IP-based packet-switching network able to provide a variety of services/applications with improved manageability and of higher quality, and with lower operation and management costs.

According to past experiences, telecommunication service and application end users are typically not sensitive to the changes of underlying network technologies, especially to the background transport networks. However, they are interested in and perceptive about what services and products the new technologies can bring to them (i.e. in services provided via the last-mile connection technology). The potential improvement brought by network convergence to users in terms of service quality and cost reduction is not that obvious; end users can have the same services and at a similar quality level within the existing network infrastructure. Existing network systems have come a long way in meeting user demands and reached a significant degree (Crimi, 2005); therefore from a user perspective, network convergence is not urgently needed at present, and it may be of interest to carriers and providers only.

The NGN represents a major research direction in telecommunications related research, and has drawn a great deal of industry-wide attention since it was first introduced. NGN research is also aligned with the well publicized research and development of IPv6 as part of the NGN infrastructure (Iekel-Johnson et al., 2008).

However, most of those works seem to show strong interests in some specific new technologies and services, not many of them investigated and addressed the network conversion from existing networks toward the NGN in a systematic manner, in particular in New Zealand. A quick scan of the literatures also shows that the telecommunications industry has not achieved an industry-wide agreement on specific technologies required to realize the NGN, only a set of standards/recommendations for an envisioned NGN framework (including desired functions, requirements and characteristics of an NGN network) were released by ITU-T. Therefore, more research about this network evaluation toward NGN to provide sophisticated guidelines is still required and valuable.

Meanwhile, some NGN compliant technologies have been tested and deployed in some countries; some potentially NGN-ready carrier-class telecommunication equipments for backbone/core transport network have emerged in the market. However, most of these developments only partially meet the NGN requirements. In New Zealand, Telecom confirmed their plans for NGN deployment and stated that according to their schedule the traditional PSTN service would be replaced by an NGN in 2012 (Pullar, 2007). However, the network convergence towards an NGN is expected to be a long term objective, and the time length of this transition process may vary as economic factors rather than technical factors will be critical. Network carriers will have to consider the significant investments made in the current network infrastructure as compared to the need for technology progress, and possibly sacrifice system performance to retain compatibility with legacy systems.

This dissertation studies NGN architecture and the underlying technologies (with a scope covering wired networks only). It focuses on the network transport stratum by explaining "why this technology is required?" from a network carrier perspective in order to compare selected technologies and identify the prevailing development directions for the telecommunication industry.

The objectives of this research project are:

- Identify the market incentives for NGN development;
- Examine fundamental technologies required to realize the expected NGN functions especially in transport stratum;
- Identify issues related to NGN implementation.

This study is interpretivist and the necessary data are collected from academic papers (13) and other relevant sources (39). These non-academic sources used in the research mainly include standards from the industry associations, such as International Telecommunications Union (ITU), and white papers from the industry leading companies, such as Cisco. These resources are valuable as they represent the status quo of the telecommunication market. This dissertation is divided into the following chapters:

- Chapter 1 - An introduction to describe the topic area, research aims, objectives and scopes, importance and reasons for this research work;
- Chapter 2 – A brief description of the research methodology used in the research project, including the research paradigm and research questions, and data collection methods;
- Chapter 3 - A concise overview of NGN including its functional infrastructure, some essential technologies and market drivers;

- Chapter 4 –A study of the network protocol (IP) to be used in NGN;
- Chapter 5 –A study of the backbone/core transport network technology evolution towards NGN;
- Chapter 6 – A discussion of issues related to NGN implementation;
- Chapter 7 – A conclusion summarizing the findings of the research.

The work contributes by presenting a comprehensive summary of NGN requirements and contrasting them to the issues arising from NGN implementation in order to identify future development trends.

Chapter 2: Methodology

This study is based on literature review and all necessary data are gathered from literature sources, no primary data collection is involved.

In general, two research paradigms in terms of philosophy held by researchers according to their world views are used to direct research: interpretivism and positivism. Interpretivist researchers hold a subjectivism stance believing there are multiple realities (truths) in the world and these truths can be interpreted differently by different researchers in different context and time (context-dependent and time-dependent). In contrast, positivist researchers hold an objectivism stance believing there is only truth (single reality) in the world, and the truth can be generated and repeated in a scientific laboratory where all conditions are under control, namely, the truth is context-independent and time-independent (Ponterotto, 2005).

Thus, interpretive descriptions inclining to answers "why' and "how" are found in interpretivist research which differs from the numeric findings in positivist research (Ponterotto, 2005). Furthermore, as described in the introduction section, this dissertation is a literature review and sets itself a goal of systematically studying NGN and related issues. All information required is based on others' research works and no primary data collection is involved, and interpretive descriptions are more suitable to elaborate research findings in this case.

In order to gain the most up-to-date information, the data collection focused on a broad range of industry standards, journals and academic proceedings accessed through IETF (Internet Engineering Task Force Internet) and ITU-T (International Telecommunications Union – Telecommunication Sector) official websites, Google Scholar and some electronic databases provided by AUT (Auckland University of Technology), which are ACM and IEEE Xplore mainly. Apart from the above, books in libraries were used for background reading as providing credible information on earlier developments in a concise format.

In detail, as this dissertation mainly focuses on the technical aspect from a network carriers' perspective, and the e-resources are the main resources for this research, in order to catch the valuable information from a limited number of related papers, some key words (such as NGN architecture, framework, technology, services, implementation, and deployment) were used in Google Scholar to search for information initially.

The richness of those papers was captured and labelled into several groups: concept, architectures of existing network or the NGN, deployment issues. In addition, the industry standards required can be acquired from IETF and ITU-T official websites.

Based on an initial literature review, and in line with the research objectives, the research questions investigated in this dissertation can be formulated as follows:

Question 1: What is the importance of NGN?

This research question aims to introduce the NGN concept before going further, thus this question can be broken into following sub-questions:

- What is the expected NGN architecture?
- What are the NGN requirements?
- Why is NGN needed?

These sub-questions will be addressed in order in section 3.1, 3.2 and 3.3. Through addressing these sub-questions, a concise description of the NGN, including NGN architecture, requirements and market drivers, is presented.

Question 2: Which technologies are the most suitable ones for NGN?

This research question aims to explore the underlying technologies required to accomplish the NGN promised functions, and this question can be broken into following sub-questions:

- What is the primary network protocol and,
- Why is it needed?
- What technologies are able to meet the NGN requirements in the transport stratum and,
- Why are they needed?

Chapter 4 describes the primary network protocol in the NGN architecture and reasons for selection in order to address the first two sub-questions: “What is the primary network protocol?” and “Why is it needed?” The other two questions, “What technologies are able to meet the NGN requirements in the transport stratum?” and “Why are they needed?” are answered in Chapter 5, where the NGN transport technologies are investigated in detail.

Question 3: What are the key factors affecting NGN deployment?

This research question is set to investigate the potential issues related to NGN deployment. Research findings related to this question are presented in Chapter 6.

The entire dissertation is constructed by addressing these research questions formulated earlier step-by-step in order to provide explicit research findings in an organized way.

Chapter 3: An Overview of the NGN Concept

The endless pursuit of network capacity and efficiency drives the telecommunication industry to search for substitutions for the existing network infrastructure to fulfil increased demand with lowered cost and improved safety. Considering the realities of the communication industry, such as the explosion of IP traffic, and the convergence of networks, in 2004 the global standard organization in telecommunication area (ITU-T) proposed an innovative concept for future networks: NGN (the Next Generation Network).

This chapter is to provide the basic information about NGN by addressing the first research question "What is the importance of NGN?" and its sub-questions. With this purpose, a general description of NGN concept and its functional architecture is presented, followed by the concise description of some core technologies required to realize the envisioned NGN infrastructure. The market drivers for NGN deployment are outlined as well in this chapter.

3.1 Definitions and Architectures

The NGN is a broad concept covering a variety of network types from wired to wireless, and from telecommunication to computer. It was designed to use a common network protocol to carry all data/service/application which may be carried by different data/service/application-specified networks currently over a common and open network infrastructure. ITU-T defines the NGN as follows:

> "*The NGN is a packet-based network able to provide Telecommunication Services to users and able to make use of multiple broadband, QoS-enabled transport technologies and in which service-related functions are independent of the underlying transport-related technologies. It enables unfettered access for users to networks and to competing service providers and services of their choice. It supports generalised mobility which will allow consistent and ubiquitous provision of services to users*." (ITU-T, 2004)

In detail, according to the ITU-T NGN standards released in 2004, within an NGN the service provisioning should be separated from the data transport, and the service-related functions should be able to offer the capabilities to create, deploy, control and manage the promised services through an independent control plane. Those NGN promised services include a variety of types such as data services and real-time services, and each type of service may consist of a variety of media types, such as image, voice and video. Intellectualized bandwidth allocation is emphasized in an NGN to assign various but appropriate network bandwidths according to demands to different NGN services and/or customers in an economic manner.

Furthermore, in order to deliver those services to end-users effectively and efficiently, a variety of broadband technologies (last mile technologies) are supported by an NGN as well. An NGN also offers possibilities for customers to customize their services in a flexible way. In addition to the above, the NGN is also capable of generalizing mobility and converging services between mobile and stationary devices, retain compatibility with legacy systems, and allow users to select service providers unrestrictedly.

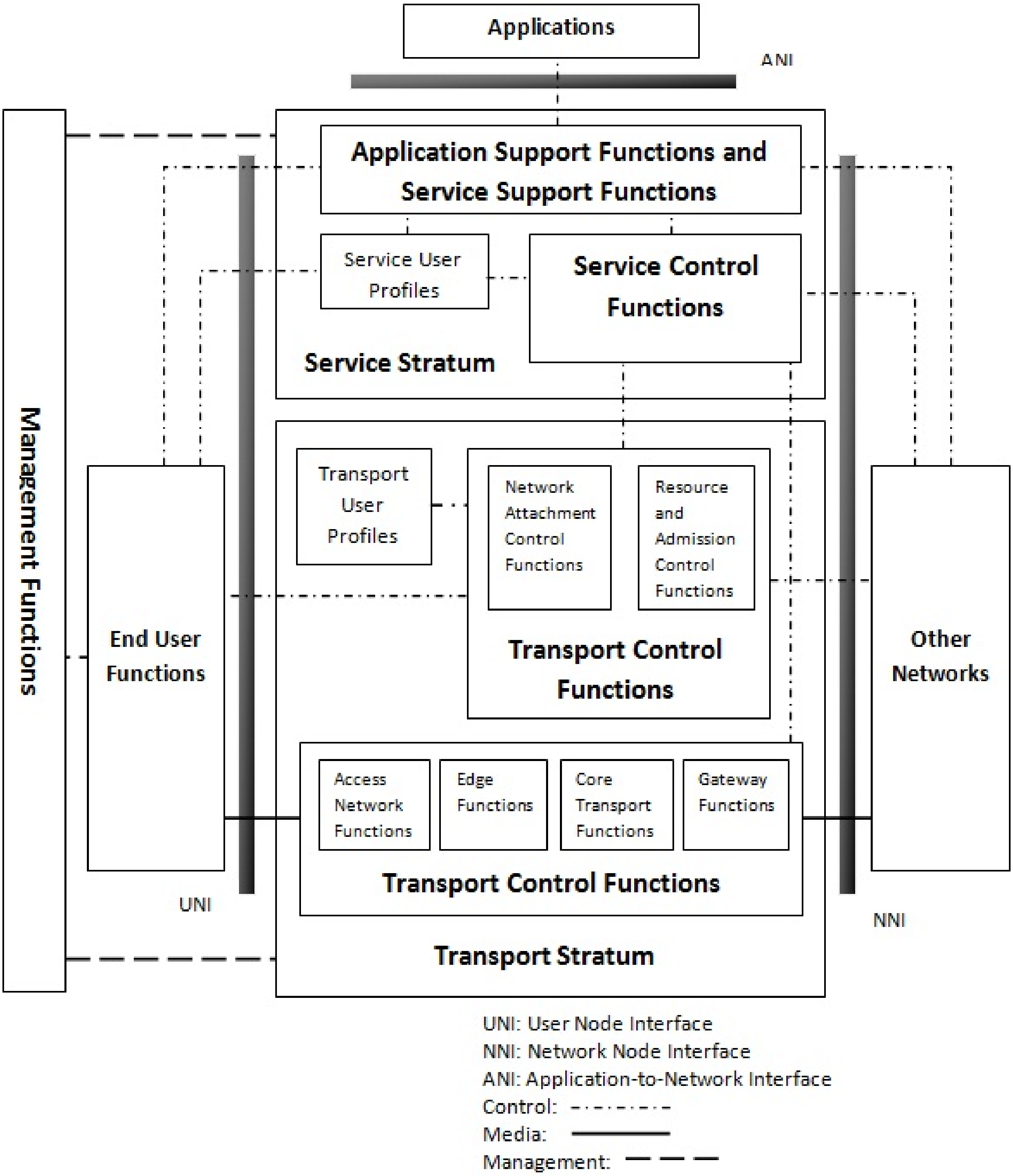

Figure 1: ITU-T NGN Functional Architecture (Source: ITU-T, 2004)

Figure 1 shows an overall functional architecture of an NGN from ITU-T, all functions of an NGN are grouped into two stratums: Service Stratum and Transport Stratum. It is noted that this envisioned ITU-T NGN architecture is a directive network framework as mentioned before, and more importantly, the appropriate technologies are required to satisfy the requirements of this architecture.

The industry leading company Cisco proposed a developed NGN architecture (Figure 2) as a response to ITU-T's initiative, its IP NGN architecture is more practical, and filled with the foundational technologies they identified. It is slightly different from the ITU-T concept in the service stratum, where Cisco dictates two layers (the service and application layer), corresponding to the service function block and application function block in ITU-T's service stratum. Figure 2 also explains the relationships between the two NGN models.

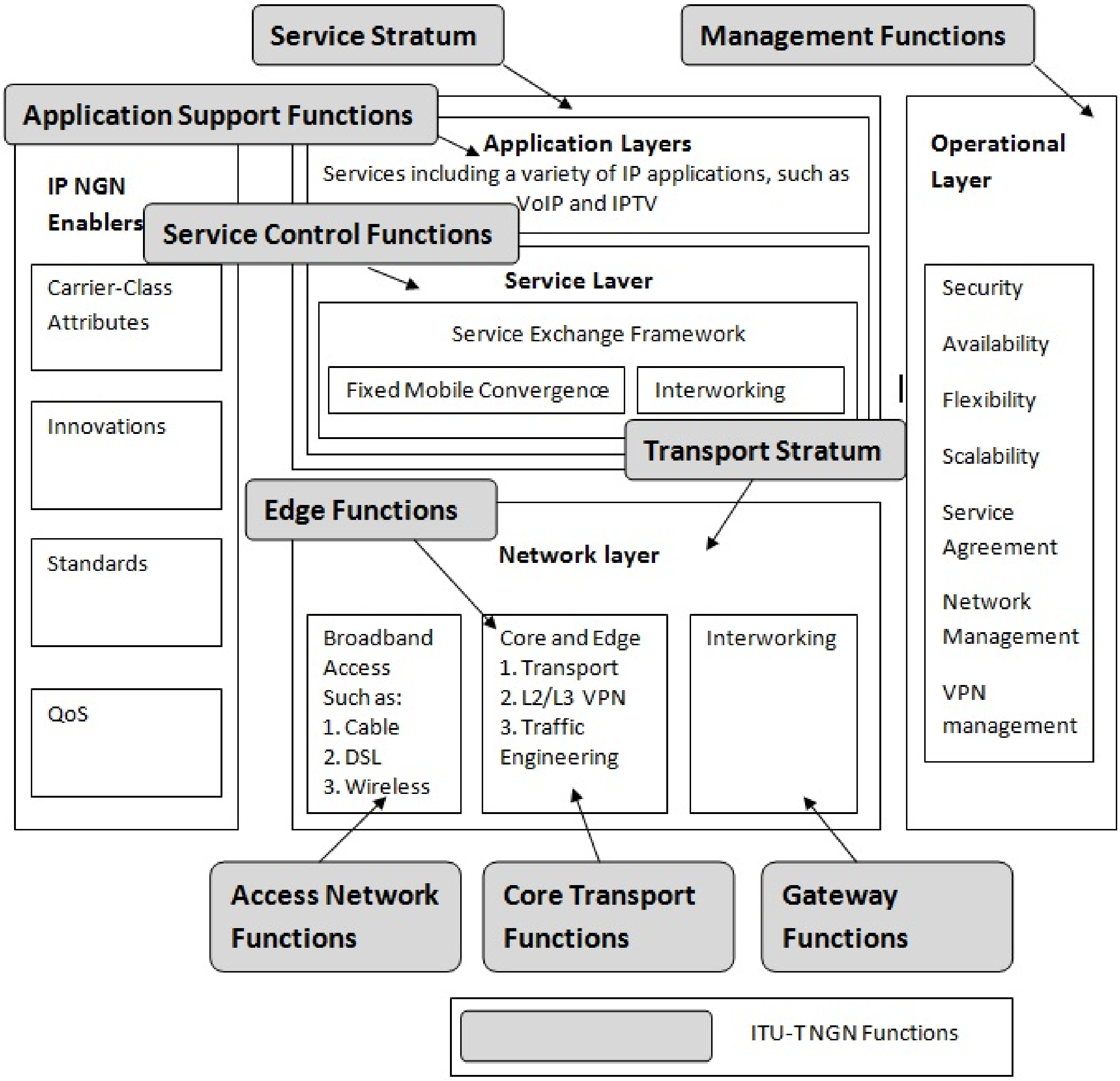

Figure 2: Cisco IP NGN Architecture (Source: Cisco, 2008)

In addition, similar to other layered network architectures, such as OSI seven-layer model and TCP/IP five-layer model, the NGN dictates a simplified two-layer hierarchical model consisting of a transport layer and a service layer as shown in

Figure 3. The reduced number of network layers represents the industry's efforts in reducing network overhead and system complexity and it is also one of the most significant updates by the NGN.

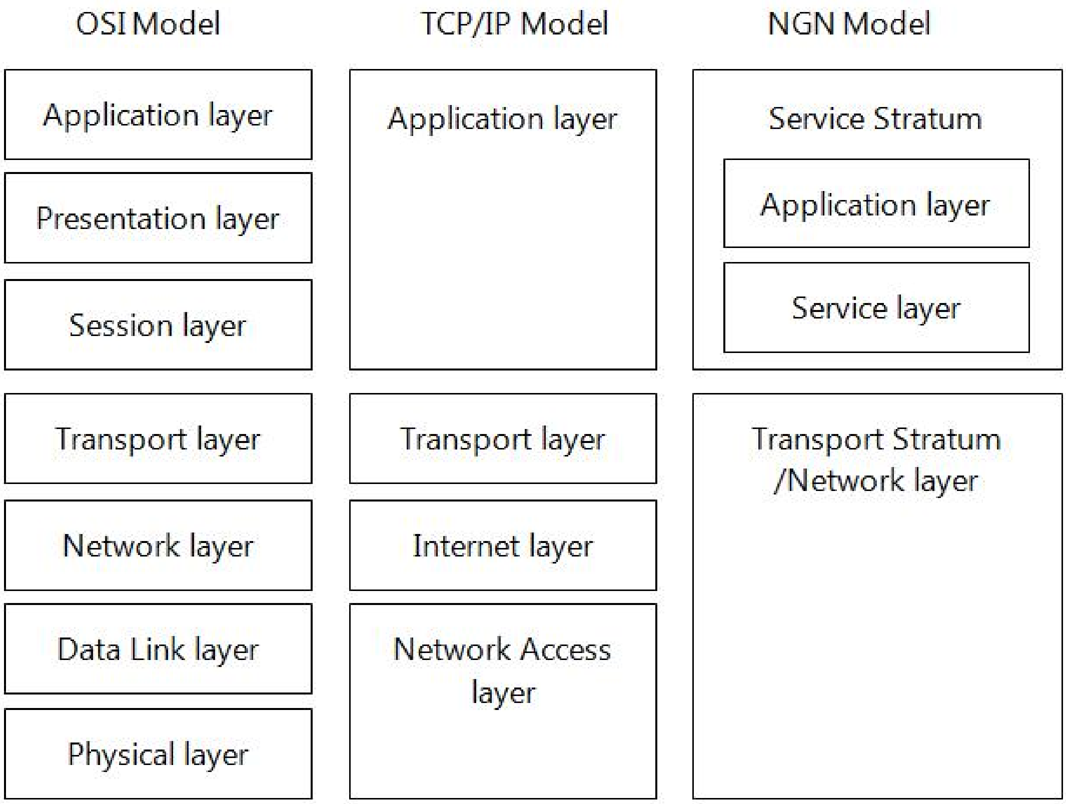

Figure 3: Comparison of OSI, TCP/IP and NGN strata (Source: Author)

As shown in Figure 1, in an NGN environment, intercommunications between two sub-networks are accomplished by an interface called NNI (Network Node Interface). Similarly, the connection with customer networks or terminals is accomplished by another interface called UNI (User Node Interface). It is noted that according to the ITU-T NGN standards these interfaces are open and standardized. An open and standardized interface is "*important to accommodate a wide variety of off-the-shelf customer equipment while maintaining business boundaries and demarcation points for the NGN environment*" (ITU-T, 2004). Therefore UNI and NNI are emphasized in ITU-T standards as general NGN reference points that can be "*mapped to specific physical interfaces depending on the particular physical implementations*" (ITU-T, 2004). Some functional blocks, such as Media Handling Functions, Gateway Functions, and Service Control functions, may be distributed over different NGN sub-networks or domains.

In the service stratum, Application Support Functions and Service Support Functions are used to achieve service/application provisioning under the control from related Service Control Functions. Similar to NNI/UNI, ANI (Application-to-Network Interface) plays an important role in service provisioning; it is used as a referent point in an NGN to deliver enhanced services/applications to NGN users in the service stratum. In addition, in the service stratum, Service User Profile is used to store users' profile information co-operating with Transport User Profile in the transport stratum (ITU-T, 2004).

The transport stratum contains transfer and related control functions for an NGN, there are two main function groups defined in ITU-T NGN standards (ITU-T, 2004):

Transport Function Group: the transport function group provides connectivity for all NEs, which are located geographically but physically connected. The transfer of data including the control and management information for data transfer is accomplished by this function block. This group includes: Access Network Functions, Edge Functions, Core Transport Functions and Gateway Functions, which are not illustrated in Figure 1.

Transport Control Function Group: this function group is required for controlling and managing data transport within the NGN infrastructure. Functions in this group include: Network Attachment Control functions which are required for registration and initialization of end user services in access network, and Resource and Admission Control functions which are required for QoS, Network Address and Protocol Translation (NAPT) and firewall traversal control support.

As the focus of this dissertation is placed on the carrier-class backbone/core transport networks, some core technologies used in the transport stratum providing connectivity for all network components within an NGN environment will be described in more detail in Chapter 5.

It is noted that the NGN standards released by ITU-T at present just define an overall framework with its mandatory requirements, but no mandatory network technologies are specified in those standards or recommendations. This situation encourages healthy competitions in the telecommunication market by enabling network solution providers to use their preferred technologies to fulfil the envisioned NGN framework once the final solution meets the NGN requirements. For illustration, Cisco uses the network protocols IP and MPLS with the optical fibre transport technology ASON/OTN to build up their core NGN transport networks.

More importantly, a basic element of the NGN concept, the network protocol, is not explicitly specified in the ITU-T's recommendations released so far, in other words, theoretically it may be any protocols once they are able to meet the NGN requirements. However, currently a industry-wide consensus has been achieved whereby the Internet Protocol (IP) is considered as the most appropriate solution to establish connectivity for all network equipments and carry data/services/applications both inside (NEs) and outside (end-user terminals) an NGN, as shown in Figure 2 Cisco IP NGN architecture.

This is mainly because IP is now indeed predominant in the network world and widely considered as the most promising technology to build up an NGN. Thus, the main idea of NGN can be finally described as "IP over everything" and "Everything over IP" (Crimi, 2005), where IP packets are used to carry all types of data over all transport mediums (optical fibre, copper line, or radio wave) across all sub-networks within an NGN. With this idea, all existing telecommunication networks and the Internet will converge into a unified IP-based packet-switching network infrastructure ultimately, and therefore NGN should be able to benefit from both the worlds of conventional telephone networks (PSTN/ISDN) and the Internet.

The NGN requirements are still under development as the range the NGN concept covers is wide, many network areas are involved, and a great number of identified or unidentified issues occur. So far a number of ITU-T standardization activities are already underway to establish more guidelines, standards or recommendations for the NGN implementation but more efforts are still required (Chae-Sub & Knight, 2005).

3.2 Core NGN Technologies Required

ITU-T has brought us a magnificent image of the future networks. Now NGN is not only a concept on the paper; its commercial implementations are already realized on a large scale. Appropriate technologies are significant for the accomplishment of the functions and abilities promised by NGN. In fact, any technologies which satisfy the NGN requirements could label themselves as NGN; some industry-wide accepted and practice-proved core NGN technologies are listed below:

Soft-switch: NGN provides PSTN/ISDN emulation and simulation services, which are used to enable end-users to use their legacy terminals with NGN continuously and have similar experience to the legacy system in an NGN environment. In conventional PSIN/ISDN systems, switches or switchboards are used to control calls, similarly, a programmable device called soft-switch or call-sever in an NGN is used to control Voice over IP (VoIP) calls, and allow users to use the legacy telephone numbering system. Soft-switch in NGN is also used to establish the interface to co-operate with the legacy PSTN/ISDN, through SG (Signalling Gateways) and MG (Media Gateways) technology (Gou, Jin & Zhao, 2004).

MPLS (Multi-Protocol Label Switching): MPLS and its subsequent development (Generalized Multi-Protocol Label Switching or GMPLS for short) are virtual circuit switching protocols, and were designed to carry data for both circuit switching nodes and packet switching nodes. MPLS is an important element enabling NGN services by providing IP based networks with basic traffic engineering ability such as CoS (Class of Service) and packet priority (Kang & Lee, 2005). It is noted that MPLS has to work in conjunction with IP within an NGN environment.

Core Transport Technology: IP over ASON over OTN: Wavelength Division Multiplexing (WDM) technology is widely used in the telecommunication backbone/core transport networks to provide solid transport services due to its tremendous line rates. The next generation optical transport technology based on WDM is developed and named Optical Transport Network (OTN). Automatically Switched Optical Network (ASON) is an independent control plane added on OTN to gain more control and management advantages. Furthermore, IP is the virtually dominant network protocol now in the world to carry a variety of services and applications. Therefore, IP, ASON and OTN compose the best technical solution for an NGN transport network at the present time (more about IP and transport networks will be studied in Chapter 4 and Chapter 5) (Lee & Morita, 2006).

Moreover, a full NGN deployment requires cooperation among a number of technologies to realize the promised services and functions, such as new last-mile broadband technology, and mobile IP technology.

3.3 The Need for an NGN

Over the last decade the explosion of data traffic in telecommunication networks has been impressive. The shift from simple voice communication to rich content interactions (video and image) over the Internet, even in terms of the simple voice communication, voice carried by packets over mobile networks and the Internet has seen a dramatic increase while the voice traffic over conventional PSTN has dropped in recent years (Lee & Knight, 2005).

As described in Chapter 1, the deployment of NGN is mainly driven by the desires of cost reduction and product differentiation from network companies (network carriers and service providers); however those network companies have a huge investment in the existing network infrastructure, and therefore a balance point between retaining current value and investing for the future must be taken into account.

The demands from customers have moved away from simple voice communications provided by their PSTN service providers towards a variety of rich-content services provided by ISPs (Internet Service Provider), in other words, customers prefer the rich-content and interactive communication possibilities offered by the Internet (Olszewski et al., 2003).

Network carriers and service providers are aware of those market changes and therefore turn to constantly deploying broadband services within the existing network infrastructure; as a result many parallel and service-specific networks are established in order to meet those increasing demands (Olszewski et al., 2003). However, those investments based on the current network infrastructure may not able to return investors expected profits mostly because of the lowered system efficiency and extra expenses on network management and maintenance caused by the increased network system complexity.

On the other hand, from a users' point of view, the services of current networks have done quite well in teams of service quality, fulfilling the demands of enabling people to communicate geographically (Crimi, 2005). However, from a network carriers' point of view, the existing network architecture has some significant drawbacks, it is too complicated and uneconomical to handle the possible traffic explosion in the future on a large scale and therefore it cannot meet the constantly increasing demands of the market. A new network infrastructure is required to handle the increasing data traffic in a cost-effective way and NGN was conceived due to this purpose.

In detail, identified by Crimi (2005), and Olszewski (2003), for network carriers and service providers, compared to the existing network infrastructure, benefits of implementing an NGN include:

Firstly, NGN deployment can reduce investment in network bandwidth updates by using the automated bandwidth sharing and allocation technology in core transport networks to fully exploit the potential of existing network bandwidth. It also can reduce OPEX (Operating Expenses, including space, power consumption, and maintenance costs) by using fewer numbers and types of NEs(Network Equipment) in a common network infrastructure, and expense caused by network fault recovery can be reduced as well by using the fast self-discovering technology.

In an NGN environment, Return of Investment (ROI) in existing networks will be retained as NGN is backwards compatible. More revenues will be generated by the shortened new service provisioning time using fewer handoffs and more new profitable or value-added services efficiently provided. Compared with the existing PSTN/ISDN CPE-based (Customer Premises Equipment) services, the NGN network-based approaches can provide more efficient and scalable services with lower costs as the network-based solutions allow for resources sharing and economies of scale to meet increasing demands on service content and quality.

Secondly, a successful NGN implementation can retain existing customers as well as to attract new ones by supporting those customers with innovative NGN services in a maintainable fashion. For example, it is easier for an NGN network operator to provide customers with integrated management services such as billing service through the Internet. As one of the most important features, the convergence of mobile and stationary networks in an NGN environment provides great flexibility and convenience for customers while it is difficult for CPE-based approaches to generate mobility.

In addition, Crimi (2005) summarized the reasons for deploying NGN in a general way in his research report:

> *"The service and content providers are forced to compete by price with each other in a market of 'ever-shrinking profit margins', thus, providing more*

sophisticated services and supporting them in a maintainable manner to attract high-margin customers is the only way for those network service and content providers to proper in the next decade. The NGN which supports new advanced services enable these network companies to retain existing market share as well as to expand."

In brief, according to those similar research works, the network convergence realized in an NGN environment can provide a cost-effective way for network carriers and service providers to offer a variety of services with guaranteed QoS, and reduce costs by eliminating the inefficiencies of current service-specific, proprietary, non-reusable and even overlapping solutions. Secondly, the NGN can also reduce the life-cycle time cost of new services provisioning to the market. Finally, the NGN deployment could be a significant strategy for network carriers and service providers to differentiate them from others, allowing them to retain competitive, as well as expanding their capabilities into new markets.

This chapter provides an overview and background about NGN. In brief, according to the initiatives from ITU-T and Cisco, NGN is a packet-based IP network designed to deliver integrated services/applications over a common network infrastructure. It provides a number of new advanced features as well as retaining compatible with legacy systems through several core technologies such as soft-switch and MPLS. The concept of NGN reflects the future trend of network convergence in the telecommunication industry, and meets the requirements of the telecommunication industry on future networks by redefining the network architecture to significantly reduce operational costs as well as to thoroughly improve network capability.

Chapter 4: The NGN Internet Protocol

NGN attempts to redefine the network infrastructure based on the current Internet and PSTN/ISDN networks, thus, as the dominant network protocol in the network world, the Internet Protocol is selected as the network protocol to carry data and deliver services/applications from the network edge to the core within an NGN infrastructure. This chapter examines the use of Internet Protocol suite in the NGN architecture by addressing the first two sub-questions for research question 2: “What is the primary network protocol?” and “Why is it needed?”

4.1 The Internet Protocol Suite

Currently, there are two basic methods used to transmit data: packet-switching and circuit-switching.

In a circuit-switching network, like PSTN/ISDN, the system decides and then establishes the path (circuit) for data transmission based on the system preloaded algorithms before data transfer begins, and during the entire data communication process the path is always-on, dedicated and exclusive, and will not be closed until the conversation ends. Thus, the entire message is transmitted between two nodes through a dedicated route in order and with a constant bit rate (Roberts, 1978).

In a packet-switching network, data is encapsulated into small segments called “packet” by the network protocol used. Each packet contains data payload and related control information, and travels through same or different routes. At the destination node the packets arrived are reassembled by the network protocol to make up the original data again. However, it is noted that there are two types of packet-switching networks: connectionless and connection-oriented. The packets encapsulated by connectionless protocols such IP, are called datagram which contains the information about their resource and destination, datagram can find their own routes towards the destination, but travelling through different routes may result in various delays. The connection-oriented packet switching is also called virtual circuit switching; it is to emulate circuit switching in packet switching networks in order to combine the best from these two network types. Similar to circuit switching, in a virtual circuit switching network a connection is established before data transmission starts, and packets are delivered in order through this dedicated route, but its bit rates could be various. The examples for virtual circuit switching include

Asynchronous Transfer Mode (ATM), Multiprotocol Label Switching (MPLS), and Transport Control Protocol (TCP) (Thurber, 1979; Roberts, 1978; & Haas & Cheriton, 1987).

Circuit switching mode can provide more reliable services as the entire message is transferred within a dedicated route with constant bit rate and low transport delay, the quality of service is therefore guaranteed. However it lacks flexibility on bandwidth allocation, in order words, it is inefficient as once the connection is established it cannot be shared with others even though it is not in continuous use. This significant drawback makes it fade out in the contemporary communication market. Packet switching communication is usually considered good from an economic viewpoint mostly because of its flexible and dynamic bandwidth allocation mechanisms, where "*a physical communication channel is effectively divided into an arbitrary number of logical variable bit-rate channels or data streams*" (Bill, 2000). The QoS problem, usually considered as a significant drawback in packet-switching networks in the past, has been mitigated recently through the integration of some quality control mechanisms.

The IP technology was designed "*in such a way that it could scale indefinitely with respect to applications and users it can support in an environment of unpredictable growth, allowing 'networks of networks' to be constructed*" (Stiller, 2000). Professor Stiller further described the advantages of IP in detail: the Internet Protocol was designed to provide an open environment to encourage innovations, and independence for upper applications to reduce the system complexity (no application layer gateway required). It is able to decouple the services from the network by allowing services running on the edge of the network rather than being integrated into the network, thus any changes applied to the services will not impact the entire network. In an IP network, the flexibility, redundancy and scalability of work distribution are emphasized by allowing network nodes to make autonomic decisions for packet routing according to the information stored in packets.

Furthermore, in the telecommunication market almost all services/applications are already running on or can run on the IP platform; an all-IP network is highly feasible. The explosion of IP data in our networks further facilitates the deployment of the all-IP network. In addition, there is already a world-wide IP network demonstrating the success of the IP technology in data transport and service/application delivery: the

Internet, where a huge number of users, developers and technicians are hooked to the IP technology, they form a solid foundation for the further developments of the IP technology.

On the other hand, the telecommunication industry has almost stopped research on the rivals of IP, such as TDM and ATM technologies, and concentrates on the IP development instead. Even though voice services are still carried by ATM/SDH networks mainly, a rapid shift to IP voice is predicted.

In brief, it is predicted that the all-IP is the future of our telecommunication networks, at least at present the all-IP network architecture is the best solution supporting most innovative and profitable services as the IP technology is relatively mature and easier to deploy.

4.2 IPv6: the NGN Network Protocol

Internet Protocol version 6, or IPv6 for short, is a later version of IP suite; it is selected as the primary network protocol for the NGN. The transition to IPv6 is usually considered important as the Internet will run out of its IPv4 addresses in the next decade, and IPv6 can provide many more potential addresses (2^{128} vs. 2^{32}). But the improved overall performance of the IPv6 Internet, including higher network throughput, enhanced QoS and etc, is also significant. (Bradner & Mankin, 1995)

IPv6 has been developed for over a decade; its development was initiated in early 1990 by IETF (the Internet Engineering Task Force) to "*address perceived scaling problems in the Internet's addressing and routing architectures*" (Nightingale, 2007). Now it has been widely accepted and deployed in the telecommunication industry, its commercial implementations are emerging on a large scale to replace its previous version.

In detail, IPv6 implementation is required as it is designed to meet the demand of the industry to handle the increasing number of Internet applications. Firstly, by the year 2010, the number of PC users is expected to grow to more than one billion; the rapid growth of the PC market stimulates demands on the Internet capacity: more IP addresses are needed. Secondly, the non-PC electronic devices with network capability, such as PDA and smart phone, are also expected to show a rapid growth in the next few years. Furthermore, the entertainment business also accelerates this transition process, more and more online entertainments, such as online music, video stores, and online gaming, require higher capacity of the Internet. In addition to the above, the rapidly increasing online communications, including instant messenger, email and etc, also result in intense demands on the Internet capacity (Dubey, 2005).

From a technical perspective, as a part of NGN, IPv6 emphasizes some important technical updates to cover the shortcomings of its previous version IPv4. In detail, one of the most significant changes while moving to IPv6 from IPv4 is the improved IP address length, from a 32-bit length in IPv4 to 128-bit long in IPv6. At present, 4,294,967,296 (2^{32}) unique addresses provided by IPv4 are almost running out due to the increased number of internet applications and inefficient resource allocation. For example, in 2008, the IPv4 addresses assigned for China were reported to be used up to 80%, and would run out in 830 days (Thompson, 2008). However, IPv6 can provide 340,282,366,920,938,463,463,374,607,431,768,211,456 (2^{128}) unique addresses, which are almost infinite for us in the coming decade.

Moreover, IPv6 improves the overall throughput of the next generation IP networks by supporting a Jumbograms mode in packet encapsulation, and it provides much larger single packet size (Maximum Transport Unit or MTU for short) than IPv4, where packets are limited to 64k, IPv6 breaks this limit and supports MTU up to 4GiB. Thus, some upper applications can gain significant performance improvement on data transfer by using larger MTU within IPv6 networks.

IPv6 developers also redesigned the IPv6 routing architecture by adopting a simplified fixed-length header structure and a more rational fragmentation mechanism, to enable faster header processing at intermediate routers and improve packet forwarding performance, consequently to enhance the overall network throughput. The checksum packet header field used for error checking in IPv4 is no longer used in IPv6 in order to avoid extra overhead caused by re-computing the checksum in intermediate routers. Instead, the error checking is performed in a lower layer by transport protocols. In addition, packet fragmentation is also no longer performed by routers in IPv6 networks; it is performed by the communication end points instead in order to improve the overall network performance.

More important, IPv6 significantly enhances its QoS performance by adopting a traffic class field and a flow label field in packet header to replace “service type” which is used in IPv4 for routers to configure packets’ priorities. In terms of security, the adoption of IPSec in IPv6 can provide end-to-end security guarantee for upper protocols or services/applications, and the enhanced security in a router level. Besides the above, IPv6 integrates a set of security mechanisms such as IP encryption and authentication by mandatorily supporting these security mechanisms in IPv6 packet header. In contrast, those security mechanisms are optional in IPv4.

In addition, IPv6 supports “plug and play”, and mobility. In IPv6 networks, the network hosts can automatically assign themselves IP address or necessary configuration parameters by sending router discovery messages (a link-local multicast router solicitation request) to and receiving replies (a router advertisement packet) from routers when connecting to the network. This advanced feature simplifies the network management, and is relatively easy for supporting mobile nodes. In addition, IPv6 mobile suit (Mobile IPv6 or MIPv6 for short) defines some new features dedicated for mobility to allow it to work as efficiently as normal IPv6. Finally, IPv6 introduces a concept of multicast scoping and labelling, which is used to limit the routing scale for multicasting and identify permanent and temporary addresses (Bradner & Mankin, 1995; & Dubey, 2005).

When moving towards a new technology, the transition process is always important to the final success, just like other NGN deployments, the transition from IPv4 to IPv6 is a long term and stepwise process. Until IPv6 hosts completely supplant IPv4 ones, a number of so-called transition mechanisms are required to enable the intercommunication between IPv6 and IPv4 nodes. These mechanisms, collectively called SIT (Simple Internet Transition) techniques, include:

Dual-Stack IP: it was designed to provide communication abilities between an IPv6 and an IPv4 node, with this approach, the network nodes have both IPv4 and Ipv6 stacks for supporting intercommunications between IPv6 and IPv4 nodes. This approach is generally considered relatively easy but increases the system complexity.

NAT-PT: Network Address Translator (NAT) or Protocol Translator (PT) makes communications among non-homogeneous networks possible by providing application-agnostic network address or protocol translation services at the IP layer.

Dual stack IP ALG: the dual stack IP ALG (Application Layer Gateway) proxies running on the network borders can provide protocol translation services at the application layer to enable communications between IPv4 and IPv6 networks.

IPv6-over-IPv4 Tunnelling: it was designed to provide the communication between two IPv6 nodes over an IPv4 network; this tunnelling technique uses IPv4 as a link layer for IPv6 through encapsulating IPv6 packets into IPv4 form so the IPv6 packets can be transmitted over the IPv4 networks (Gilligan & Nordmark, 1996).

Now many countries have started to implement their commercial IPv6 Internets after widely testing them in the education and research areas. IPv6 tests were initiated in 1996, all IPv6 networks at their early stages were inter-connected within a world-wide test bed called 6bone (www.6bone.net). In 2000, IPv6 deployment was accelerated as many network equipment vendors started to launch their IPv6 products. Since then, a number of IPv6 network deployments have been planned and implemented in Asia, Europe and U.S. on a large scale. For example, the U.S. government stated that the transition to IPv6 on their federal agency networks would be completed by 2008 (Das, 2007).

For home users, in 2007, Microsoft released their first IPv6 capable operation system: Windows Vista, and then in 2008, Google also first extended their web search engine to the IPv6 platform: www.ipv6.google.com (IPv6.com, 2008).

In particular, in New Zealand, the first international native IPv6 network for the public, the Kiwi Advanced Research and Education Network (KAREN) was established in 2006 for research and education purposes (KAREN, 2008). Thus, with the rapid deployment of IPv6 hosts, it is now possible for two network nodes to communicate in the Internet through pure IPv6 nodes, with no IPv4 involved at all since 2008 according to the record of the Internet Assigned Numbers Authority (IANA) in 2008.

This chapter provides background information and literature review in NGN portals; it partially answers the research question 2. In brief, considering the realities of the telecommunication market, the Internet Protocol is selected as the primary network protocol for NGN due to its optimized flexibility in network construction and management. After the development over a couple of decades, it is now relatively mature and has a firm technical and user foundation. As a developed version, IPv6 was designed to fix the shortcomings of its previous version (IPv4), and IPv6 hosts have been widely deployed to substitute IPv4 ones step by step, but this substitution is a long-term and gradual process. A set of mechanisms, including dual-stack, NAT-PT, and tunnelling, were introduced to ensure a seamless transition.

Chapter 5: The Next Generation Backbone/Core Transport Network

A transport network plays an essential role in the network world as it is the foundation of the entire telecommunication network system, and it provides connectivity and related control functions for other geographically-located networks. Especially, a backbone/core transport network is the central part of the transport network system; it typically refers to the high capacity carrier-class transport networks providing connectivity among other sub-transport networks.

Today network carriers are facing a number of serious challenges originated in traffic explosion and data type shift in their transport networks, and are consequently forced to search for new solutions. The desired solutions are expected to handle the increasing demand on IP data transport as well as to reduce operational costs, in particular to eliminate unnecessary capital expenditure or overlapping investment on the multiple service-specific transport networks. Great efforts were made by the telecommunication industry to search for such solutions until the emergence of the NGN concept.

As discussed in chapter 3, the NGN meets the industry's demands in the transport network segment as it is a unified and open network infrastructure able to provide higher network capacities and allow cooperation among multiple access networks to deliver various services and/or applications. On the other hand, the telecommunication industry believes the future of transport networks is photons, the all-optical network (Jiang, 2007), as the optical fibre cable can provide tremendous data transfer rates compared to other types of media like copper cable.

Furthermore, over the past decades, great progress has been achieved in terms of the applicability, survivability and scalability of optical networks. Consequently optical transport technology is widely used in transport networks currently. Therefore, using the optical transport technology to fulfil the NGN requirements in transport stratum is an ideal solution for network carriers in current stage. The NGN optical transport network has been the main research direction for the telecommunication industry in the 21st century.

As an essential part of NGN networks, besides the role of transporting data, an NGN transport network has to satisfy the common NGN requirements including IP based packet-switching, decoupling service from transport, open interface, end-to-end QoS guarantee, and etc. described in chapter 3.

This chapter therefore aims to identify and examine the primary technologies used in NGN transport networks to answer the sub-questions of research question 2: “What technologies are able to meet the NGN requirements in the transport stratum?” and “Why are they needed?”

5.1 OTN: the NGN Transport Technology

Data transmission rate and reliability are always the top priorities when network carriers develop and deploy their carrier-class core/backbone networks. Currently there are two main technologies or combinations of them widely used to form the core/backbone optical transport networks: Synchronous Digital Hierarchy (SDH) and Synchronous Optical Networking (WDM). Thus, IP data are carried by several approaches over optical fibres: IP over SDH, IP over SDH over WDM or IP over WDM.

The SDH and SONET are two close circuit switching network technologies widely used for voice or data transmission over optical fibres. As SONET is only used in U.S. and Canada while SDH is for the rest of the world, in this dissertation only the term SDH is used. SDH was originally conceived to replace the legacy Plesiochronous Digital Hierarchy (PDH) systems in the late 80s to carry larger amounts of telephone calls but later it was also used to carry data traffic. SDH adopts a Time Division Multiplexing (TDM) protocol to transfer multiple digital bit streams over a single optical fibre by multiplexing optical carrier signals in order to achieve higher overall single line rates. As SDH is a circuit-switching optical transport network, it provides permanent connections and each connection offers a constant bit rate and delay. Though SDH was originally designed to carry voice traffic, it is now widely used as a physical layer protocol to carry IP packets over optical networks; this approach is the so-called “IP over SDH” (Anne, 2005; Shafi & Mortimer, 1995).

In a similar way, Wavelength-division Multiplexing (WDM) is also a circuit switching network providing permanent connections and constant bit rates. Differing from the time division multiplexing approach in SDH, WDM adopts a wavelength-division multiplexing approach, using different wavelengths of laser light to carry different digital signals over a single optical fibre to achieve higher overall line rates. Dense WDM (DWDM) and Coarse WDM (CWDM) are two later developed versions of WDM based on same concept of wavelength (frequency) multiplexing; they have more advanced features and higher line rates to meet the increased demand of the telecommunication industry. Since the WDM technology can fully exploit the potential of optical fibres on data transmission by enabling multiplication in capacity and bidirectional communications over a single optical fibre compared with other data transfer methods, it is usually considered as the most promising technology for the NGN deployment in core/backbone transport networks (ITU-T, 2003).

With the rapid shift from voice traffic to data traffic, the existing transport networks based on the VC12/VC4 SDH and end-to-end WDM networking technologies are facing some serious challenges. Firstly, the huge amount of data traffic leads to inefficiency on bandwidth adaptation cross network edges. For example, for a GE or 10GE router port within a typical SDH transport network architecture, several VC-12/VC-4 are needed to map the required bandwidth via contiguous concatenation or virtual concatenation, and thus the efficiency of bandwidth adaptation and data transport is significantly reduced.

Furthermore, WDM network administration has become another problem as WDM is very weak at performance monitoring on the signal it carries. The third, WDM networks were designed to carry voice only so they only supported end-to-end or ring-based network topology originally which usually lacks survivability and flexibility. To solve this problem, a kind of advanced Optical Add-Drop Multiplexer (OADM) equipments, Reconfigurable Optical Add-Drop Multiplexers (ROADMs) with integrated Wavelength Block (WB) technology have been introduced into market providing flexibility on network configuration to enhance the WDM networking capability to two-direction (bidirectional communications).

However, ROADMs cannot fully solve the problem until the next generation Wavelength Selective Switch based ROADMs (WSS-ROADMs), which really support multiple-direction communication but are still under development, go into the market (Ciena, 2005; Heavy Reading, 2003; Gendron & Gidaro, 2006).

Thus, based on existing technologies, SDH over WDM technology was developed to cover those shortages by combining the best from both SDH and WDM. It is usually utilized to improve the network efficiency, capability of manageability and survivability of the WDM ring networks. However, for an all-IP network deployment, IP over SDH and WDM network is rather complicated, requiring a huge investment in network construction and maintenance. It is still not an ideal solution for an NGN. Resulting from above, Optical Transport Network (OTN) was introduced.

As an emerging technology used in NGN transport stratum, defined by ITU-T, OTN is "*composed of a set of Optical Network Elements connected by optical fibre links, able to provide functionality of transport, multiplexing, switching, management, supervision and survivability of optical channels carrying client signals*" (ITU-T, 2008). Allegedly it is able to provide "*Transport for all digital payloads with superior performance and support for the next generation of dynamic services with operational efficiencies not expected from current optical wavelength division multiplexing (WDM) transport solutions*" and "*Support for a wide range of narrowband and broadband services like SDH/SONET, IP based services, Ethernet services, ATM services, Frame Relay services and Audio/Video services*" (ITU-T, 2008).

In simple words, OTN could be described as an advanced version of WDM, but it also absorbs the advantages from SDH. As the telecommunication industry believes the future of the core transport network is photonic (all-optical), OTN can also be deemed as a compromised and transitional product between electronic networks and all-optical networks.

OTN transplants the ideas and functions of OAM&P (Operation, Administration, Management and Provision) in SDH into WDM networks, and consequently improves the performance of WDM networks in network administration. In addition, some advanced fault management and performance monitoring mechanisms are integrated into OTN to provide carrier-class QoS guarantee. It really realizes the industry-desired networking capacity of building multiple-ring, mesh or star topology networks (Ciena, 2005; Gendron & Gidaro, 2006).

5.2 ASON: an Intelligentized Transport Network Control Plane for the NGN

The NGN architecture consists of two basic function groups: transport and related control functions. The requirements in the NGN transport area have been satisfied by the OTN transport plane, thus a control plane is required to satisfy the requirements in NGN transport control area, and the Automatically Switched Optical Network (ASON) is such a solution.

As IP has been identified as the primary network protocol in NGN networks to carry services and/or applications, the major research direction in transport network technologies related research has been turned to the optimization for transmitting IP packets over optical networks. As described in previous chapters, the rapid growth of IP services and applications over recent years has made data traffic far surpass voice traffic and even now dominate the transport network, and because IP traffic is naturally abrupt, variable, uncertain and unpredictable, the constant bit-rate distribution mode in traditional optical transport networks cannot fully meet the increased demand of transporting IP data.

Furthermore, in terms of network structure, the traditional optical transport networks adapt a multilayer network model which directly leads to complicated service provisioning and massive transport overhead. Thirdly, regarding network resource allocation, WDM and its consequent developments provide required transmission capacity but cannot achieve dynamic bandwidth distribution. Thus, to overcome these technical defects, “network intelligence” was introduced to gain extra advantages on network management and resource allocation in the NGN transport stratum (Ciena, 2008).

Over recent years, researchers have attempted to integrate the intellectualized packet-based networking technology into circuit-based optical networks to achieve a so-called “intelligent optical network” consequently to cover the shortcomings of the existing optical networks. Thus, the Automatically Switched Optical Network (ASON), an intelligent network control plane based on a connection-oriented packet-switching protocol, GMPLS, was designed to accomplish alleged network intelligence such as automatic path switching and dynamic connection control.

Advocated by ITU-T, ASON, an optical transport network architecture, can offer "*dynamic signalling-based policy-driven control over OTN and SDH networks via a distributed (or partially distributed) control plane that provides auto-discovery and dynamic connection set-up*"(ITU-T,2004), it is able to intelligentize the existing optical networks to a certain extent, as Figure 4 shows.

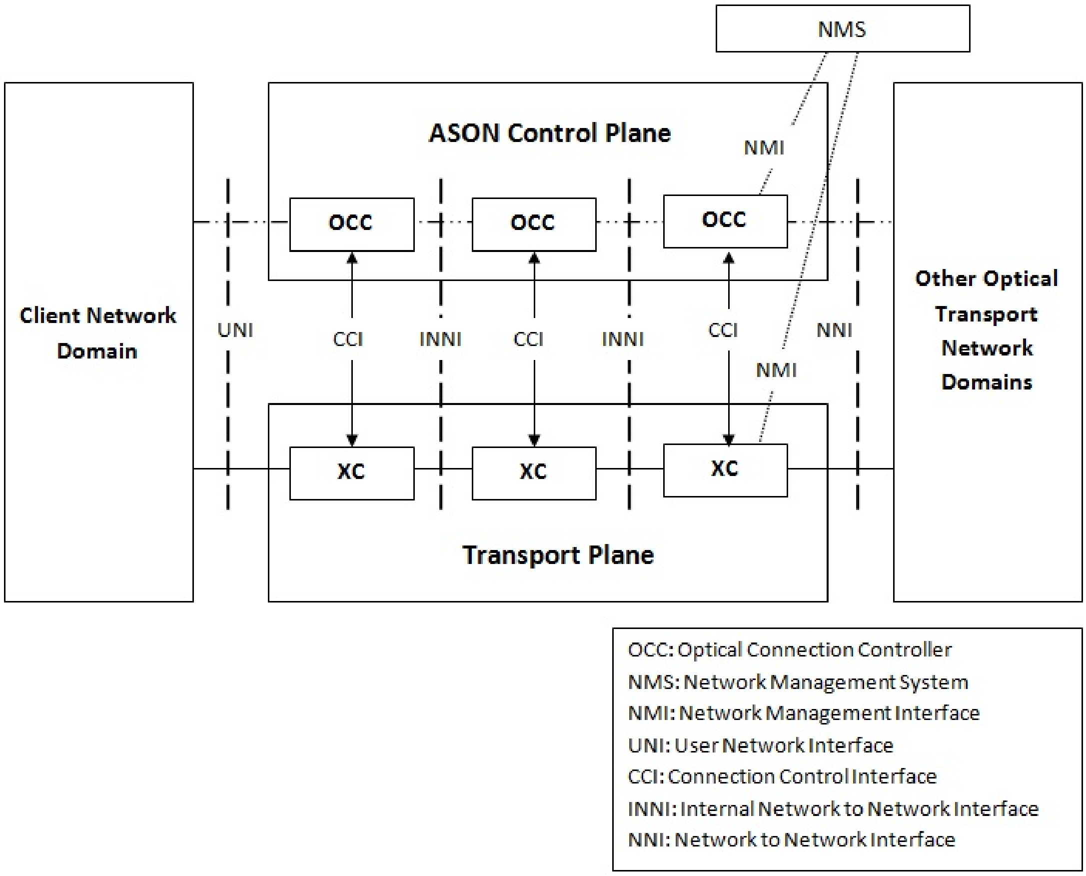

Figure 4: ASON Network Architecture (Source: Foisel, 2006)

ASON is designed to support fast service provisioning, flexible traffic engineering, enhanced network recovery, open connection control, and a variety of networks and services. In detail, firstly, with ASON implementation, automatic path switching can be accomplished by NEs (Network Elements) under the control of signalling and routing protocols. Thus an optical transport network can be upgraded from a static transport network to a dynamic and operation-manageable transport network. Moreover, an ASON network is able to establish, end and modify the end-to-end optical connections automatically from the client end or the management plane according to client requests. The integrated intelligence enables network carriers to reduce operation costs, and provide clients with diversified and personalized services in different service levels (Ciena, 2008 & Cisco, 2008).

Furthermore, compared to the conventional optical networks, the ASON architecture has better ability in network protection and fault recovery. When faults occur an ASON network is able to automatically, promptly and dynamically calculate the best routes for routing recovery according to the rational routing algorithms, constraint conditions, network topology information, usable resource information, and configuration information preloaded in routers to restore the network.

In detail, firstly, once an optical fibre cable is interrupted, hundreds of IP Repeated Optical Links (ROL) in WDM transport network system will be interrupted at the same time, and routers will conduct a large scale Fast Retransmit and Recovery (FRR) and Internal Gateway Protocol (IGP) protocol convergence. Thus, the physical interruption of optical fibre cables will pose serious risks to IP over SDH/WDM networks.

Secondly, usually the logical link of IP network is full-mesh distribution (mesh-based network), but the logical link of optical fibre network is ring-based or simple mesh distribution. Once a physical link in a WDM network is interrupted, it may cause the primary and spare logical link to be interrupted simultaneously, and consequently lengthen the recovery time of FRR to over 50ms. Finally, due to the drawbacks of MPLS FRR (Fast Re-Route) systems in network expendability, planning and administration, MPLS FRR is mainly used in IP core layer, in other layers such as the convergence layer and access layer IGP is used, therefore the end-to-end IP QoS is only partially satisfied (ITU-T, 2008 and Juniper, 2008).

Thirdly, an ASON network can have better compatibility; it was designed to allow inter-operations among different manufacturers' equipment by providing a standardized network interface. Different technologies or equipment from different vendors can be used to construct different sub-networks in different network layers or domains, and the intercommunications among those sub-networks are accomplished by E-NNI and UNI in the network edges as shown in Figure 4.

In detail, UNI is mainly used to provide inter-connections in control plane between backbone/core transport networks and access networks to offer technical guarantee for new services such as Bandwidth on Demand (BOD) and Optical Virtual Private

Network (OVPN) (Liu, 2007). E-NNI is mainly used for the inter-connections in control plane between two transport networks from different carriers or using different technologies. A standardized E-NNI is significant for establishing cross-domain end-to-end connections and routing over domains. The ASON development trend is to push more automatic functions (intelligence) into network interfaces (UNI and NNI), to further reduce manual intervention and configuration required for inter-connection of network equipment. In other words, it is to achieve the so-called "plug and play" ability in core/backbone transport networks (ITU-T, 2008).

Currently, ASON/ SDH technology is relatively mature and widely used in carrier-class core/backbone transport networks. However, as it is predicted that in the near future SDH will be substituted by OTN. ASON/OTN is the future of our core/backbone transport networks.

In conclusion, as the foundation of OTN, WDM technology has had great progress in terms of network capacity and manageability over recent years and network bandwidth is no longer the technical bottleneck for further deployment. The development focuses have been put into optimization for carrying IP packets. Compared with IP over SDH and WDM, IP over OTN infrastructure can provide higher efficiency with lower cost by eliminating a middle layer to reduce system complexity; it also reflects the trend of network layer-flattening in the telecommunication industry. Adding an independent control plane to the optical network, the ASON/OTN transport network was designed to provide enhanced network stability, reliability and security in carrier class to carry IP-based services and/or applications in a flexible, cost-efficient and transparent way within a common infrastructure, where the requirements of an NGN transport network are fully satisfied.

Chapter 6: Discussion

The previous chapters present a detailed description of the NGN by investigating the NGN network architecture, requirements, market drivers and core transport technologies. In this chapter, the focus is placed on the findings observed from previous chapters or the issues related to NGN needs, requirements and implementation. This chapter identifies the key performance limiting factors and explains how these factors can be questioned and/or improved. Thus, the last research question "What are the key factors affecting NGN deployment?" is addressed.

6.1 The Trend towards Network Convergence

The word "convergence" is frequently mentioned in this dissertation, it represents the current technology trends in the telecommunication market, and it is also the ultimate goal of NGN deployment. The network convergence in general means the various networks developed or optimised for dedicated uses converge over a common infrastructure to provide integrated services. As a result, currently network deployments have been migrating from the service-specific networks toward the networks based on a common infrastructure. Cisco introduced a broader concept of convergence. Besides the network convergence there is also an emerging convergence in service and application area, for example, voice (VoIP), video (IPTV) and data (the Internet) are delivered over a common platform (the Internet Explorer). Moreover, the management functions like billing are also integrated over or can be reached through the same platform (Weissberger, 2005).

This emerging trend of network convergence is a network evolution mainly driven by the pursuit of network efficiency from market players. In addition, it is also an interactive two-fold process: the trend of network convergence results in NGN development, but NGN development also accelerates the network convergence process.

However, it is noted that as things stand at the moment the proposed NGN concept could be deemed as a compromised product in some ways as it must take into account both future and current interests, in simple words it must be backward-compatible to retain the value of existing investments. For example, in the transport stratum NGN emphasizes a compulsory capability of supporting a wide range of existing transport networks. Moreover, NGN allows network carriers to use their existing access networks to connect the core NGN networks and user terminals to deliver services. Thus, retaining backwards compatibility may impair the final network convergence.

6.2 The Vision from Cisco

The NGN concept discussed in previous chapters is mainly derived from an ITU-T's vision, and with some industry consensuses, representing the prevailing perspective of our future network architecture. Based on this fundamental concept, Cisco, an industry leading network solution provider has a more practical vision for the NGN. Cisco accepts that an NGN should be based on the packet-switching network architecture, but emphasizes the integrated network intelligence and IP/MPLS collaborative architecture in data transport and service delivery.

In Cisco's initiative, IP and MPLS (GMPLS) are explicitly specified and emphasized as the basic network protocols in the NGN architecture for more management advantages through traffic engineering. In addition, Cisco states that its NGN development, the Intelligent Information Network is developed with a focus on "*connecting people to the applications and services*" (Cisco, 2008) rather than transporting bits which current networks are focused on. The increased intelligence in NEs enables services providers to quick deploy or change their services to meet the potential market shifts (Cisco, 2008 & Morrow, 2005).

In fact, there is no significant difference between ITU-T and Cisco in terms of the NGN architecture. Thus, when the entire industry has achieved consensus on the technical standard, the NGN deployment seems unstoppable.

6.3 Network Transition Strategies

As network convergence can provide a variety of benefits, a great number of network operators have started to deploy NGN networks to support their businesses (Cisco, 2002). "*A key critical success factor of NGN implementation is focused telecommunications industry attention on NGN service concepts and how these concepts can be realized in an NGN environment*" (Crimi, 2005).

Thus, in general there are two basic approaches for those network operators to convert their multiple service-specific networks to a converged network (an NGN network): those network operators can add the new NGN-capable devices into the existing network infrastructure and gradually transfer traffic from the old equipment to the new equipment until the entire network is upgraded to NGN, or they can elect to develop a parallel network and gradually transfer traffic to the new architecture until all traffic is completely transferred(Tellabs, 2007). Different network operators should carefully evaluate the market they are playing in, and identify appropriate strategies before upgrading their networks towards the new infrastructure. Failure to apply appropriate strategies may lead to loss of core competency.

6.4 Who Can Benefit From the NGN Implementation?

NGN promises a grand image of our future networks, for users, benefits provided by an NGN include more attractive services, more convenient access, higher quality, and cheaper prices. For network carriers or service providers it can provide benefits including lower costs, easier management, more profitable services and quicker response to market changes.

However, as the transition to the pure NGN infrastructure is a long term process (this may last for decades until all users are transferred to the NGN and all legacies are obsolete), at its early stages when the NGN and conventional networks are co-existing, the impacts of the NGN transition may not be known to users, and some issues like the inter-communication problems among different networks may cause obstacles preventing users moving to the new experiences.

However, for market players, NGN claims to *"bring all players together in an environment where they can create truly global specifications for the service-aware network of the future, to deliver dynamic, customized services on a massive scale"* (ITU-T, 2004). The impacts are supposed to be obvious and immediate as those players most likely tend to immediate returns rather than potentials.

In general, as the telecommunication industry requires huge investments in network infrastructure, in the market there are always some giants who are able to do so, these predominant players of course can directly benefit from the NGN deployment even though they may hesitate due to the protection of existing investments, but nonetheless NGN implementation will be an important business strategy for them in the next decade.

In addition, network convergence may provide opportunities for disadvantaged players to compete with predominant giants in the market as well. Another researcher, Huang (2007), stated in his thesis that the telecommunication market will be more competitive as the open environment advocated by NGN and some new technologies in NGN such as LLU (Local Loop Unbundling) will bring new opportunities for small businesses.

In brief, all parties involved into this network evolution can definitely gain benefits from the technology progress, but for users the impacts may emerge later than for market players, and for the minor market players this network evolution may provide both challenges and opportunities.

6.5 QoS

Service quality will always come first when users think of alternative services. As described in Chapter 4, IP is a connectionless packet switching network protocol which was designed for network flexibility but lacks QoS guarantee. In contrast the connection-oriented (whatever physical or virtual circuit) network protocols are better at quality control because of the dedicated communication route. Thus, the connectionless protocols are usually working in conjunction with connection-oriented protocols in packet switching networks to achieve higher QoS. In the Internet Protocol suite, the connection-oriented protocol, Transmission Control Protocol (TCP), is in place as a control protocol working with IP for the above reason. However, in an NGN, where the IP suite is selected to carry all services, the problem is in the foreground. It is no problem for data transmission service as the QoS, which is mainly the integrity of the information, can be guaranteed by TCP, but for real-time multimedia service delivery, as the different transmission routes result in various delivery time, packet delay is the main quality impairing factor. The IP suite cannot meet the QoS requirements in this kind of uses, it is why usually the VoIP voice is considered low quality compared to PSTN voice within the current network infrastructure.

On the other hand, one of the key improvements expected from an NGN network is the enhanced QoS. Thus, extra mechanisms are definitely needed within the NGN architecture: a virtual circuit switching protocol Multi Protocol Label Switching (MPLS) and its subsequent development Generalized-MPLS (GMPLS, developed for optical networks) are introduced to mitigate the QoS problem by its traffic engineering mechanisms. Through traffic engineering, the packets labelled with higher priority such as VoIP traffic can be transmitted over some faster pathways to achieve higher QoS without extra requirements on existing network bandwidths (Morrow, 2005).

However, it is noted that within the NGN infrastructure the achievement of acceptable QoS relies on the combination of various QoS-integrated mechanisms from the edge to the core. Despite the great efforts made during the NGN development, the industry still has doubts on the quality of voice services provided by an all-IP packet-switching network, whether the current widespread VoIP or future NGN voice services. Thus, along with other reasons, QoS issues may prevent the fast deployment of the NGN.

6.6 Security Concerns

As a unified network based on IP technology to integrate and replace the existing PSTN/ISDN and the Internet, besides the strengths, the weaknesses from the current Internet are also inherited by NGN; security issues may not be so important as quality issues especially in NGN optical backbone networks, but for end users it still could be another critical concern. Within the existing network infrastructure, traditional voice networks are well protected by being physically separate from computer networks; usually it is difficult for computer criminals to intrude into local PSTN networks from the Internet unless they can physically access lines, switches or terminals. However, the convergence between PSTN and the Internet provides facilities for cyber crimes as there will be no more differences between voice networks and computer networks in the future.

In pace with an initial transition from PSTN/ISDN to the Internet, VoIP, which has been deployed for years as a cheaper alternative to PSIN in particular in long distance communications, the cyber crimes involving VoIP networks are raising. According to VIPER Lab (Higdon, 2008), five top security threats are predicted for VoIP networks in 2008: denial of service, VoIP eavesdropping, attacks on Microsoft Office VoIP communication server, vishing by VoIP, and VoIP attacks against service providers.

Thus, it is not surprising to see a number of enhanced and complex security mechanisms adopted and integrated in NGN, such as the concept of Security Domain, NGN IMS Authentication, and IPSec. At present it is difficult to judge how secure an NGN is until it goes to practice, but it is certain that security will be a big challenge for NGN implementation in the future (Tu, 2005).

6.7 Emergency Call Handling

In addition to the above, special attention is focused on the emergency call handling within the NGN infrastructure. Historically, at a very early stage of VoIP, the emergency call service was neglected by service providers, as VoIP was considered as the complement only to PSTN at that time, but later when VoIP was widely deployed, many governments regulated the emergency call service as mandatory in VoIP services. Thus it has no longer been deemed as a vital problem in the future NGN.

On the other hand, mobility is one of the greatest advantages provided by the NGN, in simple English, that means users can make and receive VoIP calls virtually anywhere once they log in the network with their unique identities. Thus, similar to using mobile phones, it creates potential difficulties for the emergency call handling centre to identify the caller's position exactly (Langmantel, 2007& Newport Networks, 2008).

Furthermore, in respect of disaster recovery, the problem has not been solved yet. In a pure NGN environment, all services are achieved over a computer network, which requires electricity for its operation. A power failure will definitely interrupt all services on the user side, and there is no exception for VoIP calls. Thus, making an emergency call is a critical problem in this or similar situations. Therefore, PSTN may continue for a long time providing services in an emergency such as power failure and disaster until the solution is found.

This chapter has included a discussion of some NGN related issues, and consequently elicits the potential obstacles to NGN deployment. In brief, with a broader concept from Cisco, "convergence" in the telecommunication domain includes the convergences in three sub-areas: network, application and service. Thus Cisco proposed an IP/MPLS NGN architecture corresponding to those convergences to fulfil the NGN requirements. All parties involved in the telecommunication market seem to benefit from this network evolution, but network carriers should carefully select and apply their transition strategies to mitigate risks. In addition, QoS, security and emergency call handling may be the major obstacles to the success of NGN deployment.

Chapter 7: Summary and Conclusion

The study proposed to investigate the NGN architecture and the underlying technologies with a focus on the network transport stratum from a network carrier perspective. In detail, the study has identified the market incentives for NGN development, examined fundamental technologies required to realize the expected NGN functions especially in the transport stratum, and discussed some issues related to NGN implementation. Three main research questions were formulated:

- Question 1: What is the importance of NGN?
- Question 2: Which technologies are the most suitable ones for NGN?
- Question 3: What are the key factors affecting NGN deployment?

With respect to question 1 it was found that NGN is an IP based packet-switching network delivering all kinds of services and/or applications over a common infrastructure. It was also found that the IP and ASON/OTN transport technologies form the NGN architecture, thus research question 2 is addressed. With respect to the third research question it was found that besides network capacity, QoS issues, security concerns, and emergency call handling might affect NGN development negatively.

In conclusion, in the current telecommunication market, a new phenomenon can be observed: an ongoing rapid shift from traditional voice traffic to IP traffic, and a move from service-specific networks towards a common network infrastructure where all services are supported. Following the trends above, NGN is envisioned as a network infrastructure designed to cover the shortcomings of current networks. More specifically, NGN features include IP based packet-switching and services independent to transport. Thus, a successfully implemented NGN should be able to provide more cost-effective scalability and a better price/performance ratio (long term). NGN subscribers should be able to experience uninterrupted services. Converging networks as the migration from existing platforms should be cost effective and seamless, and the new architecture should be able to offer greater flexibility in terms of access to a great range of new applications and/or services specified by NGN. Most importantly, a significant reduction in the cost of establishing, operating and maintaining separate services of voice, data and Internet should be visible with a successful NGN deployment.

However, the network convergence is a long-term and gradual process. It may take a few decades to move all network traffic and users from the existing infrastructure to NGN. During this process, issues may occur, hampering NGN deployment- such as quality of service, security, and disaster recovery. As the expected change poses serious challenges to the market players, only the companies which include NGN as part of their sustainability strategy may be able to survive in the future. In a way network convergence can also be viewed as an opportunity provided by the technological progress which may lead towards building a revenue stream based on new services, on the sale of new equipment, and on higher efficiency. Minor market players may be also able to benefit from the open environment of the NGN infrastructure.

The rapid development of the NGN forces network carriers to question the value of their investment in the existing networks while moving to the new infrastructure; the existing investment may not be worthless but if the infrastructure already built is going to become obsolete and/or does not have the potential to meet the requirements in the future, the network carriers may have to carefully evaluate their vision and projections. Thus, the speed of moving to the NGN will be determined not so much by technological progress, but by the pace of change within the telecommunications market. Furthermore, research in the area may help identify more issues and directions in the convergence process while moving forward to the NGN architecture; it is seen to be an established trend.

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