國立交通大學

科技管理研究所

博　士　論　文

都會區寬頻通訊網路技術與趨勢之評估

Characterization of Emerging Technologies in Metropolitan Access Networks and Local Loops

博 士 生：鄭炤仁

指導教授：虞孝成教授

中　華　民　國　九　十　三　年　十　月

都會區寬頻通訊網路技術與趨勢之評估

Characterization of Emerging Technologies in Metropolitan Access Networks and Local Loops

博 士 生：鄭炤仁　　Student：Joe Zen Cheng
指導教授：虞孝成教授　　Advisor：Dr. Hsiao-Cheng Yu

國 立 交 通 大 學
科技管理研究所
博 士 論 文

A Dissertation Submitted to
Institute of Management of Technology
College of Management
National Chiao Tung University
In Partial Fulfillment of the Requirements
For the Degree of
Doctor of Philosophy
In

Management of Technology

October, 2004

Hsinchu, Taiwan, Republic of China

中華民國九十三年十月

都會區寬頻通訊網路技術與趨勢之評估

博士生：鄭炤仁　　　　　　　　　　　指導教授：虞孝成教授

國立交通大學科技管理研究所

摘要

電信自由化、網際網路 IP 應用的成長，以及無線行動通訊的普及，使電信產業在過去幾年中產生大幅成長。電信製造業者由於網路建設的需求不斷地增加，其營運收入也跟著呈現出大幅成長。由電信業營運商及製造商在 2000 年底前的股票市值，可以明顯的看出電信產業的繁榮景象。然而，在 2000 年底電信產業突然不景氣，使資本支出明顯的減少，促使電信產業的產業結構產生劇烈的改變與重組。本研究分析影響電信產業商業活動之助力與阻力，並探討電信及網際網路 dot-com 產業泡沫化過程的教訓，進一步討論未來電信產業存在的主要商機。

在電信產業不景氣的時期，全球網際網路的數據使用量仍然持續的成長，尤其是大量企業用戶開始使用乙太網路 (100M/s、1/10 Gb/s)，使企業內部的數據話務量極速的成長。不僅如此，中小企業及一般住戶使用 ADSL 及銅纜數據機的普及率不斷提高，更是促進數據業務成長的主要動力。

目前都會區網路主要是使用 SONET/SDH 的設備來「集中」傳送數據資料。但是由於 SONET/SDH 在傳輸數據時，會限制頻寬及使用的彈性，因此限制了都會網路的發展，所以需要尋找新的都會區網路接續解決方案來滿足目前的需求。由於乙太網路的技術簡單、成本低、容易聯通網路、容易處理 IP 數據、與服務提供快速的優點，再加上新發展的乙太網路 Gigabit 介面可以擴增至大區域(WAN)的通訊功能，因此使得 Gigabit 乙太網路成為滿足都會區寬頻需求最可能的解決方案。

本研究探討 Gigabit 乙太網路的進展、分析 Gigabit 乙太網路使用於都會網路的優缺點，並探討技術演進對電信業者的影響。本研究使用模糊多評準決策(Fuzzy MCDM)方法來評估何種解決方案最合適於都會區寬頻通

訊的需求。研究結果顯示 SONET/SDH 其多目標之效用值較 Gigabit 乙太網路為高。

電信自由化使電信產業在長途、國際及行動通信業務上產生越來越多的競爭，但是在區域迴路(Local Loop)的部分卻一直缺乏競爭，這種不健全的產業競爭現象，促使各國在制訂電信法規時，著重於研究如何鼓勵區域迴路的競爭，本研究分析不同的新接續技術及政府政策。研究分析結果發現，光纖能提供足夠的頻寬、使用 WLAN 及 WiMAX 可以滿足移動寬頻；而政策法規的規範上則傾向於建議無法與現有的電信商競爭的新電信業者可以進行整合，與現有的區域迴路業者進行合理的競爭。

關鍵字：電信、自由化、網際網路、乙太網路、光纖、都會區網路、區域迴路、模糊多評準決策

Characterization of Emerging Technologies in Metropolitan Access Networks and Local Loops

Ph. D. Student: Joe Zen Cheng   Advisor: Dr. Hsiao-cheng Yu

Institute of Management of Technology
College of Management
National Chiao Tung University

Abstract

Telecommunications deregulation, the exponential increase in Internet IP applications, and the popularity of mobile services have created tremendous growth in the telecommunications service industry in the past few years. With unprecedented demands on network infrastructure, telecommunications equipment manufacturers also enjoyed sales and revenue growth until the economic downturn toward the end of the year 2000. The prosperity of telecommunications service providers and equipment manufacturers were reflected notably on their respective stock performances. However, the abrupt slowdown, particularly in capital spending on networking equipment, has resulted in mass corporate restructuring and workforce realignment in the telecommunications industry. In this study, we have analyzed the "business drivers and draggers" that caused the telecommunications boom and downturn. In this context, we review lessons learned from the dot-com implosion and the downturn in the global telecommunications industry. We also discuss the telecom industry's latest developments in preparation for the next wave of business opportunities.

Despite the telecom industry downturn, global Internet traffic growth continues to create bandwidth demand in the telecommunications network. As 100 Mb/s Ethernet and 1/10 Gigabit Ethernet LANs are widely installed in enterprises, Intranet bandwidth has grown quickly. With active adoption of ADSL and cable modems, broadband accesses in the SOHO

and residential markets, more data traffic is generated in these markets as well. Presently, most telecom carriers use SONET/SDH equipment to "aggregate" data traffic in the MAN network (Metropolitan Area Network) before accessing the Internet backbone network. Because of the intrinsic limitations of SONET/SDH equipment in transporting data traffic, especially in terms of bandwidth scalability and provisioning efficiency, there is a need to find a broadband access solution that can overcome the drawbacks of SONET/SDH. Because the inherent simplicity of the technology, Ethernet offers cost-effectiveness, ease of networking, a packet-based IP friendly protocol, and rapid provisioning advantages while competing with other networking technologies. These advantages, coupled with the newly developed Gigabit WAN capability have positioned Gigabit Ethernet as a compelling technology to break the bandwidth bottleneck in the MAN environment. We review the enhancement of Gigabit Ethernet technology and discuss the pros and cons of using Gigabit Ethernet technology in the MAN network. We also address the implications of this technology evolution on telecom carriers. Fuzzy Multi-Criteria Decision Making methodology was used to evaluate Gigabit Ethernet and SONET/SDH MAN access strategies. The survey results show that the SONET/SDH MAN access strategy received a higher utility score in satisfying the multi-objectives than the Gigabit Ethernet access strategy.

Finally, although global telecom deregulation has sparked competition for long distance, international, and cellular service, there remains a lack of competition in the local loop environment. This may be of particular concern in the Internet broadband service era due to the potential aggregation of service providers. In order to foster local loop competition, special government policy attention and regulation is required. We analyzed various emerging access technologies and policy approaches. Based on the analysis, fiber offers the best bandwidth capacity while WLAN and WiMAX provide good mobile broadband access capability for end users. From a policy perspective, if a majority of the CLECs (Competitive

Local Exchange Carriers) are unable to effectively compete with incumbent carriers, then a CLEC consolidation - leading to a well-controlled monopoly - could be a solid option for future local loop networks.

Keywords: Telecommunications, Deregulation, Internet, Ethernet, SONET/SDH, LAN, MAN, local loop, Fuzzy MCDM (Multi-Criteria Decision Making)

誌謝

首先感謝虞孝成教授對本人在博士班求學間的悉心指導。 其次感謝所上曾國雄教授、徐作聖教授、洪志洋教授、袁建中教授、劉尚志教授在課業上的指導，以及博士論文口試委員徐作聖教授、洪志洋教授、唐震寰教授、朱詣旨教授、林博文教授、及鄭興教授的指導。 同時也謝謝學弟妹們在論文編輯上的支持與協助。

鄭炤仁 謹職

民國九十三年十月

于國立交通大學科技管理研究所

Contents

List of Tables

List of Figures

1. Introduction

Global telecom deregulation broke up telecom monopolies, and new players emerged in the marketplace. Ever-advancing technological innovations in computing and telecommunications have made Internet and WWW (World Wide Web) services available worldwide. Consequently, demand for telecom infrastructure equipment skyrocketed, and the telecommunications and IT (Information Industry) industries have grown remarkably in the past few years. The performance of major stock markets reflected this growth. In March 2000, the Nasdaq Index reached an all time high of 5048 compared to 2000 five years earlier. Most telecom companies' market capitalization reached an all time high at the same time. Through mergers and acquisitions, major telecom equipment suppliers such as Cisco, Lucent and Nortel, expanded their product portfolios in global markets. The Telecom Industry was perceived as the engine that would carry the global digital economy (Cheng et al., 2003).

With such a rosy outlook, the abrupt economic slowdown toward the end of 2000 caught everyone off guard. The telecom industry, once seen as unstoppable, suffered severe sales and revenue downturns. Many telecom giants, such as Lucent and Nortel, underwent numerous corporate restructurings and layoffs. By mid-2002, major carriers such as Qwest, Global Crossing, and WorldCom disclosed disastrous losses and eventually filed for bankruptcy. This shattered telecom manufacturers' hope of recovery in the near future. Wishing to understand the forces at work in this phenomenon, we gathered information reported in the business and management community and interviewed experts in the telecommunications industry. We have summarized factors that greatly contributed to the boom and gloom of the telecom industry, and offered the findings as lessons for other industries. Furthermore, we discuss the current developing telecommunications trends and issues that could greatly impact the future telecommunication industry.

Among these telecommunications issues, we identified the LAN (local Area Network) and SONET/SDH (Synchronous Optical Network/Synchronous Digital Hierarchy) technologies and telecommunications network local loop for further study because of the disruptive nature of LAN technologies in the MAN (Metropolitan Access Network) environment (Cheng, et al., 2003), and the critical nature of the local loop network in the telecommunications competition. Evolution of LAN technology and comparison between the Gigabit Ethernet and SONET/SDH technologies were analyzed. Finally, we also analyze emerging access technologies and potential alternatives to resolve the local loop network bottleneck issue in order to promote the local loop competition.

1.1 Background and Motivation

Global Internet traffic growth continues to create bandwidth demand in the telecommunications network. As 100 Mb/s Ethernet and Gigabit Ethernet LANs are widely installed in enterprises, the Intranet bandwidth grows quickly. With active adoption of ADSL and cable modem broadband accesses in the SOHO and residential markets, more data traffic is generated in these markets as well. Presently, most telecom carriers use SONET/SDH equipment to “aggregate” data traffic in the MAN network before accessing the Internet backbone network. Because of the intrinsic limitations of SONET/SDH equipment in transporting data traffic, especially in terms of bandwidth scalability and provisioning efficiency, there is a need to find a broadband access solution that can overcome the drawbacks of SONET/SDH. Because the inherent simplicity of the technology, Ethernet offers cost-effectiveness, ease of networking, packet-based IP friendly protocol, and rapid provisioning advantages while competing with other networking technologies. These advantages, coupled with the newly developed Gigabit WAN capability have positioned Gigabit Ethernet as a compelling technology to break the bandwidth bottleneck in the MAN environment. We review the evolution of Gigabit Ethernet technology and discuss the pros and cons of using Gigabit Ethernet technology in the MAN network. We also address the implications of this technology evolution on telecom carriers (Cheng, et al. 2003).

Very little literature currently exists about the models/methodologies that can be used to select the appropriate technology in the telecom carrier environment. Only expert opinions and technology assessments are available. This study is therefore motivated to demonstrate the effectiveness of using a Fuzzy-MCDM to evaluate technology selection mechanisms.

Furthermore, global telecom deregulation has sparked innovation while revolutionizing the telecom industry. Although competition for long distance, international, and cellular service is fierce, there remains a lack of competition in the local loop environment. This may be of particular concern in the Internet broadband service era due to the potential aggregation of service providers. In order to foster local loop competition, special government policy attention and regulation is required. Therefore, this study is motivated to study the policy impact on the local loop competition. The pros and cons of different policy approaches are discussed. In particular, how will the wireless LAN technology be utilized in the local loop competition is also discussed.

1.2 Purposes of Research

Telecommunications deregulation, the exponential increase in Internet IP applications, and the popularity of mobile services have created tremendous growth in the telecommunications service industry in the past few years. With unprecedented demands on network infrastructure, telecommunications equipment manufacturers have also enjoyed sales and revenue growth until the economic downturn toward the end of the year 2000. The prosperity of telecommunications service providers and equipment manufacturers reflected notably on their respective stock performance. However, the recent abrupt slowdown, particularly in capital spending on networking equipment, has resulted in mass corporate restructuring and workforce realignment in the telecommunications industry (Cheng et al., 2003). In light of changes in the telecommunications industry landscape, it is important to understand the drivers that caused the telecommunications boom and downturn. In addition, we need to study emerging technologies for broadband services and to analyze the current telecommunications bottleneck issue in order to adequately manage the future telecommunications industry trend and technologies. Based on the above description, we, therefore identify four main purposes in this research:

1. First, this research examines the “business drivers and draggers” that have caused the telecommunications boom and downturn. In addition, we review lessons learned from the popping of the Internet bubble, and the downturn in the global telecommunications industry.
2. Second, this research analyzes LAN technology evolution and its potential in the MAN environment. A comparison of Gigabit Ethernet and existing SONET/SDH technology from the carrier’s perspective is conducted to understand its application in the MAN environment.
3. Third, this research employs a Fuzzy-MCDM to demonstrate the effectiveness of the method in selecting technology alternatives in telecom carrier networks.
4. Four, this research analyzes the local loop bottleneck competition issue, particularly from the policy’s perspective. We present several alternatives that could stimulate the competition in the local loop network. We also analyze the management issues of emerging access technologies. In particular, the impact of wireless LAN technology in the local loop competition is also discussed.

1.3 Literature Discussion

Understanding the boom and downturn of the telecommunications industry should include considerations from technical, government regulations, services and business perspectives. Technical considerations include the evolution of Internet IP and wireless technologies.

Government regulations considerations include telecommunications deregulation and spectrum licensing. Service considerations include broadband multimedia and Internet services. Business considerations include business models, mergers and acquisitions and vendor financing issues. Elstrom (2001) identified factors that caused the meltdown of the telecommunications industry. From a historical perspective, Arthur (2002) discussed whether the information revolution is terminated or not, and offered insights on prominent future telecommunications trend.

Clavenna, Jander and Reardon (2001) discussed the pros and cons of the deploying Gigabit Ethernet technology in the MAN network. Seifert discussed the evolution of LAN technology. The proliferation of LAN technology in the SOHO and enterprise environment, together with the standardization of Gigabit Ethernet interfaces stimulates new WAN applications for Ethernet technology. From a technical perspective, Gigabit Ethernet has offered several distinctive advantages against the existing SONET/SDH technology. However, from the carrier's perspective, there are other qualitative parameters (such as, operations efficiency) that need to be considered while selecting the best transport technology for the MAN network.

Finally, although telecom deregulation has fostered competition in the interoffice core network, there remains a lack of competition in the local loop (so called the last mile) between incumbent carriers and CLECs. Michalis (2001) discussed the evolution of local access competition and the role of regulation in the EU (European Union) local loop competition. Gabelmann (2001) conducted research on loop unbundling issues in the European telecommunications market. Christodoulou and Vlahos (2001) published their research results on introducing "sunset clauses" in a "mix" of infrastructure and service competition models to promote local loop competition. Economides (1998) analyzed the US Telecommunications

Act of 1996 and its impact. These papers highlight the critical nature of policy and regulations in the local loop competition.

1.4 Approaches and Methodology

1.4.1 Literature Review

In order to capture the key issues of this study, we went through related literature to understand how scholars dealt with similar studies and projects. We learned from their valuable experience and useful results to avoid pitfalls that may have been made in the past. The processes of literature review are as follows: generalize a conclusion from a collection of literatures, abstract from the conclusion, and criticize and modify the conclusion. The types of literature are as follows: primary literature, secondary literature, and bibliographic instruments. From the literature review, we identified the drivers and draggers for the telecom industry boom and doom.

1.4.2 Scenario Analysis

In this paper, we analyzed the pros and cons in deploying Gigabit Ethernet technology in the MAN network. In addition, we analyzed two MAN network technology deployment scenarios, namely SONET/SDH and Gigabit Ethernet technologies. Several criteria were selected to address the qualitative issues in selecting the MAN network technology. Based on the scenario discussions, we summarized the issues and concerns in the carrier network.

For local loop competition, several scenarios were analyzed on how to promote and stimulate competition in the last mile. Under various assumptions, technology feasibility, policy setting, and cross-industry competition scenarios were discussed in detail. The summary of the scenario analysis serves as a good reference for a government agency in setting future local loop competition policy. Masini and Vasquez (2000) classified the scenario analysis into four types: (1) extrapolative and normative scenarios; (2) probable and desirable scenarios; (3) first- and second-generation scenarios; (4) trend, optimistic, pessimistic, and contrasting scenarios. In this paper, trend, pessimistic and middle ground local loop competition trends are taken as the basis of this study.

1.4.3 Fuzzy Multi-Criteria Decision Making (MCDM)

Analytic Hierarchy Process (AHP), developed more than 20 years ago while Dr. Thomas Saaty was a professor at the Wharton School of Business, continues to be the most highly regarded and widely used decision-making theory (Satty 1977, 1980). AHP has been widely applied to deal with resource distribution and proposal selection (Satty, 1980). When adopting AHP methods in carrying out research analysis, many different aspects must be taken into consideration. There are numerous evaluation indexes; moreover, their structures are hierarchical (Kerzner, 1989). Many scholars and experts have adopted the AHP method to deal with evaluation problems of relative importance (weighting) (Satty, 1980; Zahedi, 1986). The AHP method also helps in describing how much effect the high-level factors of the hierarchy have on lower-level factors in order to provide a more complete depiction of the structural and functional aspects of the whole system. As compared with a direct evaluation of the whole system, AHP provided more advantages. It is more effective, stable, and yields more flexibility (Perez, 1995). Local scholars such as Hwang, Hsin-ginn, and Chang, Jen-hsiung (2001) used the AHP method to set the weight of relative importance in performance evaluation. Wang, Nai-Hung (2000) also used the AHP method to analyze public preference of hospital types in his research where he conferred the selection factors of the general public. Wang, Mei-Hsiang and Hsu, His-Nan (2000) used the AHP method to conduct an integral analysis of a complex evaluation standard in the hope of assisting the managerial base in strategic decision making.

Many scholars use the AHP method to deal with strategy selection problems. A fuzzy notion was introduced into the AHP method (Bellman, et al., 1970; Buckley, 1985). Instead of asking the survey respondents to select a specific utility score, this notion allows a range of utility scores; this was used to study the marketing strategies of the information service industry (Tang, et al., 1999). Therefore, we use the Fuzzy AHP method to select multi-criteria MAN technologies.

1.5 Scope and Limitation

The scope of this research has the following limitations:

- In the telecom industry boom and gloom analysis, no analysis model was established to systematically identify the business drivers and draggers for the telecom industry. The divers and draggers were identified primarily based on journal review and expert in-depth interview.
- In the MAN network, although there are many competing technologies, we focused only on the comparison and trade-off between Ethernet technology and SONET/SDH.
- In the Fuzzy MCDM analysis, 12 of the 14 surveys were filled out by Chunghwa Telecom researchers and managers. CCL telecom development manager filled out the other two surveys. Therefore, the result of the Fuzzy MCDM analysis primarily reflected the incumbent carrier position and concerns. For new telecom carriers, using the same survey could result in different analysis outcomes as described in section 4.3.4.
- In the local loop network, we conducted only qualitative trade-off analysis among various access technologies.

1.6 Research Procedure and Flowchart

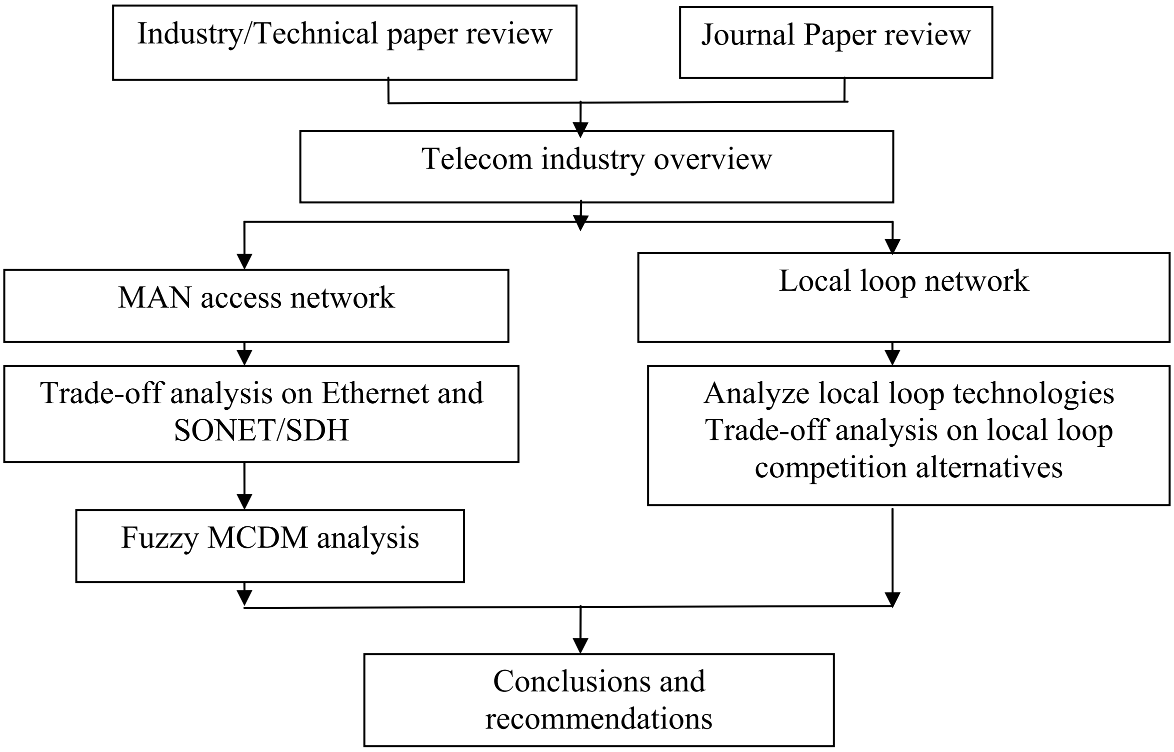


Figure 1. Research Procedure and Flowchart

1.7 Dissertation Organization

The paper is organized as follows: Chapter One described the research background, objectives, approaches and methodology; Chapter Two reviews the telecom industry boom and doom; Chapter Three analyzes the MAN access network and the LAN technology evolution; Chapter Four uses Fuzzy Multi-Criteria Decision Making approach to evaluate alternative MAN access strategies; Chapter Five discusses and analyzes the emerging access technologies and alternatives to stimulate local loop competition, and Chapter Six provides conclusions and suggestions.

1.8 Glossary

1.8.1 Acronyms

AAL 5: ATM Adaptation Layer 5

ADM: Add-Drop Multiplex

ADSL: Asynchronous Digital Subscriber Line

xDSL: x Digital Subscriber Line

AHP: Analytic Hierarchy Process

ASP: Application Service Provider

ATM: Asynchronous Transfer Mode

ATM VP Ring: ATM Virtual Path Ring

ATM PVC: ATM Permanent Virtual Circuit

BNP: Best Non-fuzzy Performance

CLEC: Competitive Local Exchange Carrier

COA: Center of Area

CSMA/CD: Carrier Sense Multiple Access with Collision Detection

DCS: Digital Cross-Connect System

DS (DS0, DS1, DS3): Digital Signal (DS0, DS1, DS3)

DWDM: Dense Wavelength Division Multiplexing

GR-253: Generic Requirement-253

IEEE: Institute of Electrical and Electronic Engineers

IP: Internet Protocol

LAN: Local Area Network

LRAIC: Long-Run Average Incremental Cost

MAN: Metropolitan Area Network

MCDM: Multiple Criteria Decision-Making

MOM: Mean of Maximal

OSS: Operations Support System

PATTERN: Planning Assistance through Technical Evaluation of Relevance Number

PLL: Phase Locked Loop

QoS: Quality of Service

RPR: Resilient Protection Ring

SOHO: Small Office, Home Office

SONET/SDH: Synchronous Optical Network/Synchronous Digital Hierarchy

SONET/SDH MSPP: SONET/SDH Multi-Service Provision Platform

SONET OC-192: SONET Optical Carrier -192

SSP: Storage Service Provider

TDM: Time Division Multiplexing

VLAN: Virtual Local Area Network

WAN: Wide Area Network

WiMAX: World Interoperability for Microwave Access

1.8.2 Terms

AAL 5:
ATM Adaptation Layer 5 – An ATM protocol layer for transporting different service data units

ADM:
Add-Drop Multiplex – A multiplexer capable of extracting or inserting lower-rate signals from a higher-rate multiplexed signals without the completely demultiplexing the signal.

ADSL:
Asynchronous Digital Subscriber Line - Asymmetric Digital Subscriber Line (ADSL), a modem technology, converts existing twisted-pair telephone lines into access paths for multimedia and high-speed data communications.

xDSL:
x Digital Subscriber Line – various DSL technologies (e.g., HSDL, VDSL)

ATM:
Asynchronous Transfer Mode – A cell-based, fast-packet technology that provides a protocol for transmitting voice and data over high-speed networks.

ATM VP Ring:
ATM Virtual Path Ring – Using ATM virtual ring architecture to improve the reliability of voice and data communications and the efficiency of bandwidth utilization.

ATM PVC:
ATM Permanent Virtual Circuit – A Permanent Virtual Circuit will establish a fixed path for ATM traffic transmission until the circuit is taken down.

CSMA/CD:

Carrier Sense Multiple Access with Collision Detection – A channel access mechanism wherein devices wishing to transmit first check the channel for a carrier. If no carrier is sensed for some period of time, devices can transmit. If two devices transmit simultaneously, a collision occurs and is detected by all colliding devices, which subsequently delays their retransmissions for some random length of time.

DCS:
Digital Cross-Connect System – A transmission system that provides cross-connect functions for tributaries between input and output signals.

DS (DS0, DS1, DS3):
Digital Signal (DS0, DS1, DS3) – A digital signal hierarchy for different signal transmission speed.

DWDM:
Dense Wavelength Division Multiplexing - An optical technology used to increase bandwidth over existing fiber optic backbones. DWDM works by combining and transmitting multiple signals simultaneously at different wavelengths on the same fiber.

GR-253:
Generic Requirement-253 – A requirement that specifies the SONET requirements.

LAN:
Local Area Network - A local area network (LAN) is a group of computers and associated devices that share a common communications line or wireless link and typically share the resources of a single processor or server within a small geographic area (for example, within an office building).

MAN:
Metropolitan Area Network – A data communication network covering the geographic area of a city (generally, larger than a LAN but smaller than a WAN)

OSS:
Operations Support System – Systems that provide operations support for telecom service providers.

PATTERN:
Planning Assistance through Technical Evaluation of Relevance Number

PLL:
Phase Locked Loop – A method to extract timing from the incoming signal.

RPR:
Resilient Protection Ring – A term that refers to the specific efforts of the IEEE 802.17 working group to generate a resilient packet ring protocol for Wide and Metro Area Networks.

SONET/SDH:
Synchronous Optical Network/Synchronous Digital Hierarchy - SONET and SDH are a set of related standards for synchronous data transmission over fiber optic networks. SONET is the United States version of the standard published by the American National Standards Institute

(ANSI). SDH is the international version of the standard published by the International Telecommunications Union (ITU).

SONET OC-192:
SONET Optical Carrier –192 – Defined standard for the SONET optical data rate transmitting at 9.953 Gb/s.

TDM:
Time Division Multiplexing – A form of transmission in which different flows are combined on the basis of time slots.

VLAN:
Virtual Local Area Network - Virtual LANs (VLANs) can be viewed as a group of devices on different physical LAN segments which can communicate with each other as if they were all on the same physical LAN segment

WAN:
Wide Area Network - A wide area network (WAN) is a geographically dispersed telecommunications network. The term distinguishes a broader telecommunication structure from a local area network (LAN).

2. Telecom Industry Review and Analysis

The telecom industry has long been perceived as stable and growing. In the US, Bell Systems has provided consumers with stable POTS (Plain Old Telephone Service) for over a century. Until the emergence of the Internet, voice had been the predominant service. As packet-switched data traffic converged with circuit-switched voice traffic, new network architecture and requirements evolved, and the demand for next generation network infrastructure surged. Additionally, the abundance of capital feeding the vision of 3G multimedia mobile service markets further accelerated the growth of the telecom industry (Cheng, et al., 2003). Through journal review and in-depth expert interviews, major business drivers and draggers were identified for the boom and gloom of the telecom industry. The selection of these drivers and draggers were primarily based on their significant impact on the overall telecom industry market capitalization.

2.1 Growth in The Telecommunications Industry

Major business drivers for this phenomenal growth have included global telecommunications deregulation, e-commerce, high-speed Internet access, IP packet technology, mobile communications services, the new digital economy, acquisition strategy, and vendor equipment financing.

2.1.1 Driver: the global telecommunications deregulation

Telecommunications deregulation has opened up the local, long-distance, international, cable and cellular telephone markets in many countries. The breakup of telecom monopolies has enabled competitive carriers to offer telecom services and has forced incumbent monopolies to upgrade their networks, improving overall telecommunication services. New carriers, such as Qwest Communications and Level 3 Communications of the U.S., deployed optical fiber core networks to offer end-to-end broadband services to US enterprise customers. Carriers, such as Global Crossing, deployed undersea optical fiber cables connecting continents. Following international standards, new wireless service providers can offer seamless wireless roaming service to mass-market customers. For example, since wireless service was deregulated in Taiwan, six new cellular service providers began competing with incumbent Chunghwa Telecom, the previous Taiwan telecom monopoly. Telecom deregulation permitted cable operators to offer voice service in their cable network which pressured the incumbent telephony operators to upgrade their twisted copper pair network infrastructure to offer xDSL broadband access services. Telecom deregulation has eliminated many telecom business limitations and has created an open competitive environment for telecom equipment vendors and service operators around the world.

Since many new carriers have had to start from scratch, the need for new telecom infrastructure equipment was tremendous, particularly for fiber optic and IP data networking equipment. Additionally, the incumbent operators also generated a huge demand for network upgrades and enhancements. As a result, growth in the telecom equipment market was extraordinary, adding even more fuel to the worldwide economic boom, particularly in the telecom industry. (Table 1). In this driver, government played a pivotal role in generating new telecom business demand.

Table 1. Equipment Needed by Telecom carriers

Carriers	**Needs**
New Telecom Carriers	Deploy new telecom infrastructure
Incumbent Carriers	Upgrade and enhance existing network infrastructure in anticipation of a surge in Internet traffic and competition in service quality

2.1.2. Driver: E-commerce

The proliferation of the Internet and the WWW, as well as the development of B2B (Business to Business) and B2C (Business to Consumer) E-commerce has enabled enterprises and consumers worldwide to conduct business through communication via telecom networks. For example, Amazon.com sells books and other merchandise via the Internet. Dell Computer employs B2C to allow customers to order computers on-line, while it uses the Internet to establish supply chain management systems with its suppliers to minimize inventory and speed up delivery.

In addition, there are e-marketplaces for suppliers and buyers to trade electronically over the network (Business Online 2000). Closely related to B2B and B2C is the ASP (Application Service Provider) model which delivers software application services to users via the network (Business Online, 2000). For example, many small-sized IC design houses are not able to afford expensive IC-design software tools. An ASP model allows IC design houses to use the tool via the network on a monthly subscription fee basis, which can avoid the costly up front capital investment and on-going software maintenance and upgrade expenses.

Lastly, to ensure reliable Internet enabled E-commerce service, IDC (Internet Data Center) and web hosting companies (such as Exodus) specialize in providing around-the-clock backend computer processing and storage services (Business Online, 2000). Some of them have even allied with telecom carriers to secure the necessary bandwidth to minimize transmission delay for their customers.

These new E-commerce business models have moved many business activities from the traditional physical world to cyberspace, where they have created huge demand for information technology and telecom networking equipment, such as bridges, routers, and servers (Table 2). Essentially, business and end user E-commerce needs stimulated telecom growth.

Table 2. Equipment Needed by E-commerce Companies

E-commerce Player	**Needs**
Dot-com	Computer servers; routers
Trading Hub	Computer server; routers
IDC	Server farm; routers; facility
ASP	Bandwidth; servers
B2B – supply chain management	Servers; routers

2.1.3 Driver : high-speed Internet access

The explosion of Internet traffic was beyond anyone's imagination (Beranek, 2000). Regardless of measurement criteria, its growth was remarkable on all fronts – the number of hosts, the number of users, the amount of traffic, the number of links, the bandwidth of individual links, or the growth of ISPs (Internet Service Providers).

Web surfing, e-mail, on-line banking, on-line trading, music on demand, and distance learning all rely on the last-mile high speed Internet access link between telecom carrier office and customer premises. As these web-based activities become more enriched with video, audio, and graphics, customers are no longer satisfied with the traditional modem dial-up access, and instead broadband access becomes essential. To meet customer demand, ISPs and cable operators use xDSL and cable modem technologies to offer high speed Internet access. In the core network, Gigabit routers and Gigabit Fiber Optic Transmission Systems have been deployed to make ready for broadband Internet services. These broadband access and core network upgrades have again created huge demand for telecommunications equipment (Table 3).

Table 3. Equipment Needed for High Speed Internet Access

Internet Connection	Needs
Access Network	xDSL; cable modem
Core Network	Gigabit Router; Gigabit Fiber Optic Transmission System

2.1.4 Driver : IP packet technology

As Internet and WWW applications grow worldwide, data traffic is expected to exceed voice traffic in the PSTN (Public Switched Telephone Network). To meet this demand, the traditional PSTN is pressured to evolve. Circuit switching, the foundation of the PSTN is being supplanted by packet switching, a technology more suitable for transporting data. Routers and Call Agents, so called "soft switches"-- such as Sonus soft switch -- are based on IP technology and are being developed and deployed to replace traditional circuit switches. In addition to these, a whole spectrum of IP-based equipment and functionalities will need to be developed and integrated into the new network. The evolution of IP technology has pushed development of IP-based telecom equipment (Cheng, et al., 2003).

Furthermore, to achieve the full operational efficiency of IP networks, the vision of an "All IP" network has been promoted by the industry. "IP over DWDM" and "Wireless IP" have been hot R&D topics in the NGN (Next Generation Network) IP deployment. Since the service features, operations, and management of an IP network are fundamentally different from that of the existing PSTN network, this IP network evolution will indeed require huge capital spending by telecom service providers. Big R&D investment among telecom manufacturers to develop the new IP technologies and equipment, ranging from IP CPE gateway, IP core network, and IP network management systems, etc., have already begun. The emergence of IP packet technology has created an expensive new technology push (supply side driver) in the telecom industry.

2.1.5 Driver : mobile communications services

The convenience of wireless communications generated tremendous global user demand. In particularly, GSM (Global System for Mobil Communications) has had unprecedented success in the worldwide wireless communications market. By 2000, two out of three Europeans had a mobile phone. Asian GSM market penetration is also proceeding at breath-taking pace. For example, cell phone market penetration rate in Taiwan has reached over 100%. Seamless roaming ability is one of the key features for GSM's success in the worldwide wireless market, and to lure consumers into becoming mobile service subscribers, wireless service operators subsidize mobile handsets. While wireless operators are busy expanding their wireless networks, mobile handset manufacturers also enjoyed revenue expansion (Table 4). Today, mobile communications have become the fastest growing and most lucrative market for telecom service providers and manufacturers (Cheng, et al., 2003).

Table 4. Equipment Needed by Mobile Service Operators and Subscribers

Mobile Operators/Subscribers	**Needs**
Mobile Core Network Operators	Base Station, Mobile Switching Center
Mobile Service Subscribers	Mobile Handsets

2.1.6 Driver: promise of new digital economy

The perceived potential of E-commerce via the Internet created an optimistic vision of the so-called "New Economy" which was going to revolutionize the traditional brick-and-mortar "Old Economy". Underpinning the "New Economy Internet Era" was the assumption and perception of a new economic business model - "Fast coverage of network facilities and dominance of customer base take precedence over short-term revenue or profitability." It was assumed that profitability would come naturally after market share was secured. To attract customers, Websites rushed to offer free services and content, generating tremendous Internet traffic throughout the world. New Economy proponents thought that Internet traffic would go wherever bandwidth was available, and that delays in network expansion would only result in customer dissatisfaction with service throughput and response time, an increase in customer churn rate, loss of revenue, and eventual business decay. The New Economy became a race to expand investment into service development as well as network equipment and facilities deployment.

The stock market and the venture capitalists concurred and supported such visions and strategies. The combined results were an abundant supply of capital generously invested to the Telecom Service Providers, E-Commerce Providers, Information Content Providers, Internet Services Providers, etc., and led to an unprecedented expansion in the telecom industry from 1995 to 2000 (Cheng, et al., 2003).

2.1.7 Driver: acquisition strategies

As Internet service providers continue to demand faster broadband Internet technologies and solutions to compete in the market of digital economy, telecom equipment suppliers remain under pressure to shorten the development cycle to come up with new versions of products and systems. Many suppliers acquire small, innovative technology companies to gain access to new technologies and product ideas for IP, optical, broadband, and wireless, etc. For example, Cisco acquired more than 40 companies in the past few years to beef up its networking product offering.

Since the stock prices of Cisco and most other telecom manufacturers had high valuations over the past few years, they were able to leverage their high stock prices to acquire target startup companies. For example, Cisco paid a premium price of $7 billion for optical equipment maker Cerent and $5.7 billion in stock for ArrowPoint Communications. Overall, Cisco's acquisitions have contributed to 40% of Cisco's $25 billion in revenue in 2000 (Shinak, 2001).

Imitating Cisco's successful acquisition model, many other telecom suppliers employed the same strategy to broaden their product offerings. Often, bidding on acquisition targets created tremendous market values for startups, which may not have even had a customer or a commercial product. These high acquisition prices on telecom startups not only changed the traditional rules of "market valuation", but also changed the rules of "wealth creation". Consequently, the impact of these high market valuations of telecom startups attracted more venture capitalists investing in this sector. When investors perceived an increase in their market competitiveness, the acquirers' market valuation also increased. The stock market's positive feedback on acquisition contributed to the temporary prosperity of the telecom industry.

2.1.8 Driver: telecom equipment vendor financing

Building up telecom infrastructure requires huge capital investments. However, it takes time to sign up fee-paying subscribers and to build up revenue streams from telecom services. To obtain the necessary capital for network deployment becomes a critical issue, particularly for new telecom service startups. Naturally, telecom service providers sought financial assistance from telecom equipment vendors. The financial assistance could range from investing money in the company, accepting startup company stock in exchange for equipment, or making loans with flexible payments towards the purchase price of the equipment. In a promising telecom market where service operators looked at promising future and equipment manufacturers enjoyed tremendous revenue growth, "vendor financing" was a common practice among telecom equipment suppliers. In a highly competitive telecom equipment market, "vendor financing" was also essential for major telecom equipment manufacturers to win contracts from telecom service providers. With this easy source of capital, new startups as well as incumbent telecom service providers further accelerated their network buildups to expand their market size and to compete for market share. This buildup, in turn, fueled the demand for telecom equipment and resulted in revenue growth for telecom equipment vendors (Rosenbush, et al., 2001).

Table 5 summarizes the business drivers that brought about the explosion of growth in the telecommunications industry.

Table 5. Summary of Business Drivers for Telecom Boom

Business Drivers	**Results**
Telecommunications Deregulation	New CLECs, ILECs, cable and mobile wireless carriers; demand in new network infrastructures and network upgrades
E-Commerce	Demand in IT and networking products
High Speed Internet Access	Demand in high speed Internet access and core equipment
Packet Technology	Demand in IP NGN products
High Growth of Mobile Communications	Global demand of mobile equipment
New Digital Economy	Market shares are top priority and bandwidth drives demand; continuous infrastructure investment
Acquisition Strategy	High market valuation; abundant capital for start ups
Vendor Financing	Available capital for faster network buildups; more capital spending

2.2 Gloom in The Telecommunications Industry

Many factors contributed to the slowdown of the global economy, which started the third quarter of 2000. However, the telecom industry has certainly been one of the major contributors to this economic downturn. In this section, we look at the history of the telecom industry to see what "business draggers" have slowed down the telecommunications industry.

Over the years, too much capital was invested in the telecom industry, which resulted in too many companies producing too many products. The telecom network was overbuilt, and bandwidth was oversupplied. Oversupply inevitably caused fierce price competition. The narrow or even negative profit margins dampened capital spending among telecom service providers. Decreased spending further created a downward spiral effect on the telecommunications industry for both service providers and manufacturers (Cheng, et al., 2003).

In this section, we summarize various business draggers, including the 3G license auction, uncertainty of 3G profitability, network over-build and brutal price competition, the heavy debt of telecom startups and dot-coms, bad loans of telecom vendors, second-hand equipment, B2C and B2B investment spending cuts by corporate America, and write-offs on acquisitions which all contributed to the downturn of the telecommunications industry.

2.2.1 Dragger: 3G license auction

From 1994 until now, the U.S. government has received spectrum bids totaling more than $41 billion. Envisioning the potential fiscal income to the government, and inspired by the success of GSM, a few European telecom regulators chose to award their 3G licenses based on the auction mechanism. In 1997, the British government hired game theorist Ken Binmore, a London University economics professor, to help design a 3G auction. In April 2000, five licenses sold for an incredible $35.4 billion, shocking everyone. It left even the free spending mobile industry breathless (Foroohar, 2001).

The impact of the UK spectrum auction quickly spread to other European countries. In August 2000, the total take for the German auction was a record $46.1 billion. In 2000, carriers across Europe paid $110 Euro billion for 3G licenses. (See Table 6) Inevitably, this prohibitive amount of money had to come from global financial markets.

Table 6. 3G License Costs

Country	Issue date	License Costs in Billions	License cost per Capita
Finland *	3/99	$0.0	$0.0
Spain	3/00	0.5	11.2
Britain	4/00	35.4	594.2
Japan **	6/00	0.0	0.0
Netherlands.	7/00	2.5	158.9
Germany	08/00	46.1	566.9
Italy	10/00	10.0	174.2
Austria	11/00	0.7	86
Norway	11/00	0.9	20.5
S. Korea	12/00	3.3	69.6
Australia	3/01	1.2	30.3
Singapore	4/01	0.2	42.6

*Granted without compensation

** Granted to the provider at no cost pending review

In addition to auction bids, these carriers had to spend huge amounts of money to build 3G network infrastructure. The high licensing expenses put these telecom carriers in deep debt even before they started to build their 3G networks, let alone generate any revenue. Coupled with the fact of dropping average revenue per GSM user and the uncertainty of 3G launch dates and consumers' acceptance of 3G services, bankers and financial analysts became concerned about the future financial soundness of European mobile service operators. Fearing the lack of payback capability of these mobile operators, banks hesitated to lend to these telecom carriers. Stock market analysts realized that mobile operators could no longer sustain high enough profitability to justify their high valuation. Alarmed investors began profit-taking actions by selling mobile service stocks. As a result, stock prices of financial institutions that had financed or invested heavily in the telecom industry also plunged. Doubt about mobile operators' limited earning capability arising from prohibitively expensive 3G licensing costs rippled across different industry sectors on different continents (Foroohar, 2001). In retrospect, it appears that the financial burden created by European 3G licensing auctions triggered the global economic slowdown.

2.2.2 Dragger: uncertainty about 3G rollout and profitability

In anticipation of a continued fall in average revenue per user, second generation wireless service operators looked to 3G broadband services as the next promising opportunity for business growth. Wireless equipment manufacturers competed to invest heavily in the R&D of 3G system equipment and handsets. Spending by most of the major wireless equipment manufacturers on 3G products and system development curved upward steeply (Foroohar, 2001). As 3G equipment manufacturers continued to promote and encourage 3G capabilities and full-color video wireless handsets, wireless service providers, investors, and consumers became excited and anxious for the arrival of 3G.

However, in auctioning 3G licenses, the U.K. and Germany in April and August of 2000 required the licensees to pay prohibitive auction bids. Wireless carriers and investors became seriously concerned about the availability date for 3G network systems and the potential profitability of 3G services. They found that 3G standards had not been finalized, a few interfaces had not been defined, and the technologies of 3G system equipment and handsets would not be mature until the end of 2002 or 2003. Japan had to postpone its initial 3G service launch from May till October of 2001. Since experimental 3G systems were based on an unstable 3G standard, their service offerings could be only a subset of full-blown 3G services. Besides disappointment over the delay of 3G availability, there exists competition from 2.5G substituting technologies, i.e., GPRS and EDGE, which can offer similar wireless data services. These concerns about 3G have created a negative impact on the stock market performance of the mobile service industry.

2.2.3 Dragger: network overbuild and brutal price competition

As a result of telecommunications deregulation in the U.S. and some European countries, many new telecom service operators were established, causing an excessive over-build of telecom networks in almost all telecom markets. According to Solomon Brothers (Hu, 2001), worldwide telecom carriers spent over $35 billion to build up to 100 million miles of fiber optical network in 1999 and 2000. The utilization of such broadband optical networks, however, only reached 5%. As technological enhancements in optical communications advanced, new generations of telecom equipment e.g. DWDMs, and routers etc., with larger capacity, faster speed, and lower per unit costs kept coming on the market, pushing telecom operators to purchase them just to stay competitive. This excessive capacity inevitably resulted in price competition, and prices for long distance data transport fell 20% to 50% annually (Foroohar, 2001).

By 2000, most telecom service providers had expanded their capital investment and operating expenses, substantially exceeding the growth rate of their service revenues. Additionally, the price war further eroded service operators' future prospect of profitability (Henry, 2001). When bandwidth became excessive and demand lagged behind never-ending investment requirements, investors began questioning the validity of the business model of the telecom service industry.

2.2.4 Dragger: heavy debt among telecom startups and dot.coms

In the past few years, global telecom service operators, particularly in the U.S. and Europe, had access to abundant capital through financial institutions, stock markets, and vendor financing for their network buildups and expansions. Consequently, they accumulated heavy debt. Total carrier debt reached 91% of sales compared with only 29% in 1997 (Henry, 2001). As the capital market felt the rising risk of these heavy debts, it balked at its over-optimistic investment practices and instead focused on the bottom line of the telecom start-ups and

Internet related companies. Investors looked for profit, not subscriber numbers or market share. The resulting downward spiral effect on startups and Internet dot-coms was tremendous. Some analysts estimated that U.S. and European telecom carriers might have $700 billion in debt and more than $100 billion in junk bonds that will either end up in default or be restructured (Elstrom, et al., 2001). The impact of the heavy debt of telecom carriers became a major contributor to the tumble of global stock markets in the 3rd quarter of 2000.

2.2.5 Dragger: bad loans by telecom vendors

As more telecom start up companies experienced bankruptcies and failures, defaulted loans provided by telecom manufacturers caused serious financial damage. For example, the five leading North American equipment makers alone had $4.8 billion worth of vendor financing on their books. Nortel Networks had $1.6 billion; Cisco had $475 million; and Lucent Technologies Inc. had $1.3 billion. As telecom service providers failed, vendor-financed bad loans dragged the telecom manufacturing industry down (Rosenbush, et al., 2001).

2.2.6 Dragger: second-hand equipment

With the abrupt slow-down of the telecom service industry, telecom equipment purchases came to a virtual standstill. These purchase cuts created excessive inventory problems for networking equipment suppliers and computer server manufacturers. Compounding these inventory problems, the bankrupt dot-com companies flooded the second-hand equipment market with many used or "near new" routers, servers, and other networking gear which they sold for only one-tenth of the original price. The supply of second-hand equipment worsened the sales of new telecom equipment. For example, Cisco Systems' inventory ballooned a further 29% in the second quarter of 2001 to $2.53 billion after a massive 59% increase in the first (Miller, et al., 2001). Due to their mutual dependence, the telecom equipment industry collapsed following the telecom service industry in this economic slow-down.

2.2.7 Dragger: B2C and B2B investment cuts

Global stock investors not only scrutinized the profitability of telecom service and equipment industries, but also began using the evaluation criteria of the "old economy" to scrutinize the financial health of all Internet related companies and investment activities of the "new economy". Consequently, not only investments in dot-com companies, but also spending on B2C and B2B hardware and software quickly fell. Most US corporations reported spending only one-third of their original projections in 2001 (Miller, et al., 2001).

The impact of these cutbacks in capital spending on telecom and information technology equipment started a downward spiral for the telecommunications industry and across all related downstream industries.

2.2.8 Dragger: write-offs of acquisitions

Acquisition had been one of the most effective strategies that telecom manufacturers employed to expand their business portfolios; however, many of those acquisitions were done under the assumption of sustained market growth. Some were worth very little after the economic slowdown. From January 2000 to February 2001, Nortel spent $17.1 billion on acquisitions. Then, in June 2001, Nortel announced a $12.3 billion write-off, which was primarily associated with those acquisitions as "impaired assets". Cisco also took $289 million in write-offs for impaired assets. Although Cisco took a relatively small write-off compared to Nortel, there were still huge potential write-offs for Cisco as well as other telecom manufacturers in light of their past acquisition investments. As the economy slowed down, these "impaired assets" further deepened the financial crisis in the telecom manufacturering industry (Lashinsky, 2001).

Table 7 summarizes the business draggers that undermined the telecommunications industry boom.

Table 7. Summary of Business Draggers Undermining the Telecom Boom

Business Draggers	Results
3G license auction bid	Heavy financial burden on 3G telecom operators; financial institutions hesitated to continue to support telecom carriers; triggered the global telecom industry slowdown
Uncertain 3G profitability outlook	Created a negative impact on the stock performance of the mobile profitability service industry
Network overbuild and brutal price competition	Investors began to question the validity of the telecom service industry's business model and profitability
Heavy debt among telecom startups and dot.coms	Short on investment capital, most of them ended up in bankruptcy which contributed to the tumble of global stock markets
Second-hand equipment	Cut sales of new telecom equipment
Bad loans by telecom manufacturers	Caused severe financial damage on telecom manufacturers
B2C and B2B investment cuts	Generated a downward spiral effect on the telecom and related industries
Write-offs on acquisitions	Deepened the financial crisis on the telecom manufacturing industry

2.3 Telecommunications Industry's Latest Developments and Possible Next Steps

After the telecommunications bubble burst in late 2000, the overall industry was damaged severely. The giant telecom carriers and manufacturers underwent large scale downsizing and were forced to reverse their financial forecasts and growth prospects. Many companies folded. Further, questionable accounting practices and bankruptcies dampened investors' confidence in the telecommunications industry. For telecom service operators, lack of capital meant delays in network enhancement and new service development. The impact on telecom equipment manufacturers will likely be huge write-offs in accounts receivable and shrinkage of future revenues. Hence, more telecommunications consolidations may be forthcoming. The short-term outlook for the telecommunications industry will be bleak until existing losses are recovered. Is, however, the information revolution dead? Will the telecommunications economy thrive again? If so, when? In this section, we will examine the internal innovation and external forces and trends that may push the telecommunications industry back on track in the future.

2.3.1 Adopting supply chain management

The strategy for a growing economy is investment for expansion. However, for a shrinking economy, the strategy has to be cost cutting and improving efficiency. Focusing on core competency and outsourcing non-core functions has become a global trend across industries. Dell Computer's success strategy in the PC industry is a role model for the telecommunications industry. In this horizontal integration business model, overall operational efficiency is gained through supply chain management across all levels of suppliers. Sharing information with upstream suppliers on market trends as well as products ordered by end customers on a near real-time basis can increase production planning efficiency, reduce inventories, and speed up product delivery by upstream suppliers as well as downstream telecommunications equipment vendors. Pursuing Supply Chain Management can push costs down, drive up demand, and improve the telecommunication industry's financial performance. In the current over-supplied telecom market, more outsourcing and partnership formation will occur in the industry, and supply chain management systems will be the key enabler for such horizontal integration.

2.3.2 Generating new revenue with SMS and MMS

In light of the uncertain 3G perspectives and many wireless carriers' difficult financial situations, it might take several years before 3G wireless platforms can be established to deliver on promised multimedia services. Meanwhile, wireless carriers are looking for killer applications to generate new revenue based on the existing 2.5G GPRS data platform. Currently, SMS (Short Message Service), a text-based messaging service, has become quite popular among cellular phone users. Greetings, jokes, stock quotes, weather/flight information, and bank statements are among the many kinds of SMS services offered by wireless carriers. An enhancement to SMS is MMS (Multimedia Message Service), which allows subscribers to transmit pictures, music or video clips, as well as file transfers among mobile phone subscribers. Fortunately, such enhanced multimedia service can be offered based on the existing 2G wireless network infrastructure. It means no huge network investment is necessary to generate potentially substantial revenues for wireless carriers. Moreover, once subscribers become familiar with and accustomed to the MMS services, they will demand faster transmission speed and wider bandwidth. By that time, broadband 3G technologies will be driven by market needs rather than a new technology looking for opportunity. The promising interactive Multimedia Message Service not only can help generate additional revenues, but can also prepare a smooth path for evolution to third-generation wireless communication (Cheng, et al., 2003).

2.3.3 Emerging wireless-LAN technology

While 3G promises to offer broadband wireless Internet access data services in the future, IEEE 802.11 wireless LAN technology is becoming increasingly available in the enterprise and public hot spots (e.g. airports, restaurants, hotels, and other public places). In addition, with the growing penetration of ADSL/cable modems into the residential market, there is a growing need to connect multiple PCs and peripherals in homes. As installation becomes easier and prices fall, wireless LAN will work well as a home network. The popularity and quick proliferation of wireless LAN can be attributed to the following factors:

1. Need to access the Internet outside the office or home

2. Popularity of notebook PCs and PDAs
3. Availability of enterprise virtual private network applications
4. High data transfer rate (e.g. 11 Mps or 54 Mps),
5. Affordable equipment prices
6. Compatibility with existing LAN protocols (IP compatible)
7. No operations license or frequency usage fees required (ISM band)

Although LANs have some potential in the wireless data service market, wireless LANs also have several disadvantages for broadband wireless Internet access, and such limitations constrain wireless LAN from becoming a broad-based public service offering. For example, LAN lacks large area coverage for seamless service; small base station coverage restricts high-speed mobility service; it lacks features such as roaming, security, and privacy protection that are expected from a public telecommunications network. These situations may improve since a few fixed-line carriers are planning to deploy wireless LANs on a large scale.

The emergence of wireless LAN has changed the landscape of existing wireless service competition, and it has negatively impacted the deployment of 3G networks. However, since the strength of 3G is in its wide-area coverage and high-speed mobility, wireless LAN could potentially complement 3G networks by providing subscribers with a variety of service capabilities in the future.

2.3.4 3G Business models for wireless services

In the 2G arenas, subscribers create their own voice content and the wireless carriers simply build wireless networks to establish connectivity between subscribers. Because 3G technologies target interactive multimedia services, business models for 3G carriers become much more complex. First of all, 3G wireless carriers need to make sure that they provide appealing information content and service capabilities, either homegrown or developed through partnership with ICPs (Information Content Providers), in order to attract subscribers to the multimedia services. Second, because 3G handsets must process, store, and display large amounts of data, they must have specially designed operating systems (e.g. Symbian), faster CPUs, larger color displays, and more battery capacity. Consequently, the 3G-handset prices run as high as $800 dollars (Baker, 2002). Furthermore, information services face language and format compatibility issues. For example, German travelers in Spain can check weather and movie schedules back home in Berlin, but unless they understand Spanish, they can not utilize information provided in Madrid. Because the delivery of a 3G-multimedia service will involve wireless network infrastructure, information content, and CPE (customer premises equipment), the issue of interoperability among various providers is critical. Not only network transmission and protocol layers needs to interoperate, but also the presentation layer of Web services and applications need to work seamlessly in order to fulfill 3G promises. Nevertheless, 3G handsets can roam across service providers' boundaries, but the 3G services may not be as easily portable as expected. All these vulnerabilities are business challenges faced by 3G services providers (Baker, 2002), and they require a genuinely concerted effort among all 3G players to truly realize the potential of 3G multimedia services.

In contrast to the challenges of providing multimedia content, users themselves create the content of video telephony. Hence, mobile video telephony has the potential to be one of the killer applications for 3G. The recovery of the global economy, the emergence of 3G killer applications, the price to performance ratio of 3G services, and the availability and affordability of 3G handsets will impact the growth of 3G services.

2.4 Summary

In this section we discussed the drivers and draggers that caused the expansion and contraction of the global telecom industry before and after the year 2000. The growth was stimulated by the prospect of the "New Economy", but unfortunately expectations were unrealistic: the evolution from the old economy to the New Economy would happen much faster and would have a greater impact. Consequently, too many telecom service operators sprang up; there was too much investment in the telecom industry and in telecom R&D; and too many people became employed in the telecom industry. The resulting over-capacity in the telecom network and insufficient revenue for service providers brought about the situation facing the industry today. Prohibitively high auction bids for 3G licenses in the UK and Germany weakened the optimistic mood of investors towards the telecom industry, and this loss of confidence kicked off the downward spiral of the telecom market valuation and dragged over-priced New Economy companies down.

In the next two sections, we will focus on two important issues that are of particular important to the telecom industry in light of the current environment. These two issues are the MAN (Metropolitan Area Network) network access strategy and the local loop access and competition.

3. MAN Access Network

The rapid increase in internet users throughout the world has resulted in exponential growth of Internet traffic in WANs (Wide Area Networks). Despite the recent telecom industry slowdown, worldwide Internet traffic, which is continuing to double every year, is forecast to reach 5,175 petabits per day in 2007 from 180 petabits per day in 2002 (Telecommunications Industry Association, 2002). In addition to more users, Internet applications have become more bandwidth intensive as multimedia content becomes indispensable. To meet the increased demand for bandwidth, DWDM (Dense Wavelength Division Multiplexing) optical systems have been widely deployed in the backbone network (Ferreira, et al., 2002). Residential networks deploy ADSL (Asynchronous Digital Subscriber Line) and cable modems to provide subscribers with broadband access (Cheng, et al., 2003). Connecting the broadband access network and the broadband backbone network is the MAN (Metropolitan Area Network).

Originally, the metropolitan area networks were designed and deployed to handle voice traffic. Data requirements arose only as an afterthought. The infrastructure of MANs is mostly based on TDM (Time Division Multiplexing) technology, such as the SONET/SDH (Synchronous Optical Network/Synchronous Digital Hierarchy) system, which was designed for connection-oriented voice traffic rather than connectionless data traffic. As Internet data traffic has outgrown the traditional voice traffic and has become the dominant traffic type, the transmission throughput limitation of the MAN to handle data traffic has become a bottleneck. Enterprises face a growing bandwidth mismatch as they try to push 100 Mb/s LAN or Gigabit Ethernet applications through T1/E1 or T3/E3 pipes to the core network. The convergence of data, toll-quality voice, and broadcast-quality video bit streams in the metropolitan network requires MAN to evolve into a data-centric architecture (www.extremenetworks.com).

Due to the simplicity and cost-effectiveness of the protocol, Etherenet has been widely deployed in the enterprise LAN (Local Area Network) environment to handle the data traffic. Standard interfaces are readily available for 10/100/1000 Mbps Ethernet and the 10 Gbps Ethernet standard will also follow suit, given its IEEE standardization status. Because of Ethernet's relative simplicity and the economies of scale from the existing Ethernet installed based, infrastructure equipment costs for Ethernet are significantly less than for Frame Relay and ATM. The implications of this wide deployment extend beyond economics of scale to less obvious benefits. For example, Ethernet is much easier to learn than SONET and ATM technologies, which has an important impact on employment hiring and availability. This inexpensive, "good enough" technology/protocol is an asynchronous frame-based technology that has certain flexibility advantages over its more rigid cell-based or synchronous competitors. With suitable rate-limiting functions to manage the available resources, and with sufficiently large trunk capacity, Ethernet can provide rapid bandwidth on demand. For networking, it is important to remove the internworking issues between platforms and environments in order to make service provisioning and activation simpler. Because of its IP friendly nature, Ethernet eliminates a layer of complexity (e.g., ATM and SONET) from WAN access, thus reducing configuration requirements. Ethernet's plug-and-play feature also enables a simple migration path from low to high speeds. Consequently, integrating and interfacing end-customer IT (Information Technology) systems is relatively simple with Ethernet Metro services. All of the above advantages coupled with the newly developed Gigabit WAN capability have well positioned Gigabit Ethernet as a compelling technology to break the bandwidth bottleneck in the MAN environment (www.metroethernetforum.org).

This section first discusses the current mode of broadband service operations in the carrier's MAN environment. The enhancement of Gigabit Ethernet technology and the pros and cons of using Gigabit Ethernet technology in the MAN network are also reviewed. Finally, the implications of this technology evolution on carriers are discussed.

3.1 Architecture Comparison: Present Mode of MAN Operations

To provide enterprises with broadband services, Telecom carriers have deployed SONET/SDH rings in the MANs. With the promise of ATM (Asynchronous Transfer Mode) providing necessary QoS (Quality of Service) for multi-media services, ATM and SONET/SDH rings have become the choice of network architecture for most MAN carriers (www.extremenetworks.com).

In order to accommodate the burst nature of data traffic, customers are asking for features such as flexible bandwidth allocation and short service provisioning time. However, due to the TDM nature of the SONET/SDH network architecture, telecom carriers can offer only leased lines in fixed increments of DS0s (64kb/s), e.g. DS1 (24 DS0s) and DS3 (28 DS1s) or fixed bandwidths in optical carriers (Finneran, 2001). Variable bandwidth leased line service is not possible under the SONET/SDH architecture. There exists the throughput mismatch issue of fitting Ethernet service rates into SONET/SDH transmission rates. If a client wants a 100Mb/s Ethernet service, a carrier must provision a 155 Mb/s SONET channel to carry it, often throwing away the other 55 Mb/s. This inefficiency doesn't exist with Ethernet as the transmission layer. Furthermore, to provide an end-to-end SONET/SDH service requires a long lead-time for the coordination of equipment and facilities before service can be activated. At times, the provisioning time for a SONET/SDH service can range from weeks to months. This long service provisioning time has become detrimental in the competitive business environment (Information Technology, 2000).

Because of the lack of bandwidth flexibility and the long service provisioning time of SONET/SDH equipment, service carriers face the following business risks:

1.*Revenue Loss*: Since SONET/SDH can not offer variable bandwidth service, customers who need such flexibility, for example 10 Mb/s bandwidth, turn to other service providers who can meet this demand. This means a revenue loss for the SONET/SDH carriers.

2.*High Operating Cost*: The complexity of the ATM and SONET/SDH equipment provisioning not only requires a skilled workforce to do planning, engineering, installation and maintenance, but also needs comprehensive backend OSSs (Operations Support Systems) support in order to offer ATM over SONET/SDH services. Maintaining a well-trained workforce and sophisticated backend OSSs translates into high operating costs. In addition, the relatively high cost of ATM equipment further erodes a carrier's profitability.

To address the above business challenges, a solution with flexible bandwidth allocation, that is data/IP friendly and quick provisioning in the MAN is essential. Several competing technologies potentially address the above objectives. For example, ATM VP Ring, SONET/SDH MSPP, RPR (Resilient Protection Ring), and Gigabit Ethernet over WDM optical network are all emerging solutions for the MAN network. This section focuses on exploring the feasibility of adopting the Gigabit Ethernet technology in the MAN environment. Challenges as well as pros and cons of deploying Gigabit Ethernet technology in the MAN network will also be discussed (Clavenna, et al., 2001).

3.2 Evolution of Ethernet Technology: from LAN to MAN and WAN

Ethernet is the most widely used local area network (LAN) technology for data communications applications. The most popular version of Ethernet supports a data transmission rate of 10 Mb/s, while newer versions of Ethernet called "Fast Ethernet" and "Gigabit Ethernet" support data rates up to 100 Mb/s and 1Gb/s (1000 Mb/s). Ten gigabit Ethernet has been proposed and is under development. In addition to the traditional physical twisted pair copper cable, Gigabit Ethernet can also use fiber optical cable as the transmission media to take advantage of its large bandwidth capability. Today, Ethernet-based LANs already own 95% of the corporate desktops market share (Clavenna, et al., 2001). The share is steadily increasing as Ethernet continues to enhance its features and transmission rates.

Ethernet success in the LAN environment can be attributed to its continued technology enhancements to meet users' needs.

1. Initially, Ethernet employed basic technology and simple protocols to provide fundamental LAN functionalities. This simplicity translated into high reliability and low maintenance cost for Ethernet users. As a result, Ethernet became widely accepted in the LAN market.
2. Because each Ethernet node must first "sense" the medium before starting to transmit data, this requires the transmission delay to be small enough so that the node at the other end of the cable knows when to transmit in order to avoid a collision. This effectively limits the cable length of Ethernet LANs. As a result, Ethernet "islands" proliferated in the business environment. As more Ethernet islands were deployed, connecting Ethernet islands together for inter-communications became a challenge.
3. In 1984, the Ethernet switch (also known as Bridge) was introduced. It provided a simple, fast, self-learning algorithm, enabling multiple Ethernet networks to be transparently interconnected. This allows the expansion of the Ethernet LAN coverage in the enterprise environment. Furthermore, an Ethernet switch can increase the bandwidth efficiency of individual LANs by assigning users that don't communicate with each other very often to separate LANs, and users that do communicate with each other frequently to the same LAN. By doing so, the total effective LAN bandwidth can be increased. However, a basic Ethernet switch is limited to a single spanning tree environment and requires that no loops exist in the LAN topology.
4. In 1985, VLAN (Virtual LAN), also known as the multi-tree Bridge, was invented. VLAN

removes the single spanning tree limitation and enables arbitrary LAN topology. Furthermore, VLAN offers unlimited capacity and redundancy, traffic priority, and easy reconfiguration advantages for Ethernet users. With the introduction of the VLAN, Ethernet switches began to dominate routers in the LAN environment (Seifert).

Due to the characteristics of CSMA/CD (Carrier Sense Multiple Access with Collision Detection) protocol, Ethernet LAN transmission distance has to be proportionally reduced as the transmission rate increases. For example, for a minimum packet size of 64 bytes, a 10 Mb/s Ethernet can reach a maximum length of 2500 meters. Under the same packet size, a 100 Mb/s Ethernet LAN can only extend 250 meters. This distance limitation is of a particular concern for the introduction of Gigabit Ethernet. With the high data rate of a Gigabit Ethernet LAN, the applicable coverage is too small relative to the physical environment of an enterprise. Any resolution to this distance shrinking issue has to keep the integrity of the Ethernet frame structure in order to maintain backward compatibility with the large number of existing Ethernet equipment (Information Technology, 2000).

To solve this problem, while keeping the same Ethernet frame format, the concept of full-duplex Ethernet was developed. In a full-duplex Ethernet, the CSMA/CD protocol is replaced by the function of a switch. By removing the CSMA/CD protocol constraints and replacing it with a switch, Ethernet transmission distance is no longer limited. For example, using fiber optic transmission media, an Ethernet LAN can cover up to 80 kilometers. With this enhancement, Gigabit Ethernet can be extended to cover a metropolitan area. As a result, Ethernet LAN can expand into an Ethernet MAN (Metropolitan Area Network) (Information Technology, 2000). The evolution of Ethernet technologies is summarized in Table 8.

Table 8. Ethernet Technology Evolution

Ethernet	Provide LAN functions
Ethernet switch (bridge)	Connecting and providing switching functions for Ethernet LANs, and increasing Ethernet LAN bandwidth efficiency
VLAN (multi-tree bridge)	Eliminating LAN loop-free topology limitation, Enabling arbitrary LAN topology and capacity.
Gigabit Ethernet without CSMA/CD	Ethernet transmission distance is only limited by the transmission characteristics of the physical media.

The advantages of Ethernet are summarized below:

1. Plug and play fast provisioning time
2. Unlimited transmission distance (the removal of CSMA/CD)
3. No network topology limitation (the introduction of VLAN)
4. Multiple kinds of transmission media (fiber optical or coaxial twisted cable)
5. High transmission rate (10 Mb/s, 100 Mb/s, 1 Gb/s, 10 Gb/s and higher rates)
6. Good price/performance (line speed switching)
7. Enormous installed base worldwide
8. Internet IP friendly
9. Scaleable bandwidth
10. Applicable for LAN, MAN and WAN applications

In light of the above attributes, Gigabit Ethernet that uses fiber optical cable as the transmission medium can be used for MAN or even WAN applications. Because Ethernet has the attributes of easy provisioning and bandwidth flexibility, it appears that Gigabit Ethernet could be a candidate for MAN access to alleviate the bandwidth bottleneck in broadband access.

3.3 Benefits of Using Gigabit Ethernet Technology for MAN Access

Since Gigabit Ethernet is ideal for extension to the MAN environment, telecom carriers can integrate it into a broadband solution that offers *bandwidth scalability and easy deployment.* In addition to fast provisioning and bandwidth scalability, additional benefits of simplified network architecture and reduced cost can also be realized (Clavenna, et al., 2001).

3.3.1 Simplified network architecture

If carriers offer conventional DS3 (45 Mb/s) broadband service, they will have to provision DCS (Digital Cross-Connect System) and SONET/SDH ADM (Add-Drop Multiplex) ring in their existing network. With Gigabit Ethernet technology, a telecom carrier could provide broadband connection to users by deploying a series of Ethernet switches linked with leased fiber cables. The elimination of DCS and SONET/SDH ADM equipment in the network architecture not only translates into equipment cost savings, but also simplifies network operations. It is because service provisioning and activation process now require fewer operations tasks with Gigabit Ethernet architecture. This, in turn, could result in substantial operations savings for the telecom carriers.

3.3.2 Eliminate protocol conversion

Compared to ATM-based xDSL service, IP-based xDSL service can simplify the network protocol conversion process by using Gigabit Ethernet as the transport vehicle. For ATM-based xDSL service, an ATM PVC circuit has to be set up between the xDSL remote terminal and the ATM network. This requires the layer 2 ATM and layer 3 AAL5 protocol stacks to be established before an IP layer protocol can be transmitted. However, if the xDSL service is offered via the IP-based equipment such as Gigabit Ethernet, an ATM PVC connection is not needed. Therefore, there is no need to perform ATM and AAL5 protocol conversions.

3.3.3 Asynchronous network vs. Synchronous network

Because the SONET/SDH network operates in synchronous mode, it requires highly accurate network timing. Complex network synchronization mechanisms based on stratum 1 to stratum 4 timing clock is needed to keep SONET/SDH equipment inter-operating synchronously. Without strict synchronization in timing, transmission impairments such as jitter and slip occur. Therefore, it is critical to have a comprehensive network synchronization plan, in terms of timing signal redundancy and protection, to ensure the network integrity. The cost of engineering and maintaining such a network synchronization mechanism, particularly for the accuracy and stability of stratum 1 clock, is prohibitively high. In addition, at each equipment line card a PLL (phase locked loop) is needed to extract the timing signal from the core network. The cost of PLLs, which constitutes a significant portion of the line card cost, adds to the total capital investment of a synchronous network (GR-253, 2000).

Since Gigabit Ethernet operates in asynchronous mode, it does not require network synchronization nor sophisticated PLL in each line card. This can reduce overall network equipment costs as well as operating expenses.

3.3.4 Ethernet equipment cost advantage

A study conducted by Dell'Oro Group (Clavenna, et al., 2001) reported that Ethernet bandwidth is approximately 85 percent cheaper than SONET bandwidth. Telecom carriers need to spend only $150,000 on Ethernet equipment to get bandwidth equivalent to a $1 million SONET network.

The Dell'Oro study compared the average selling price of Fast Ethernet (100 Mb/s), Gigabit Ethernet and 10-Gigabit Ethernet switches with that of the OC-3 (155 Mb/s), OC-12 (622 Mb/s), OC-48 (2.5 Gb/s) and OC-192 (10 Gb/s) SONET equipment. A common price/performance metric can be used; these prices are converted into dollars per Gigabit of bandwidth. As shown in Figure 2, by 2004, the cost difference in deploying one Gigabit of bandwidth using 10 Gb/s Ethernet versus SONET OC-192 was several thousand dollars.

With over 100 million installed Ethernet LANs in the world, there are a large group of users and skillful technicians who are familiar with Ethernet technology. The convenience of the "plug and play" feature and the backward compatibility to lower speed Ethernet LANs suggest a smooth migration path for enterprise IT applications which might push the demand for Gigabit Ethernet high and eventually drive its cost down. In addition to applications such as fast Internet access and low cost transport of IP data among multiple sites within a metro area, other advanced applications of MANs will be possible through leveraging Gigabit Ethernet capabilities.

3.3.5 Global end-to-end LAN connection

Because Gigabit Ethernet maintains the Ethernet frame format throughout the core network, an end-to-end Ethernet LAN connection becomes possible for enterprise customers. The advantages include no necessity for protocol conversion at the network edge, improved network performance, and efficiency in bandwidth utilization. The transparent LAN-to-LAN connection will allow enterprise LANs to exchange data and files without the worry of losing data integrity. Implied in this is the large number of the installed enterprise Ethernet LANs will not become obsolete with the emergence of Gigabit Ethernet technology (www.appliancom.com).

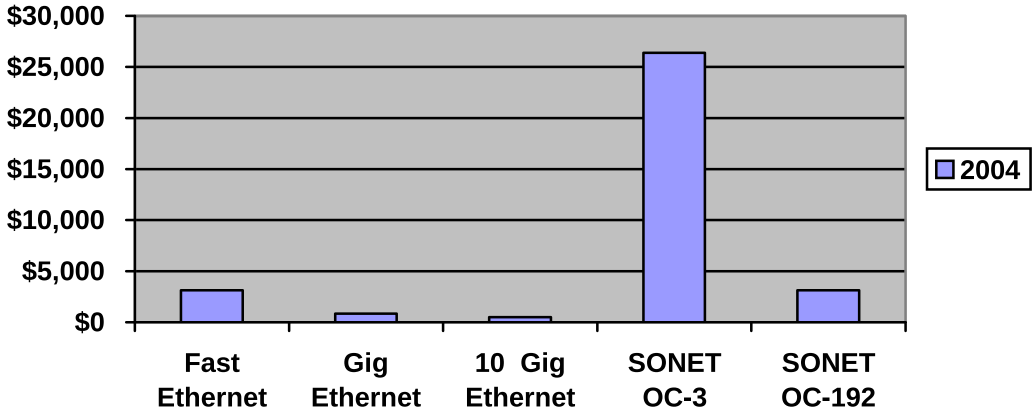


Figure 2. Dollar Per Gigabit of Bandwidth in 2004, by Dell'Oro Group

3.3.6 High speed ASP and SSP access

Most ASPs (Application Service providers) and SSPs (Storage Service Providers) experience slow transmission speed and throughput bottlenecks in the access network. To prevent service quality from degrading, ASPs and SSPs have to put a limit on the number of simultaneous users they can serve. Since Gigabit Ethernet offers gigabit per second access bandwidth, the network access bottleneck is alleviated and the ASP and SSP should have no problem servicing all of their customers. The bandwidth flexibility of Gigabit Ethernet offers much better broadband access than hard-wired private lines. It should be noted that for SSPs the storage devices could either be distributed over locations connected via Gigabit Ethernet WAN or MAN or attached to a Gigabit Ethernet LAN within a single premise (www.appliancom.com).

3.4 Ethernet Challenges in Network Operations and Management

Although Gigabit Ethernet offers many unique capabilities and advantages which can satisfy business needs in a metropolitan network, there are challenging issues that need to be resolved with respect to inter-working with or replacing the existing SONET/SDH and ATM networks.

3.4.1 Can Gigabit Ethernet provide the equivalent QoS (quality of service) that is currently provided by SONET/SDH and ATM?

Providing quality service that meets customers' requirements is a fundamental concern of telecom carriers. Enterprise customers demand guaranteed quality of service to ensure reliable business operations. Therefore, if telecom carriers were to apply Gigabit Ethernet technology to achieve bandwidth scalability and fast provisioning time for their business customers, it would be critical to maintain the existing level of QoS.

Unlike ATM, Gigabit Ethernet does not have admission control capability to regulate individual user's traffic stream. Gigabit Ethernet can only rely on "policy-based" QoS to manage the aggregated traffic. The policy-based QoS always reserves additional bandwidth capacity (i.e., over engineering the bandwidth requirement) sufficient to meet the QoS objective at peak hour traffic demand. Since Gigabit Ethernet equipment has a cost advantage over SONET/SDH and ATM equipment, "over engineering" is a small price to pay to reap the benefit of bandwidth flexibility. In the future, the QoS capability may be provided at the IP layer (such as IP/MPLS protocol) once the IP QoS capability becomes mature.

3.4.2 Can Gigabit Ethernet provide the network performance monitoring capability that is currently provided by SONET/SDH and ATM?

There are several overhead bytes (e.g., the B1 byte) in the current SONET/SDH frame format designed for monitoring the network transmission performance (GR-253, 2000). By analyzing the network performance monitoring information, carriers can detect network degradation, localize faults, and take proper maintenance actions before service-affecting failures take place. In contrast, however, in the Gigabit Ethernet frame format there exists no overhead byte for performance monitoring. Gigabit Ethernet can only monitor whether the incoming packets are in error. Once an error occurs, Gigabit Ethernet will report error messages to the network management system through the standard SNMP interface. The error reporting mechanism is much slower compared to the performance monitoring capability of SONET/SDH or ATM technologies.

The IEEE 802.3 standards committee is in the process of defining a WAN PHY layer protocol for the transmission of Gigabit Ethernet traffic via the existing SONET/SDH equipment. Having Gigabit Ethernet transported in the SONET/SDH payloads can leverage the existing performance monitoring capability of SONET/SDH equipment. This WAN PHY layer protocol provides a foundation for telecom carriers to monitor the transmission performance of Gigabit Ethernet (Information Technology, 2000).

The drawback of the lack of performance monitoring capability of Gigabit Ethernet is becoming less critical. Because most transmission networks are fiber-based with high performance and reliability, the majority of failures are event-driven (e.g., fiber cut) rather then caused by equipment or facility degradation. The existence of performance monitoring capability may not be as critical as in the past.

3.4.3 Can Gigabit Ethernet provide network protection switching and fault isolation capabilities that are currently provided by SONET/SDH and ATM?

SONET/SDH frame structure has signaling overhead bytes (e.g., the K1 and K2 bytes) that can be used to provide protection-switching functions within a 50ms interval (GR-253, 2000). Furthermore, there are overhead bytes in the SONET/SDH format to provide fault isolation.

Gigabit Ethernet has no signaling capability to provide any protection switching or fault isolation functions. Alarms will be reported through the SNMP interface to the appropriate network management center. Although the Ethernet aggregate link capability can also provide a similar protection function within 1 second, it is incompatible with the 50 ms switching time of SONET/SDH. The WAN PHY layer protocol can leverage the protection switching and fault isolation functions built in the SONET/SDH frame format.

3.4.4 How can Gigabit Ethernet scale up in large carrier network?

Because Ethernet is traditionally used as a LAN in a private enterprise environment, the scale and size of any single Ethernet network is much smaller compared to a public telecom network. However, there will be multiple Gigabit Ethernets complementing the functions of SONET/SDH systems. The SNMP network management interface can be scaled up to manage clusters of Gigabit Ethernets. An end-to-end Ethernet connection (LAN, MAN to WAN) has the benefit of a homogenous layer-2 network management system that can simplify the operations management of a telecom network.

Ethernet technology has evolved into multi-gigabit bandwidth with applications extending from LAN, MAN, and even to WAN. Telecom carriers are faced with fast growing Internet data traffic that exceeds traditional voice traffic. Gigabit Ethernet technology holds the promise to relieve the critical bandwidth bottleneck in the access network.

The simple protocol of Ethernet can offer telecom carriers many advantages in terms of simplified network architecture and substantial equipment cost reduction. The dynamic bandwidth allocation flexibility makes many new business applications possible. This, in turn, will create new revenue opportunities while reducing capital investments for telecom carriers. Compared with existing SONET/SDH and ATM infrastructure, Ethernet technology has some weaknesses in the areas of network

3.5 Summary

Ethernet technology has evolved into multi-gigabit bandwidth with applications extending from LAN, MAN, and even to WAN. Telecom carriers are faced with fast growing Internet data traffic that exceeds traditional voice traffic. Gigabit Ethernet technology holds the promise to relieve the critical bandwidth bottleneck in the access network.

The simple protocol of Ethernet can offer telecom carriers many advantages in terms of simplified network architecture and substantial equipment cost reduction. The dynamic bandwidth allocation flexibility makes many new business applications possible. This, in turn, will create new revenue opportunities while reducing capital investments for telecom carriers. Compared with existing SONET/SDH and ATM infrastructure, Ethernet technology has some weaknesses in the areas of network operations and management. As Gigabit Ethernet can be transported over the existing SONET/SDH and ATM infrastructure, the characteristics of both technologies can complement each other. For applications less concerned about QoS, the Gigabit Ethernet is already an ideal solution. As Ethernet technology and its communications protocols continue to evolve, its potential and impact as a broadband end-to-end architecture is emerging. When and how to leverage Gigabit Ethernet technology's capabilities will remain a business challenge for telecom carriers.

In order to help telecom carriers to quantitatively select the best MAN access technology, we have employed the Fuzzy MCDM (Multi-Criteria Decision Making) method in the next section to further study the MAN access technology issue.

4. Using a Fuzzy Multi-Criteria Decision Making Approach To Evaluate MAN Access Technologies

Global Internet traffic growth continues to create bandwidth demand in the telecommunications network. As 100 Mb/s Ethernet and Gigabit Ethernet LANs are widely installed in enterprises, Intranet bandwidth grows quickly. With the active adoption of ADSL and cable modem broadband accesses in the SOHO and residential markets, these markets generate more data traffic as well. Current telecom carriers predominately use SONET/SDH equipment to “aggregate” data traffic in the MAN network (Metropolitan Area Network) before accessing the Internet backbone network. Because of the intrinsic limitations of SONET/SDH equipment in transporting data traffic, especially in terms of bandwidth scalability and provisioning efficiency, there is a need to find a broadband access solution that can overcome these drawbacks. The emergence of Gigabit Ethernet technology provides benefits that the SONET/SDH equipment lacks. However, Gigabit Ethernet also presents some shortcomings. The deployment of different access technologies leads to different implications and byproducts.

The convergence of data, toll-quality voice, and broadcast-quality video bit streams in the metropolitan network requires MAN to evolve into a data-centric architecture (www.extremenetworks.com). In order to meet voice and data service requirements of the average customer, telecom carriers must evaluate their access technology strategy in the MAN network for future broadband services. Since the strategy needs to address network operations, equipment cost, service flexibility and other complex issues that may not be precisely represented by mathematic data, the proper evaluation of MAN access strategy in a complicated and fuzzy environment has grown into a critical issue for telecom carriers. The purpose of this study is to help telecom carriers set a MAN access strategy in a fuzzy qualitative environment by employing a fuzzy MCDM method. An empirical study provides an example to examine the practicality and usefulness of the method. Under the overall telecom carrier goal, several "aspects" and "criteria" are identified to evaluate two access strategies. Based on the experiences and opinions of different stakeholders, we can calculate the contribution value of each strategy and rank the strategies accordingly.

Because multiple criteria are included in evaluating different alternatives, a hierarchy method (Kerzner, 1989) was employed. Many scholars use the AHP (Analytic Hierarchy Process) (Saaty, 1977, 1980) method to conduct research related to alternative evaluations. For example, Chen (1997) published "Fuzzy theory application in selecting management strategy"; Tang et al. (1999) conducted research on "A hierarchy fuzzy MCDM method for studying electronic marketing strategies in the information service industry". Since using "A is more important than B" to do comparison is easier (or more apt) than "A is 5 times more important than B", several scholars employed the "Fuzzy Analytic Hierarchy Process" (Buckley, 1985) to deal with the fuzzy linguistic scale issue. By using the fuzzy analytic hierarchy process, interviewers can better express their perspectives and opinions. For example, Cheng and Mon (1994) applied this method to "Evaluating weapon systems by the analytical hierarchy process based on fuzzy scales".

This study employed 1985 Buckley's "fuzzy AHP" method to conduct alternative evaluation research. Survey questionnaires were distributed to 2 different stakeholder groups for feedback. In total, 14 survey questionnaires were collected for analysis. AHP ECPro and EXCEL spreadsheet software analyzed the survey data. Study results show that the SONET/SDH MAN access strategy received a higher ranking than the Gigabit Ethernet access strategy.

This section is organized as follows. Section 4.1 reviews the evolution of Ethernet technology. Section 4.2 establishes the MCDM model for evaluating different MAN access technologies. Section 4.3 examines the practicality and usefulness of this method via an example and its empirical results. The last section gives conclusions and suggestions.

4.1 Ethernet Technology: from LAN to MAN and WAN

Ethernet is the most widely used local area network (LAN) technology for data communications applications (www.techguide.com). With the standardization of Gigabit Ethernet, “Gigabit Ethernet” can support data rates up to 10 Gb/s (10,000 Mb/s). In addition to the traditional physical twisted pair copper cable, Gigabit Ethernet can also use fiber optic cable as the transmission media to take advantage of its large bandwidth capability. Today, Ethernet-based LANs already own 95% of the corporate desktop market share (Clavenna, 2001). The share is steadily increasing as Ethernet continues to enhance its features and transmission rates.

Ethernet success in the LAN environment continues due to constant technological enhancement. Ethernet employs basic technology and simple protocols to provide fundamental LAN functionality. As Ethernet evolved from Ethernet switch (also known as multi-tree bridge) to VLAN (Virtual LAN), Ethernet offered unlimited capacity and redundancy, traffic priority, and easy reconfiguration advantages for Ethernet users (Seifert). Subsequently, by removing the CSMA/CD protocol constraints and replacing it with a switch, Ethernet transmission distance is no longer limited. With this enhancement, Gigabit Ethernet can be extended to cover metropolitan areas. In short, more customers get more services. With the advent of 10-Gigabit Ethernet, which works only with fiber optic cable, Ethernet can cover WAN (Wide Area Network) applications.

As the Ethernet’s evolution illustrates, time has brought many changes. Data rates, coverage area, supported media and functionality have all expanded rapidly. This, in turn, enables Ethernet to surmount many of its former limitations and in so doing to expand beyond LAN into MAN and (now) WAN. However, as Ethernet evolves, a number of questions also arise about its true capability and role in the new market as compared with the existing SONET/SDH access technology.

In the next section, we attempt to develop a hierarchy model using the fuzzy MCDM method to evaluate different access network strategies. The analysis will help telecom carrier leaders understand the implications of different MAN access strategies as based on different business criteria.

4.2 Building a Hierarchy Model for Evaluating Different MAN Access Strategies

The emerging broadband service demands in the MAN have forced telecom carriers to evaluate different access strategies in order to meet customer needs. Many business criteria need to be considered while selecting an access strategy. However, many business criteria are fuzzy in nature and in mutual conflict. For example, if an access strategy only focuses on the equipment cost, the issue of equipment retrofit and backward compatibility could have a negative impact on the telecom carrier network operation and maintenance costs. Therefore, how to select a business strategy that can reach a compromise solution becomes a critical issue.

4.2.1 Building a hierarchy strategy model

The PATTERN (Planning Assistance through Technical Evaluation of Relevance Number) method and concept (NASA PATTERN, 1965, 1996; Tzeng, 1977; Tzeng and Shiau, 1987; Tzeng. et al., 1992; Tzeng and Teng, 1994; Tang, et al., 1999) to build a hierarchy strategy system for evaluating business strategies was employed in this paper. The PATTERN procedures include three steps: (1) scenario writing, (2) building a relevance tree, and (3) evaluation. In this section, we focus on scenario writing and building a relevance tree. The business issues can be classified into three categories: (1) Network Services (2) Network Equipment Costs, and (3) Network Operations. Based on the literature review and experience, relevance trees are used to create hierarchy strategies to identify the critical business issues and criteria using scenario writing. The elements of relevance trees become a relevance set consisting of statements derived from "goal" through aspect, objective, planning to implementation. This kind of system corresponds with evaluation processes for telecom carriers to evaluate critical network access strategies/issues (as shown in Figure 3).

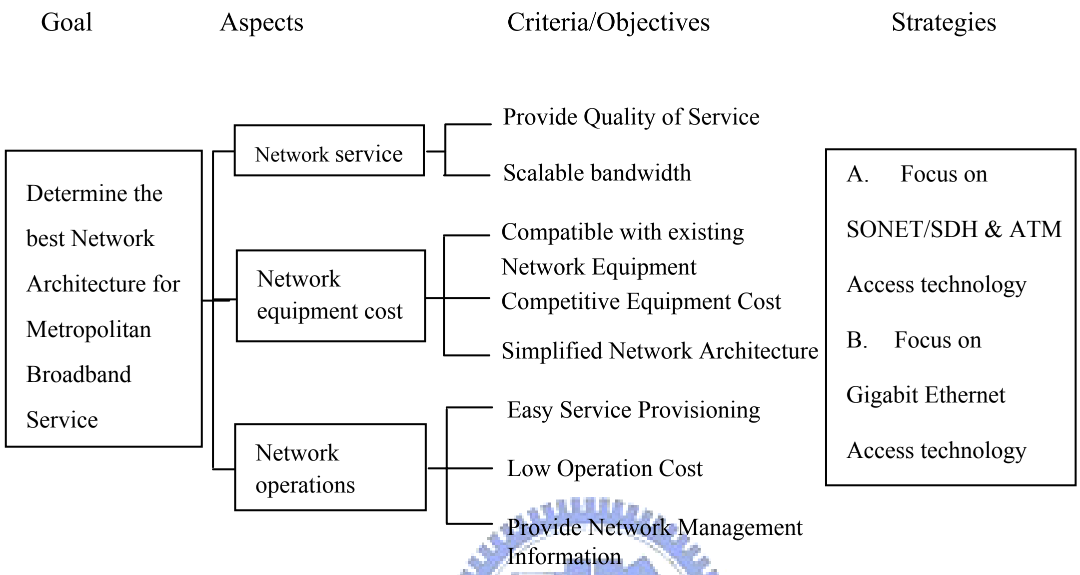


Figure 3. Relevance System of Hierarchy Strategies for Access Technology

4.2.2 Access strategy for MAN

Based on different focuses and criteria, different access strategies can be selected for consideration. However, since the criteria for each network access strategy are in conflict with each other, it is important for telecom carriers to consider all aspects of the business environment so that carriers can balance their short-term and long-term goals. Two different strategies are summarized in Table 9.

Table 9. MAN access strategies for the telecom carriers

Criteria/Issues	Strategies
• Telecom carriers need to provide proven carriergrade scalable broadband solutions and service for customers. • It is critical to maintain network operations through comprehensive network management information. • Leveraging existing SONET/SDH infrastructure to generate revenue is important, particularly during the telecom downturn.	*A. Focus on SONET/SDH and ATM access technology:* Telecom carriers continue to enhance and improve existing SONET/SDH and ATM networks and their respective operations support systems to offer quality broadband services.
• Telecom carriers should offer bandwidth flexibility to customers. • The convergence of voice and data service will be the major business drivers for future broadband services • Internet IP protocol and WDM optical bandwidth will continue to stimulate the Ethernet deployment and to continue to drive down the cost of Ethernet technology.	*B. Focus on Gigabit Ethernet access technology:* To offer broadband service, telecom carriers will aggressively deploy Gigabit Ethernet in the MAN to take advantage of potential benefits offered by Gigabit Ethernet.

4.2.3 Fuzzy MCDM Method

In a simple environment or using a single measurement index, the traditional minimum cost, maximum profit or cost efficiency methods can be employed to conduct alternate evaluations. However, in an increasingly complex and diversified decision making environment, there is much correlated information that needs to be analyzed and traditional analysis is not suitable for problem solving (Tzeng, et al., 1992; Tzeng & Tsaur, 1993; Tzeng and Teng, 1994; Tsaur et al., 1997; Tang et al., 1999). Therefore, this research uses the MCDM to evaluate different MAN access strategies.

Since evaluators may have different perceptions on different objectives and criteria, in terms of their importance and possible adverse consequences, evaluation is conducted in an uncertain and fuzzy environment. This fuzzy evaluation design allows evaluators to express their opinions in a fuzzy expression manner. For these reasons, the Fuzzy MCDM was selected to conduct this evaluation.

4.2.4 The process of evaluating the hierarchy strategies

The evaluation process includes two steps.

4.2.4.1 Evaluating the weights for the hierarchy relevance system using AHP (Analytic Hierarchy Process)

The AHP weighting is determined by evaluators who conduct pairwise comparisons. This matches the criteria to discover the comparative importance of each. If there are evaluation criteria/objectives, then the decision-makers have to conduct a pairwise comparison. Moreover, the relative importance derived from these pairwise comparisons allows a certain degree of inconsistency within a domain. Saaty used the principle eigenvector of the pairwise comparison matrix derived from the scaling ration to find the comparative weight among the criteria of the hierarchy system for the enterprise business strategies.

4.2.4.2 Obtaining performance values

The evaluators choose a score for each business strategy based on their subjective judgment. In this way, we can use the methods of fuzzy theory to estimate the achievement level of each strategy in a fuzzy environment. Since Zadeh introduced fuzzy set theory (Zadeh, 1965), and Bellman and Zadeh (1970) described the decision-making method in fuzzy environments, an increasing number of studies have dealt with uncertain fuzzy problems by applying fuzzy set theory. The application of fuzzy theory to obtain performance values can be described as follows:

1. Fuzzy Set: Fuzzy numbers are a fuzzy subset of real numbers, and they represent an expansion of the idea of a confidence interval.
2. Linguistic Variable: According to Zadeh (1975), it is very difficult for conventional quantification to reasonably express complex and/or hard-to-define situations; thus, the notion of a linguistic variable is necessary in such situations. A linguistic variable is a variable whose value are words or sentences in a natural or artificial language. For

example, the expression "maximize network bandwidth and QoS " or "reduce operations cost" represents a linguistic variable in the context of this study. Linguistic variables may take on effect-values such as "very high (very good), "high (good)", "fair", "low (bad)", and "very low (very bad)". The use of linguistic variables is rather widespread at present and the linguistic effect values of enterprise business strategies found in this study are primarily used to assess the linguistic ratings given by the evaluators. Furthermore, linguistic variables are used as a way to measure the achievement of the performance value for each criteria/objectives (Fig. 4).

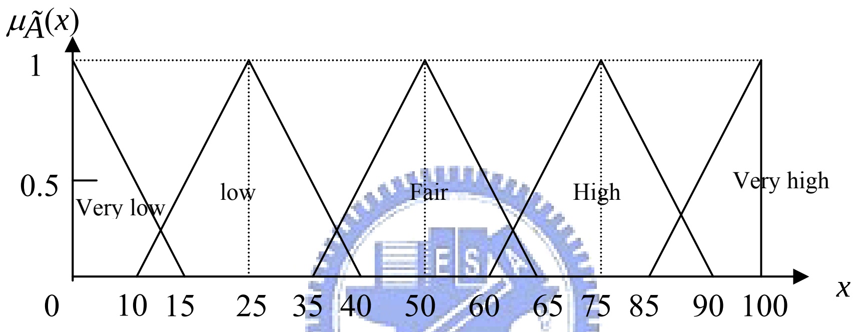


Figure 4. The membership function of the five levels of linguistic variables (hypothetical example)

3. Fuzzy Multiple Criteria Decision-Making: Bellman and Zadeh (1970) were the first to probe into the decision-making problem under a fuzzy environment, and they heralded the advent of Fuzzy MCDM. This study uses this method to evaluate various business strategies and ranks each strategy according to its score.
4. Fuzzy synthetic decision: The weights of each criteria/objective of the MAN access strategies as well as fuzzy performance values have to be integrated by the calculation of fuzzy numbers so they can be assigned a fuzzy performance value for the integral evaluation. This procedure is a part of fuzzy synthetic decision making.
5. Ranking the strategies (fuzzy number): The result of fuzzy synthetic decision of each alternative is, of course, a fuzzy number. Therefore, it is necessary that the nonfuzzy

ranking method for fuzzy numbers be employed to compare strategies. In other words, the procedure of defuzzification is to locate the Best Nonfuzzy Performance value (BNP). Methods of such defuzzified fuzzy ranking generally include mean of maximal (MOM), center of area (COA), and α-cut - three methods in all (Zhau & Govind, 1991; Teng & Tzeng, 1996). To utilize the COA method to find out the BNP is both simple and practical, and there is no need to bring in the preference of any evaluators. For those reasons, the COA method is used in this study.

4.3 Empirical Study and Discussions

We give an empirical study in Taiwan as an example to show the practicality and usefulness of the proposed method through 14 samples. These 14 surveys were filled out by 12 Chunghwa Telecom researchers and managers and 2 CCL (Computer and Communications Lab) telecom development managers. The process of evaluating the business strategies can be expressed in the following:

4.3.1 Evaluating the criteria/objectives weights

We derived the weights (importance) attributed to each criterion/objective through two decision-making groups in the Taiwan telecom community: a telecom carrier and a telecom R&D institution. The criteria weights are shown in Table 10. Based on the obtained weights, "Network Service" has the highest score (0.422) among all evaluated aspects. This result indicates that service is the most important issue for telecom carriers. Ultimately, the objective of network equipment and network operations is to deliver service to end customers. Network equipment cost and operations should not compromise service delivery. In other words, telecom carriers should find the appropriate network equipment and operations environment to deliver the services required by customers. The criterion receiving the highest weight (0.253) is "Provide QoS" service. This result implies that customer concern centers around quality of service. The underlying technology needed to deliver the service is not a major a concern to customers. What telecom carriers really need to ensure is that customers can receive the quality of service promised by the telecom carriers.

Table 10. The criteria weights for evaluating business strategies

Aspect and criteria	Importance	
Item	Weight	
Network Service	0.422 (1)	
Provide quality of service		0.253
Provide scalable bandwidth		0.169
Network equipment cost	0.241 (3)	
Compatible With existing Network Equipment		0.112
Competitive Equipment Cost		0.062
Simplified Network Architecture		0.068
Network operations	0.337 (2)	
Easy Service Provisioning		0.160
Low Operation Cost		0.069
Provide Network Management Information		0.108

[a] Parentheses () denote the order of importance (weight) of each criterion/objective.

4.3.2 Estimating the performance matrix

The evaluators can define their own individual ranges for the linguistic variables employed in this study according to their subjective judgments within a scale of 0-100. Table 11 reveals a degree of variation in their subjective judgments on a scale from 0-100. This paper employs COA (Center of Area) to convert the five level evaluator fuzzy linguistic variables to non-fuzzy BNP (Best Non-Fuzzy Performance) values. Since each evaluator provides feedback on 8 criteria for 2 strategies, a performance matrix can be established for each eigenvector.

Table 11. The subjective cognition results of evaluators towards the five levels of linguistic variables

Evaluator	Very low impact	Low impact	Fair	High impact	Very high impact
1	(0, 10, 25)	(20,30,55)	(50,60,75)	(75,85,90)	(80,90,100)
2	(0,10,15)	(10,25,400	(35,50,65)	(60,75,90)	(85,90,100)
…	…	…	…	…	…
14	(0,20,40)	(35,45,550	(50,65,80)	(75,85,90)	(90,95,100)

The utility score matrix $\vec{S}_n$ of subject n will be multiplied by the vector of weighting factors of its survey group, say $\vec{W}_i$, to get $\vec{U}_n$, where u_n^k is the utility score weighted by the weighting factors of survey group i for licensing mechanism k by subject n.

$$\vec{S}_n = \begin{array}{c} \\ \text{Criterion1} \\ \text{Criterion2} \\ \cdots \\ \cdots \\ \text{Criterion12} \end{array} \begin{array}{c} \begin{array}{cccc} \text{Strategy A} & \text{Strategy B} & \text{Strategy C} & \text{Strategy D} \end{array} \\ \left[\begin{array}{cccc} s_{n1}^{A} & s_{n1}^{B} & s_{n1}^{C} & s_{n1}^{D} \\ s_{n2}^{A} & s_{n2}^{B} & s_{n2}^{C} & s_{n2}^{D} \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ s_{n12}^{A} & s_{n12}^{B} & s_{n12}^{C} & s_{n12}^{D} \end{array} \right] \end{array}$$

4.3.3 Ranking the business strategies

From criteria weights obtained by AHP (Table 10) and the performance matrix for each evaluator, the BNP values for two strategies can then be found for each evaluator. After BNP values are calculated for all evaluators, an average BNP value can then be obtained for each business strategy. The ranking of the seven business strategies is detailed in Table 12, namely, $A \succ B$.

Table 12. The evaluation results of MAN access strategies

MAN network access strategies	BNP_i
A. Focus on the SONET/SDH and ATM Access Technology	92.49 (1)
B. Focus on the Gigabit Ethernet Access Technology	80.64 (2)

[a] Parentheses () denote the ranking of each business strategy.

4.3.4 Discussions

Based on the analyzed results, the MAN access strategy "A" focusing on the SONET/SDH and ATM technology has the highest BNP score. This result highlights the following points:

1. Although SONET/SDH system has limitations, its ability to provide quality of service and network surveillance information outweighs its technical shortcomings, such as bandwidth scalability.
2. Since the evaluator from the telecom carrier group is an incumbent carrier in Taiwan, this result reflects that the incumbent carrier prefers a path of evolution rather than revolution. In other words, leveraging the existing SONET/SDH infrastructure to offer broadband services is more important than eliminating the existing SONET/SDH systems and deploying a new Gigabit Ethernet network. The issue of total network cost may prohibit incumbent carriers to have a "desert start" in deploying the Gigabit Ethernet network in the MAN environment. On the contrary, for a new telecom carrier, because they do not have the existing network infrastructure compatibility issue (i.e., a "Greenfield" deployment), the choice of network architecture and access technology typically will favor the promising technology with good potential which, in this case, would be the Gigabit Ethernet technology. This is consistent with the approach that most of the telecom carriers, such as Yipes (www.yipes.com) and OnFiber (www.onfiber.com), serving the metropolitan customers have selected Gigabit Ethernet as their access technology.
3. The weight of network operations aspect (0.337) is much higher than the weight of network equipment cost aspect (0.241). This result indicates that telecom carriers should focus on the total cost (first cost and future maintenance cost) of the network equipment and not just the initial equipment purchasing cost. Particularly, if the incumbent telecom carrier already has the network management systems to support the circuit-based SONET/SDH operations, deploying the IP-based Gigabit Ethernet technology will create challenging network

operation compatibility issues for the telecom carriers. If the telecom carrier decides to operate 2 layers of network operations, then the total network operation cost may offset the Gigabit Ethernet equipment cost advantage. How to cost effectively manage the access technology will be particularly critical to the incumbent carriers when offering broadband service.

4. The purpose of technology is to provide service to users. The first priority of a telecom carrier is to offer high quality service to its customers. Therefore, a telecom carrier should be “service focused” and not only focus on technology.
5. Bandwidth scalability criteria (0.169) received the second highest score of all criteria. Since bandwidth scalability is one of the major strengths of Gigabit Ethernet technology, if the issues of QoS, network management functions, and network compatibility can be addressed, it is conceivable that the Gigabit Ethernet technology will play a major role in the future broadband network.
6. Strategy A and strategy B BNP values were 92.49 and 80.24, respectively. These 2 BNP values are relatively high scores compared with the possible 100 total score. They reflect that both access technologies have the capabilities to address different carrier’s network requirements, particularly strategy A. In addition, the BNP difference between the two strategies is only 12.25, possibly suggesting that a combination of the two strategies could form an evolutionary approach as a viable way to address the MAN access technology issue.

Since June 2002, 10-Gigabit Ethernet technology has been standardized to be compatible with the OC-192 SONET/SDH transport payload format. Therefore, the deployment of 10-Gigabit Ethernet technology over OC-192 SONET/SDH (Ethernet over SONET/SDH) infrastructure appears to be a promising alternative for future broadband service (IEEE Standard 802.3AE-2002). It is observed in Table 3 that working with the existing infrastructure (backward compatibility) while evaluating a new network technology is an important issue. Therefore, the carrier's position - incumbent or start up - will have a big impact on the selection of a new network technology.

From the results of practical applications in evaluating the two access strategies, the proposed method makes a good evaluation and appears to be the most effective and appropriate one in a fuzzy environment. Through this fuzzy MCDM method, senior business executives could gain significant insight on the telecom carrier's network and business qualitative issues while setting a MAN access strategy.

4.4 Summary

Ethernet technology has evolved into multi-gigabit bandwidth with applications extending from LAN, MAN, and even to WAN. Telecom carriers are faced with fast growing Internet data traffic that exceeds traditional voice traffic. Gigabit Ethernet technology holds the promise of relieving the critical bandwidth bottleneck in the access network. Although the simple Ethernet protocol can offer telecom carriers many advantages in terms of simplified network architecture, substantial equipment cost reduction, and dynamic bandwidth allocation flexibility compared with existing SONET/SDH and ATM infrastructure, Ethernet technology also possess weaknesses in the areas of network operations and management. How to select the appropriate access technology in the MAN becomes a critical network planning issue, particularly in light of emerging broadband service demands.

Because a lot of technology insight is not quantifiable, how to "measure" these "qualitative" issues, such as a technology's compatibility with existing infrastructure is of particular importance to telecom carriers. Depending on a carrier's business position (such as incumbent carrier versus new start-up), different approaches may be applied by different carriers when setting an access technology strategy. This study discusses how to apply the fuzzy MCDM method to evaluate different access strategies in a fuzzy and complicated network and business environment. Using this method, not only can telecom carriers avoid overlooking significant qualitative issues, but they can also prioritize network and business objectives while establishing their access technology strategy.

Lastly, our example of an empirical study in Taiwan is based on the results of a generalized model evaluating the network access strategies in a fuzzy environment. From the results of this practical application, it was found that technology advantages alone may not be sufficient to address all business and network issues. This proposed method appears to be appropriate and effective to address the qualitative issues in a fuzzy business environment.

5. Local Loop Access and Technologies

Global telecom deregulation has introduced competition between the incumbent telecom carriers and new CLECs (Competitive Local Exchange Carriers). CLECs have been aggressively building their core network capacity to offer services to their customers. As a result, telecom tariffs for long distance, international, and mobile services have been substantially reduced due to fierce competition among telecom carriers. Core network competition has also manifested in the form of a price reduction for network trunk services. Although telecom deregulation has fostered competition in the core network, there remains a lack of competition in the local loop between incumbent carriers and CLECs. The terms “local loop” and “local loop competition” are defined as the access network that provides the interconnection between the core network and subscribers and competition for carriers to gain access to subscribers, respectively. Table 13 (Clark, 2002) illustrates the local loop competition status in four Asian telecom markets. Based on market share results in Table 5-1, competition does exist in the IDD (International Direct Dialing) market. However, the incumbent carriers continue to dominate in three local Asian telecom markets.

The lack of competition in the local loop can be attributed to the high construction cost of such a loop and the long payback period. Incumbent carriers already have a local loop that is connected to the majority of residential customers. Furthermore, because the incumbent carrier’s local loop has been fully depreciated, incumbent carriers own a huge cost advantage over new entrants. As a result, CLECs are hesitant to build out their own local loop to compete with the incumbent carriers. In theory, a local loop should provide the critical connectivity between residential customers and the bandwidth rich core network. Without the proper telecom policy regulations, the local loop could become a bottleneck for full service competition. This may be of particular importance in the Internet broadband service era because of the participation of content providers, ISPs (Internet Service Providers), ASPs

(Applications Service Providers) and carriers in the broadband service business model. Establishing a level playing field in the local loop environment so as to foster competition among various players has become a critical issue.

Several scholars have studied issues related to local loop competition and regulation. For example, Michalis (2001) discussed the evolution of local access competition and the role of regulation in the EU (European Union) local loop competition. Gabelmann (2001) conducted research on loop unbundling issues in the European telecommunications market. Christodoulou and Vlahos (2001) published their research results on introducing "sunset clauses" in a "mix" of infrastructure and service competition models to promote local loop competition. Economides (1998) analyzed the US Telecommunications Act of 1996 and its impact. In this section, we will review and analyze the current global local loop competition status and the emerging local loop technologies, examine issues and concerns for different local loop competition models and their respective strategic implications, and identify alternative models and approaches for local loop competition, particularly in light of the current telecom downturn.

Table 13. Asia incumbent IDD carriers and local market share

Market	Incumbent	Local loop competitors	Incumbent IDD market share	Incumbent local market share
Hong Kong	PCCW	3 FTNS, 1 cable, 6 cellular	38%	90%
Australia	Telstra	1 fixed, 4 cellular	48%	83%
Taiwan	Chunghwa Telecom	4 cellular, 3 fixed	80%	99%
Singapore	Singapore Telecom	1 fixed, 3 cellular	10%	NA

IDD: International Direct Dialing

5.1 Local Loop Access: Technology Perspectives

Local loop access refers to the physical wireline or wireless access connection between a termination point at a residential customer's house and the subscriber's main distribution frame (or operator's local switch or equivalent facility) in the carrier's CO (central office). It is considered “the last mile” between the customer premises and the local exchange. Local loop access can be accomplished either through a wireline or wireless network.

5.1.1 Wireline local loop

Incumbent carriers traditionally use copper wire for local loop transmissions. Twisted copper wire can carry narrowband voice traffic to a central office for switching. As ISDN (Integrated Service Digital Network) technology became available in the mid-1980s, voice and data (128 Kb/s) can be simultaneously transmitted on copper wire between CPE (customer premise equipment) and a central office. Recently, xDSL (digital subscriber line) technology has further enabled copper wire to provide simultaneous broadband data (megabit) and voice services. Among xDSL technologies, ADSL has been the most widely deployed DSL technology for broadband service. Since the existing copper loop can be upgraded to provide broadband service via DSL technology, and in light of the applications stemming from both the Internet and the world wide web, incumbent carriers have been aggressively deploying ADSL equipment to meet customer demands for broadband service. Under the current ADSL network design, voice and data services are carried via different frequencies on a copper wire. Therefore, it is possible to split the ADSL line into voice and data traffic and allow subscribers to pick and choose different carriers to provide voice and data services for them. The arrangement, called line sharing, occurs when two carriers offer service over different frequencies of the same copper wire.

Other potential local loop access technologies and architectures include the following:

- **FTTx:** FTTx is a network where an optical fiber runs from the telephone switch to the subscriber's premises - business or home. For the past few years, telecom companies have been working diligently to provide us with pseudo-broadband Internet connections over copper (DSL) and cable (cable modem), with practical speeds of up to 1.5 Mbps. No doubt improvements will be made over the next few years to squeeze more out of copper and cable. However, fiber which can provide download speeds of up to 155 Mbps remains a viable candidate for the access network. Such speeds will enable instantaneous data transfer and video on demand. It also provides a future-proof network in that one does not have to upgrade from ADSL to xDSL to digital co-ax to digital wireless. Optic fiber has higher reliability and does not need electric powering and is immune to lighting and other transients. These properties of the fiber lead to lowest powering costs and operational costs (such as maintenance, provisioning, and facilities planning). However, challenges such as making FTTx cost effective will create obstacles along the way to providing FTTx. Also the lack of product standardization and the lack of greater bandwidth demand from consumer and business applications have so far made FTTx deployment impractical. Several new technologies are leading to cost reduction of FTTH. Previously a single fiber was needed to connect to each home separately. Technology advances permit N-way distribution of the bits to many homes through resource sharing circuits (Passive Optic Network based FTTx). Recent advances in loop lasers, fiber and other components, and chips for compressing digital video greatly reduce system costs and will bring FTTx to the forefront of broadband access technology. It will provide service providers with the potential to increase revenues from applications such as interactive access, pay-per-view, video on demand, and subscription services (www.xilinx.com).

- **PON:** A passive optical network (PON) is a system that brings optical fiber cabling and signals all or most of the way to the end user. Depending on where the PON terminates, the system can be described as FTTx. The passive simply describes the fact that optical transmission has no power requirements or active electronic parts once the signal is going through the network. Essentially, carriers want to connect each customer site with a wavelength of light, but they want to avoid having to dedicate a fiber to every wavelength. PONs address this issue by bundling together multiple wavelengths (up to 32 at present) so they can be carried over a single access line from the carrier's central office (CO) to a manhole or controlled environmental vault close to a cluster of customer sites. At that point, the wavelengths are broken out and each one is steered into a different short length of fiber to an individual site. A different scheme is used for collecting traffic traveling in the opposite direction - from user sites to the CO. In this case, each site is given a specific time slot to transmit, using a polling scheme similar to the one used in old networks. PONs share the costs of fiber and much of the equipment located with the service provider among several customers, while also eliminating expensive, powered equipment between the service provider and these customers. The optical path is "transparent" to bit rate, modulation format (e.g., digital or analog), and protocol (e.g., SONET/SDH, IP, Ethernet). Such transparency results from nothing being installed between the service provider and the customer, which is specific to the bit rate, modulation format, etc., allowing services to be mixed or economically upgraded in the future as needed. New services and/or new customers can be added by changing service-specific equipment only at the ends of the network, and only for those customers affected. Such flexibility is not the case in most of today's other access network architectures. Despite their advantages, PONs face significant obstacles on the road to success. The fact that PONs share bandwidth among multiple subscribers lowers service costs and helps carriers efficiently amortize the equipment and operations expenses. However, any amount of upstream bandwidth transmitted over a PON will be divvied up among the number of users at the customer site. Therefore, on a 155-Mbit/s PON link with four splits, each subscriber will receive 38.75 Mbps. Addition of splitters to links that have already been split leads to lowering of the final available bandwidth. Also, the fact that PONs do not regenerate or convert optical signals mid-network makes them cheaper, but it also limits their reach. Without regeneration, light signals lose power quickly, consequently losing transmission capability.

Due to these disadvantages and the availability of other broadband access alternatives the market for PONs will remain relatively small for the next few years. Currently, ATM-based PON and Ethernet-based PON are the two main PON technologies that are available in the market (www.xilinx.com).

- **Cable TV:** Cable TV (CATV) Access refers to the use of CATV network facilities to provide "always-on" connections to the Internet from a PC. The key components of this system are the cable modem, the Hybrid Fiber Coaxial (HFC) Cable link and the Cable Modem Termination System (CMTS). The cable modem takes data from a PC and modulates it for transmission over the HFC line. The signal then travels all the way to a service provider's office where it gets terminated at a CMTS along with other HFC cables. HFC lines have inherently higher bandwidth capacity than an ordinary phone line, up to a 1000 times, as they are designed to carry video. CATV Access technology therefore provides very fast access speeds typically ranging from 500 kbps to 10 Mbps, depending on the number of users sharing the link. The performance of the cable network is inversely proportional to the number of users accessing the network in the neighborhood. In North America, Data Over Cable Service Interface Specification (DOCSIS) is the CATV Access standard and in Europe, Digital Audio Video Council (DAVIC) standards are used. In addition to video transmission, cable operators have been upgrading their networks to provide voice communications to their subscribers. A cable modem (set-top box) is used to integrate voice and data traffic for two-way communications at a customer site (www.xilinx.com).

Although FTTH and Gigabit Ethernet network access technologies can offer gigabits of bandwidth to subscribers, the high construction fee of laying fiber makes it economically unfeasible for local loop deployment in the near future. Meanwhile, cable networks are now competing directly with ADSL technology for Internet broadband local access in most countries.

5.1.2 Wireless local loop

Fixed access wireless local loops (WLL) are typically comprised of a base station and WAFUs (wireless access fixed units) residing at customer sites to provide subscribers with voice communications. Instead of having to do construction work on a street to lay copper or fiber for the local loop network, WLL gives companies an easier way to provide a local loop connections. In addition, WLL can provide communications for remote areas that can be justified as part of a wireline local loop deployment. Some PCS (Personal Communications System) technologies (such as CDMA) with an emphasis on mobility and wide coverage could also provide WLL functions. WLL is typically intended for narrow band voice communications.

5.1.3 Fixed wireless broadband

The Internet explosion caused a surge in demand for new telecommunication services. Network operators prefer wireless spectrum when classical copper or fiber lines are too costly, too congested, or simply unavailable. Fixed wireless is an ideal technology for providing high-speed Internet (data, voice and video) services to business and residential subscribers. Fixed wireless broadband uses spectrum in the 2 GHz to 42 GHz frequency bands. The types of fixed wireless technologies include LMDS (local multipoint distribution service), MMDS (multi-channel multipoint distribution service), cellular/PCS (personal communication system), DBS (direct broadcast satellite), and digital terrestrial. LMDS point-to-point wireless applications include connections between cell phone towers and central offices, or trunk connections between metropolitan buildings at data rates between 150 Mbps and 620 Mbps over a range of 2 km. Point-to-multipoint products can transmit packets at 150 Mbps omnidirectionally over a distance of 1 to 3 km. LMDS operates in 24 GHz, 28 GHz, and 39

GHz frequencies - achieving data rates of 100Mbps, with 45 Mbps being more typical rates. Fixed wireless radios serve both public networks and private enterprise. Early point-to-point radio links offered megabit speeds at T1/E1 rates to extend the copper in PDH networks. Today's radio links will require adjustable speeds in the gigabit range to support OC-192 rates in today's growing SONET/SDH networks. MMDS technology uses 2.1GHz to 2.7GHz frequencies with a 50-km range and data rates of 128 Kbps to 10 Mbps - promising to be a good alternative for DSL and cable modems. Fixed wireless has however been slow to deploy and develop, and remains a distant third to cable modem access and DSL in total number of broadband subscribers. Some challenges in the deployment include technology standardization, developing a broader base of hardware manufacturers, and continuing the trend toward consolidation among fixed wireless service providers. Also, reliability is severely impacted by inclement weather - where in foggy or story conditions the signal is distorted, thus forcing vendors to locate transmitters closer to each other. LMDS and MMDS are the typical fixed wireless technologies, with other previously established wireless technologies such as cellular/PCs, DBS and digital terrestrial being good, viable alternatives for providing high-speed Internet access (www.xilinx.com).

5.1.4 WLAN

Wireless LANs are the technology that will connect users in an enterprise or corporate network. The common Ethernet protocol between LAN WLAN has fueled the proliferation of WLAN deployment. Much like 10/100 Mbps Ethernet is omnipresent at the desktop, likely the future will see wireless LANs provide similar connectivity - a connection to the Internet and the ability to access data anywhere and anytime. They combine data connectivity with user mobility and provide a good general-purpose connectivity alternative for a broad range of business customers and consumers. Also, with strong popularity in vertical markets such as health-care, retail, manufacturing, warehousing, and academia, productivity gains are realized by using handheld terminals and notebook PCs to transmit real-time information to centralized hosts for processing. Currently, WLAN is being widely deployed in the hot spots (such as, coffee shops, airports) for Internet access. Because of the WLAN popularity, there is effort in extending WALN from the current LAN environment to outdoor and WAN (Wide Area Network) communications (www.xilinx.com).

5.1.5 WiMAX

The 802.16 standard, amended in January, 2004 by the IEEE to cover frequency bands in the range between 2 GHz and 11 GHz, specifies a metropolitan area networking protocol that will enable a wireless alternative for cable, DSL and T1 level services for last mile broadband access, as well as providing backhaul for 801.11 hotspots. The new 802.16a standard specifies a protocol that among other things supports low latency applications such as voice and video, provides broadband connectivity without requiring a direct line of sight between subscriber terminals and the base station (BTS) and is intended to support hundreds if not thousands of subscribers from a single BTS. The standard will help accelerate the introduction of wireless broadband equipment into the marketplace, speeding up last-mile broadband deployment worldwide by enabling service providers to increase system performance and reliability. The 802.16a standard is designed to deliver carrier class performance in terms of robustness and QoS and has been designed from the ground up to deliver a suite of services over a scalable, long range, high capacity "last mile" wireless communications for carriers and service providers around the world. In BWA, applications include residential broadband access--DSL-level service for SOHO. This will help enable last-mile broadband deployment wirelessly and will be an alternative method to deliver data, voice and video to homes and SME. For example, service providers could use an 802.16 standard-compliant CPE (customer premise equipment - the box that resides at the customer's premise) to deliver POTS and

Internet access to residential consumers or small business. In addition, it can be used to provide T1-speed network connectivity to their Wi-Fi access points. Today, it can take up to three months or more for service providers to provision a T1 network line for a business customer, if the service is not currently available in the customer's neighborhood or building. With wireless broadband technology, the same service provider could provision the same speed of network access as the wired broadband solution in a matter of days and at a fraction of the cost (assumes the service provider has an established base station). In addition, a service provider could use WiMAX (World Interoperability for Microwave Access) to offer "on demand" high- speed bandwidth for events such as tradeshows with hundreds or thousands of hot spot users or nomadic businesses such as construction sites with sporadic broadband connectivity. WiMAX has been seen as a complement to the WLAN technology. A comparison between these 2 technologies is shown in Table 14 (www.wimaxforum.org).

Table 14. 802.11 and 802.16 Technical Comparison

	802.11 (WLAN)	**802.16 (WiMAX)**	**Technical Difference**
Range	Sub ~ 300 ft (add access points for greater coverage)	Up to 30 miles; Typical cell size of 4-6 miles	802.16 PHY tolerates greater multi-path, delay spread (reflections) via implementation of a 256 FFT vs 64 FFT for 802.11
Coverage	Optimized for indoor performance, short range	Outdoor NLOS (No Line Of Sight) performance Standard support for advanced antenna techniques	802.16 systems have an overall higher system gain, delivering greater penetration through obstacles at longer distance
Scalability	Intended for LAN applications, users scale from one to tens with one subscriber for each CPE device Fixed channel sizes (20 MHz)	Designed to efficiently support from one to hundreds of CPEs, with unlimited subscribers behind each CPE Fixed channel sizes from 1.5 MHz to 20 MHz	802.11 can only be used in license exempt spectrum 9limited number of channels) 802.16 can use all available frequencies, multiple channels support cellular deployment.
Bit Rate	54 Mbs in 20 MHz channel	100 Mbs in a 20 MHz channel	Higher modulations coupled with flexible error correction results in more efficient use of spectrum
QoS	No QoS support	QoS built into MAC for voice/video and differentiated service levels	802.11: contention-based MAC (CSMA/CA) basically wireless Ethernet 802.16: Dynamic TDMA-based MAC with on-demand bandwidth allocation

Although WLL has many benefits when compared with a wireline local loop, a host of other issues - signal degradation/interference, security, line of sight (for LMDS technology), spectrum bandwidth limitation, population density, and spectrum license fees - have crippled its' deployment in local loop access networks. However, as technology (such as 3G wireless technology) and system functions constantly improve, wireless access will remain a viable player in the local loop environments (www.wimaxforum.org).

Table 15 summarizes the pros and cons of these emerging local loop technologies.

Table 15 Summary of the Emerging Local Loop Technologies

Technology	Advantages	Disadvantages
ADSL	Easy installation; Medium (Megabit) bandwidth; Inexpensive system cost	Bandwidth limitation
FTTx	Abundant bandwidth	Expensive fiber, component and installation fees; lack of product standardization supply
PON	Low maintenance cost; cost sharing	Shared upstream bandwidth; expensive fiber component; lack of standardization
CATV	Higher bandwidth than ADSL; easy installation	Shared bandwidth
WLL	Easy installation	Unstable service quality reliability; narrow bandwidth
Fixed Wireless Broadband	Easy installation	Reliability and service quality impacted by environment; limited spectrum licenses
WLAN	Easy installation; many available products	Limited distance (indoor and LAN) ; No QoS; Security concerns; mainly for data service
WiMAX	IEEE MAN standard to serve last mile broadband needs	Lack of available products; network interoperability; security concerns; mainly for data service

As shown above, copper wire remains the dominant vehicle for local loop access within worldwide telecom networks. As ADSL becomes available in copper local access networks, it also provides the technical capability to "unbundle" the copper wire network for loop access competition.

5.2 Local Loop Competition: Business Perspectives

After receiving a fixed wireline license from the government, CLECs need to establish both core and access networks in order to provide end-to-end service to customers. The wide deployment of fiber in core networks enables CLECs to challenge incumbent carriers for IDD and long-distance services; however, the aforementioned difficulties of building a local access network results in the incumbent carriers dominating local loop markets. This dominance leaves CLECs unable to establish a direct business relationship by offering local telephone and enhanced services to end customers. With various players offering services in the emerging broadband service market, this is of critical importance. Without a single delivery channel, service and content innovations are seriously inhibited. Furthermore, in order to allow subscribers to enjoy the benefits of deregulation in local access markets, fostering a local loop competition environment becomes an important issue. Therefore, one should ask "How can CLECs compete with incumbent carriers in the local loop network?" in this newly deregulated era.

Conceivably, there are three approaches for building competition in the local loop. One approach is to require CLECs to build out their own local loop infrastructure through government regulation. Another way is to require an incumbent carrier to "unbundle" its network to "lease" facilities or bandwidth to CLECs. The third approach combines a hybrid of infrastructure and services. The pros and cons of each approach are discussed below.

5.3 An Infrastructure-Based Competition Model

Infrastructure-based competition will require a CLEC to establish its own local loop to compete with incumbent carriers. CLEC could use various technologies/facilities to build a local loop. There are several advantages for implementing infrastructure-based competition:

- CLEC will have better control of its own network and services.

- Without leasing local loop facilities from an incumbent carrier, many potential disputes (such as loop quality or operation response time) between an incumbent carrier and CLECs could be eliminated.
- In the long term, the infrastructure allows market forces to foster local loop competition among various carriers.
- For Internet broadband ISP, ASP and content providers, multiple local loop carriers create additional options when selecting the appropriate physical delivery channel for local customers.

While infrastructure-based competition provides many benefits, the model is not without drawbacks:

- Since an incumbent carrier's local loop is fully depreciated, or unless government regulation provides incentives or tax relief to CLECs, CLECs will be at a cost disadvantage while competing with the incumbent carrier.
- In the short term, because the incumbent carrier holds a cost advantage against CLECs, government may have to regulate the incumbent carrier's subscriber access fee to avoid unfair competition between incumbent carriers and CLECs.
- If a CLEC decides to replicate the incumbent carrier copper network as its own local loop, this may severely hinder future broadband service development for a nation in the long run. From the perspective of resources, duplicating a bandwidth-limited local loop may not be a good strategic investment for a nation.
- The time needed to build up a local loop network that connects to every home, puts CLECs at a disadvantage while getting their service to market. For a wireline local loop,

this is especially problematic due to the difficulty of obtaining construction permits from various municipalities and city government agencies.

It will require a concerted effort from various government agencies (such as the Treasury Department for tax issues and the Communications Agency for policy issues) in order to make infrastructure –based competition work.

5.4 Service-Based Competition Model

In a service-based competition model, the incumbent carrier will "unbundle" its own local loop network and allow other CLECs to "lease" bandwidth or facilities from them. In this arrangement, CLECs will not be allowed to build their own local loops and will rely on the incumbent local loop to offer service to their potential customers. Competition will be based on the differentiations in service among various competitors. This competition model presents some advantages:

- CLECs will be able to offer services to residential customers once a license is obtained.
- No duplicated local loop investment can allow CLECs to earmark their resources for other areas, such as network operations and infrastructure deployment. These areas are critical to business operations.

There are several policies, business, and technical issues related to this service-based competition:

- Because the incumbent carrier will lease its facility (such as copper wire) to CLECs, the price agreement between the CLEC and the incumbent carrier is a pivotal element. Due to the full depreciation of local loop facilities, a government regulatory agency must manage this service-based price to foster competition. An unsubstantial lease price will discourage the incumbent carrier from leasing its facility to CLECs; an excessive price will hinder fair competition. In addition, the incumbent carrier may view this pricing mechanism as a way to subsidize CLECs. This, in turn, could create a “passive and non-cooperative” attitude while working with CLECs. On the contrary, if the lease price is set too high, CLECs will have no incentive to lease bandwidth or facility from the incumbent carrier. Moreover, if a perception of inefficient service exits, CLECs may see the high lease price as a way of subsidizing the incumbent carrier’s operational inefficiency. A balance can only be achieved if a proper lease price rewards the incumbent carrier’s efforts,or penalizes the incumbent for inefficient operations,while nurturing local loop competition. This is a critical challenge for the government agency.

- Government will need to provide enough incentive to the incumbent carrier to continuously upgrade the local loop facility. Otherwise, the local loop will soon be obsolete and hinder the development of a national telecom infrastructure.
- Since certain services are tied directly to particular network designs, competitors sharing a common network infrastructure could not be separated via any distinctive services. Price would then become the dominant marketing factor. ADSL access service is a good example of this service-based model.
- As technology and networks continue to evolve, some services can only be offered via certain local loop architecture or technology. If the incumbent carrier decides not to upgrade its infrastructure or delay its network upgrade schedule, this could hinder a CLEC’s ability to offer new or enhanced services. Moreover, if a local loop network design cannot provide the necessary communication functions for CLEC’s back-end operations support system or application platform, some services or applications would not be able to market to their potential customers. This, in turn, would restrict CLECs from fully competing against an incumbent carrier.

- For broadband service and content providers, a single local loop network may not give them enough leverage during broadband service delivery contract negotiations.

In the service based competition model, there are three forms of local loop unbundling (Michalis, 2001).

- *Full unbundling:* An incumbent copper pair is rented to a CLEC for its exclusive use. The CLEC will have full control of the copper pair and the relationship with the customer.
- *High-speed bit stream access:* The incumbent carrier installs a high-speed access link (such as a DSL link) to the customer premises. The incumbent carrier will then lease the high-speed link to a CLEC to deliver high bandwidth service to customers. This arrangement usually involves some kind of DSL service package.
- *Line sharing*: The incumbent carrier and a CLEC can offer services over different frequencies of the same copper pair through ADSL technology as described in section 2.1. For example, the incumbent carrier can continue to provide basic telephone services whereas competitors can offer high bandwidth data service by using their own ADSL modems.

For line sharing mechanisms, the unused part of a frequency spectrum on a DSL link presents a growth opportunity for future broadband services. In Europe, BT was required to unbundle its local loop in mid-2001 and Deutch Telecom has already been required to offer full-unbundled access to new entrants. For Asian markets, Table 16 summarizes the current service-based competition status for each unbundling approach (Clark, 2002):

Table 16. Asia Local Loop Unbundling Status

Unbundling Option	Status
Full Unbundling	Available in Australia, Hong Kong, Singapore, Taiwan, and Japan
High speed bit stream access	Available in Japan, Hong Kong, Australia, Taiwan and Singapore

5.5 Mix of Infrastructure and Service-Based Competition Model

A combination of the infrastructure-based and facility wholesale service-based models presents a third possibility for local loop competition. On one hand, CLECs would like to feature better operations and management control in certain areas or for certain customers in the loop competition. On the other hand, CLECs also want to leverage ubiquitous local loop connectivity of the incumbent carrier for coverage so that they do not have to build an entire local loop network. For example, CLECs may deploy fiber rings for certain industrial campuses while leasing facilities to serve remote residential customers. This practice provides CLECs with the flexibility to construct its own local loop and lease facilities from the incumbent carrier. As for the incumbent carrier, they may feel that CLEC are "cream scraping" by building their local loop to serve their most profitable customers while leasing facilities for areas that are not economically justifiable to the local loop. For this combined mode of competition to work, the facility lease price is not the only issue. The business relationship between the incumbent carriers and the CLECs is critical while promoting competition in the local loop. A policy and regulation framework will need to be established to balance the interests of the incumbent carrier and the CLECs in order to make this model work. Table 17 summarizes the advantages, disadvantages, and issues for different approaches.

Table 17. Advantages and disadvantages/issues for different local loop competition models

Local Loop Competition Model	Advantages	Disadvantages/Issues
Infrastructure based model	Clear operations and network responsibilities Avoid potential disputes Foster long term competition Provide multiple options for service and content providers	Need price regulation for local loop competition Local loop duplication may result in resource and investment inefficiency Local loop construction may delay competition
Service based model	Minimal delay in local loop competition Avoid duplicate local loop investment	Need proper pricing model to foster competition Need incentive for the incumbent carrier to upgrade local loop Difficult to differentiate services Certain services are dependent on a specific network design/architecture Limited delivery options for service and content providers
Mix of infrastructure and service-based model	Offer CLECs necessary flexibility in local loop competition Promote local loop competition Avoid duplicate local loop investment Offer multiple delivery options for services and content providers	Incumbent carrier perceives CLECs are "cream scraping" Need incentive for incumbent carriers to upgrade its local loop Need proper pricing model for local loop unbundling

5.6 Review of Local Loop Competition Status

Three landmarks of deregulation and liberalization have been the US Telecommunications Act, the World Trade organization reference paper and the liberalization of the European Union market in 1998 after a number of EU Directives. All of these policies encourage infrastructure-based entry as the preferred means of expanding coverage and deploying new technologies and/or services. As the Internet revolution continues, local loop competition becomes even more important for the Telecom regulatory agencies. For example, the conclusion of the European Council Meeting in Lisbon in March, 2000 called on the EU's member states "to work towards introducing greater competition in local access networks before the end of 2000 and unbundling the local loop in order to help bring about a substantial reduction in the costs of using the Internet" (Christodoulou, et al., 2001). In this section, we will examine the state of local loop competition in several countries from Europe, North America and Asia.

5.6.1 Review of overall European Union (EU) status

Despite regulation and the threat of litigation by the European Commission (EC), Europe's record on unbundling telecommunication local loop remains abysmal, with less than 0.01 percent of European lines having been unbundled to new entrants, according to a study published by the European Competitive Telecommunications Association (ECTA). Since the EU passed its law forcing member states to open the local loop to new entrants, incumbent carriers hold a 97 percent share of the Internet provider market. In addition, for the 4.1 million DSL lines, the new entrants provide only 3 percent over unbundled local loops, according to the ECTA (a pan European pro-competitive trade association for European telecom companies). The EU has called on regulators to provide hands-on monitoring and set binding deadlines with credible penalties in order to accomplish local loop unbundling (Rohde, 2002).

5.6.2 Review of UK status

In the UK, the regulator, Office of Telecommunications (OFTEL), traditionally promotes infrastructure-based competition. However, after a 15-year monopoly, BT (British Telecom) still accounted for around 85% of the residential connections. In addition to the pressure of complying with the EU directives on equal access and/or carrier pre-selection, OFTEL was also under criticism based on the UK's Communications Managers Association (CMA) survey indicting that 78% of the UK business users believes that OFTEL has failed to deliver effective nationwide competition. Subsequently, in December of 2000, OFTEL announced a competitive pricing model for local loop unbundling. (Christodoulou, et al., 2001).

5.6.3 Review of US status

After the 1996 Telecommunications Act, the US Federal regulatory authority, FCC, issued a policy requiring incumbent local exchange carriers (i.e., RBOCs) to offer unbundled network elements to third parties, and to offer its public telecommunications services to CLECs at wholesale rates. Even though the Telecommunications Act has required incumbent carriers to unbundle their network elements "at cost" to their competitors, the local incumbent carriers have failed to do so. For example, because of difficulties in accessing the local loop, AT&T decided to get into the local telephone market via cable television connections in 1999. In 2001, less than four percent of the local telecommunication market belonged to new entrants. The lack of local loop competition led to the demise of the hopes of long distance companies to become major competitors in the local market and the substantial failure of the Telecommunications Act (Economides, 2001).

Furthermore, the recent March 2002 tentative ruling by the FCC classified the incumbent carrier's consumer broadband Internet access service as information (not telecom) service could potentially eliminate the unbundled local loop provisioning network for incumbent carriers. This is because information service cannot be regulated at the state or city level and will be under less stringent regulations (Rosenbush, 2002). If this FCC ruling were to become official, it would have a big impact on the US local loop competition in the future.

5.6.4 Review of Asian countries status

In the past two years, Asian regulators have brought competition into the local loop by forcing incumbent carriers to unbundle the customer access network. However, the results have been disappointing (see Table 1). CLECs have barely made a mark on building their own access network. LMDS wireless technology did not compete effectively with the existing copper loops. Cable telephone service, as tried by Australia's Optus, was an expensive alternative. Neither technological nor economic conditions have been able to generate competition in the local loop. In an attempt to foster the loop competition, the Hong Kong regulator OFTA has decided to remove the limits on the number of fixed network licenses on January 1, 2003. Now, how to promote local loop competition remains a challenging issue for many Asian regulators (Clark, 2002). Table 18 summarizes the status of global local loop competition.

Table 18. Global Local Loop Competition Status

Continent	Method to promote local loop competition
Europe	Local loop unbundling
US	Local loop unbundling
Asia	Local loop unbundling; LMDS

5.7 Potential Approaches to Promote Local Loop Competition

In light of across-the-board disappointments of attempts to open up local loop competition, it is apparent that the original global deregulation objective to create "full" telecommunication network competition has not been achieved. Stimulating local loop competition is no easy task. Many questions still revolve around this issue. For example - should CLECs be encouraged or forced to build their infrastructure network? Should regulators require the incumbent carrier to provide all three local loop unbundling options (Table 17) to CLECs? In this section, we will discuss issues, concerns, and potential approaches to promote competition in the local loop.

5.7.1 Present mode of competition: role of regulator

The regulator plays a pivotal role in making the necessary policies to ensure local loop competition. First, a regulator needs to determine which local loop competition model shall be adopted. Based on the Christodoulou and Vlahos (2001) analysis, the "mix" of infrastructure and service competition stimulates investment by both incumbents and CLECs while offering better consumer benefits. Secondly, as specified in almost all deregulation documents (such as the 1996 US Telecommunications Act), unbundling the local loop is a requirement for all incumbent carriers. A regulator should clearly set loop unbundling milestones for all incumbent carriers to provide all possible unbundling options to CLECs. In addition, a regulator should carefully monitor the progress of loop unbundling schedules and take appropriate action when necessary. Thirdly, a regulator also needs to address the following "complementary" issues in order to foster the competition in the local loop environment.

- *Local number portability*: Incumbent carriers need to provide a local number portability feature so that subscribers do not have to change their telephone number if switching to a different CLEC.
- *Service resale*: In addition to local loop unbundling, incumbent carriers shall also make local service available at the wholesale price to CLECs to further promote competition.
- *Lease price for unbundled facility*: The methodology used to calculate the cost and determine the unbundled facility lease price is a complex and crucial issue. Table 19 summarizes pricing methodology employed by each EU regulatory authority (EU Commission, 2000). Most of the regulators adopted the long-run average incremental cost (LRAIC) system to determine the facility lease price. Since the facility lease price carries a "build or lease" signal to CLECs, there may be a need to have a phase approach to calculate the lease facility price. For instance, a regulator can adopt the LRAIC at the inception of competition, and further distribute costs once full competition is established. According to Christodoulou and Vlahos (2001), the introduction of a "sunset clause" in the price calculation not only provides a strong incentive to invest for both incumbents and CLECs, but also allows CLECs to enter in service competition and to acquire important knowledge about their new market before they start investing in their own facilities.

- *Interconnection pricing rule:* Since a CLEC typically has a small network infrastructure and a smaller subscriber base in the early days of competition, most of the subscriber's calls may need to be terminated at the incumbent's network for connection. These calls will then need to bear the interconnection fees for accessing the incumbent network. On the contrary, most of the incumbent carrier's calls are "internal" calls and there is no need to pay for the network interconnection fees. In other words, the price of cross-network calls exceeds the price of internal calls. This "calling circle discount" tends to favor the incumbent carrier over an external network. Three possible price rules, namely reciprocity, imputation and unbundling, could facilitate the early market competition (Economides, et al., 1996).

As indicated, one of the critical issues for a regulator is to monitor the status of the local loop competition and take appropriate action during and after the transitional period (such as modifying the calculation methodology for facility lease price). The objective is to neutralize the incumbent's market dominance and lower entry barriers for CLECs during the early stages of local loop competition.

Table 19. Local Loop Unbundling Pricing Methodologies

Country	Unbundle Pricing methodology
Austria	FL-LRAIC (forward looking-long run average incremental cost)
Denmark	FDHC/LRAIC 200+ (fully distributed historical cost/ long run average incremental cost)
Germany	LRIC (long run incremental cost)
Ireland	FDHC (fully distributed historical cost)
Netherlands	Embedded direct cost (EDC)
UK	FL-LRAIC

5.7.2 Organization divestiture: a monopolized local loop network

In light of the lack of competition progress in the local loop, other approaches must also be considered. A potentially different approach to promote competition is to disintegrate the vertical incumbent's business model, divest the local loop from the incumbent carrier and CLECs (if any), and establish the local loop as an independent network infrastructure company for all carriers. This local loop infrastructure company will not offer any telecom "service" to end customers. Instead, the local loop company will sell "wholesale" service to all carriers (Lynch, 2002). In addition, this local loop company will be subject to regulation due to its monopoly position in the local loop market. Once competition blossoms in the local loop (such as wireless local loop carriers or cable carriers), the regulator can then ease the restrictions and allow the market to govern competition. By separating the local loop from the incumbent carriers, the new local loop company will be motivated to work with both the incumbent carrier and CLECs to offer local services to end customers. This, in turn, should eliminate CLEC complaints of excess charges, delays or restrictions when trying to provide local services. This new model should also promote competition in the local loop. In the interests of national resources, having a local loop company to maintain and upgrade the local loop network can also avoid the duplication the existing copper network. Furthermore, because of its monopoly position and guaranteed rate of return by the regulator, the local loop company is in a better position to build a ubiquitous broadband local loop for all subscribers.

5.7.3 Oligopoly competition

The recent telecom downturn has had a severe financial impact on both telecom carriers (incumbents and CLECs) and telecom manufacturers. Deregulation and competition have driven down service prices while the demands for services have not generated sufficient positive cash flow for CLECs. In addition, the compressed technology cycle, which makes the period of return on capital even shorter, further exacerbates the problem. As a result, most

American CLECs have perished. Other CLECs around the world, such as TelstraClear (New Zealand's number two carrier), StartHub (Singapore's number two operator), and Energis (UK's new entrants), continue to struggle in the telecom market. Meanwhile, incumbent carriers continue to dominate and control most of the voice and broadband Internet services (Lynch, 2002).

Recent global economy woes and telecom scandals (such as WorldCom and Global Crossing) ensure that CLECs will have further difficulty in obtaining the necessary capital to compete in the local loop network. At the same time, local incumbent carriers continue to expand their coverage through mergers (such as the merger of Southwestern Bell, Ameritech, and Pacific Bell into SBC) and other investments. Meanwhile, cable, satellite TV, media, and wireless communications sectors also are going through sweeping consolidations. The local loop competition landscape may be very different in the near future. Future major competitors against incumbent carries may be cable operators or wireless carriers (such as 3G operators) and not CLECs. This scenario is of particular relevance to broadband communications. Since these competitors are from different telecom sectors, regulators will need to look at the competition from an oligopolistic perspective (Rosenbush, 2002). In oligopoly competition, incumbent carriers might need to be given less stringent regulations than those required for telecom local loop competition so as to compete with other cross-industry players, such as cable operators.

If the above-mentioned competition does not occur, and the local loop continues to be dominated by the incumbent carriers, alternate options could be considered. A regulator could encourage CLEC's to consolidate in order to create competition in the local loop. Although an oligopoly may not provide the lowest price to consumers, it offers an opportunity to build ubiquitous broadband networks and some degree of competition.

In summary, depending on each country's situation, a regulator may have to employ different local loop competition approaches to foster local loop competition. In addition, within a country, different approaches may have to be applied during different competition cycles due to market dynamics. However, no matter what approach is taken, the regulator will play a pivotal role in local loop competition. Table 20 summarizes the different approaches to promote local loop competition.

Table 20. Different approaches to promote local loop competition

Approach	Assumption	Issues
Present mode of competition	CLECs are viable competitors against the incumbent carrier	• Local number portability • Service resale • Lease price for unbundled facility • Interconnection pricing rule
Organization divestiture	Many CLECs viable competitors against the incumbent carrier	• A monopoly local loop company establishment • Efficiency of the local loop company
Oligopoly competition	No viable CLEC competition; viable new cross industry competitors	• Cross industry sector regulation • CLECs consolidation and oligopoly competition efficiency

5.8 Summary

The intent of telecom deregulation was to promote competition and the public interest. Competition in the long distance arena has been a great success. Not only there are large facility-based competitors in the long distance market, but also there are a large number of resellers that buy wholesale service from the facility-based long distance carriers and sell to consumers. Conversely, local access networks have been virtually devoid of competition. Globally, the "last mile" local loop remains to be largely controlled and dominated by incumbent carriers. The lack of competition in the local loop may be of particular concern in the broadband service era because of the participation of content, ISP and/or ASP providers in the offering of services. Moreover, consumers did not enjoy the full price benefits that were supposed to be realized as a result of the telecom deregulation. It will be a significant failure if the interests of entrenched monopolists, rather than public interest, dictate the future of the telecommunications sector.

Various emerging access technologies are being developed to meet the last mile demands. Based on the successful evolution of LAN technology , it is found that backward technology compatibility is one of the important factors in managing technology trends and evolution. Therefore, it is deemed that WLAN posses high potential to serve in the local loop access service. From a policy perspective, there are three possible models (infrastructure-based, service-based, and a mix of infrastructure and service) that CLECs can employ to compete with incumbent carriers. Each model has pros and cons. Typically, CLECs have taken the "mix" approach to compete with incumbents. Consequently, the effectiveness of the incumbent's ability to unbundle the local loop has become a critical issue in local loop competition. Our analysis shows that several "complementary" issues need to be addressed before full competition can take place in the local loop. Alternatively, a radical local loop divestiture model is also a potential option for local loop competition. Furthermore, in light of the recent telecom bubble and the emerging of cross-industry competitors (e.g., cable operators), if most of CLECs are unable to effectively compete with incumbent carriers, then a CLEC consolidation creating oligopolistic competition could also be a viable option for local loop networks.

6. Conclusions and Suggestions

The Internet revolution has instead become an evolution. While the economic slowdown continues, more bankruptcies and mergers are expected to occur in the telecom industry. Smaller and weaker carriers cannot survive in the market, and the assets of bankrupt companies will be sold to remaining stronger players. While capital spending continues to fall, many telecom manufacturers will continue to restructure their corporations, trim work forces, better manage suppliers and inventories, identify core competitive advantages, and focus on their operation's efficiency to improve profitability. Those that survive will focus even more keenly on profitability and return on investment. Financial institutions that hold telecom debt could also face severe financial crisis. Notwithstanding, this worldwide telecom downturn could be a process that "weeds out the weak" and eventually provides a better foundation for healthy growth in the future. (Elstrom, et al., 2001).

6.1 Conclusions

The recent wave in the telecommunications and information advancement does not make the telecom and IT industry radically different from previous industrial experiences. Although this telecom slowdown has caused a severe setback in global telecom development, history has shown that full use of any new technology will arrive eventually. However, the new technology must be made user friendly, and new business models must be developed to make it happen. This evolutionary process may take several decades. On the upside, it would be well to remember that, from batch mainframe computing to desktop computing, and wireless technologies to Web-based services, new digital information technologies are continuously being developed (Arthur, 2002). The wire-line and wireless Internet evolution will be an ongoing process that will have a far-reaching impact in the future. Broadband 3G wireless manufacturers and service operators are re-structuring and re-positioning themselves in order to prepare for the next wave of opportunities to arrive.

Even though the telecom industry is going through the restructuring process, telecom carriers are faced with fast growing Internet data traffic that exceeds traditional voice traffic. Gigabit Ethernet technology holds the promise to relieve the critical bandwidth bottleneck in the access network. As Ethernet technology has evolved into multi-gigabit bandwidth with applications extending from LAN, MAN, and even to WAN, Gigabit Ethernet offers several technical advantages against the incumbent SONET/SDH technology. However, selecting the best technology for MAN network not only needs to address the technology issue, but also needs to evaluate network operations, services, and compatibility issues. In other words, it is important to analyze a problem from a "system and multi-criteria" perspective to derive an optimal solution. Using the fuzzy MCDM method to study the issue can help telecom carriers to address both quantitative and qualitative issues in a complex business environment. The ranking of the criteria also provide insight on enterprise business and service priority to avoid any prejudgments or oversight while establishing an MAN access strategy.

Given that this is a first attempt to address the qualitative issues while selecting an access technology by using fuzzy MCDM, it is believed that significant insights have been observed and a foundation for future research has been established. In order to achieve a more complete and pragmatic MAN access strategy, the evaluation hierarchy system will need to be examined at a lower level to further reflect network and business issues. A number of extensions could be further explored, including survey design, the use of group decision-makers, correlation among various criteria, evaluating the weights for the hierarchy relevance system using ANP (Analytic Network Process), and different de-fuzzy ranking methods.

Because of the lack of bottleneck access in the "last mile" of the telecom network, there is little competition in the global local loop of telecom network. This lack of competition in the local loop could severely hinder the development of broadband service access and content availability for the local loop subscribers. As a result, how to stimulate the local loop competition has become a critical issue for the telecom regulators. At the same time, there are several emerging access technologies that are being developed to address these market needs. Fiber, cable and wireless solutions are three main access technologies that offer alternatives for existing copper network. Each access technology has its pros and cons while trying to meet customer's service demands. Among these technologies, WLAN deserves particular attention because of Taiwan's leading WLAN manufacturing capability and industry output. If WLAN could be extended to serve the long range and outdoor environment while meeting the carrier's performance and operations requirements, there will be tremendous market opportunities for Taiwan's wireless industry to penetrate into the telecom local loop access market. At the same time, WiMAX is emerging as the MAN access wireless solution. Unlike previous MMDS and LMDS broadband access technologies, which were designed for fixed units, WiMAX is expected to be used in laptop computers for broadband data access. The mobility aspect of the WiMAX application together with the existing base of the laptop users could stimulate the growth of broadband data applications for wireless WANs. At the same time, the fiber access system continues to hold promise for the last mile broadband services. Managing access technologies from the carriers, manufacturers and government perspectives could have different focuses. For example, manufacturers will continue to look for technology innovation in access technology areas while carriers will look for technology that can help them to provide services that will meet subscriber's needs in a cost effective manners. Government regulators will primarily endorse technologies that can create a fair competition environment to meet subscriber's needs. Therefore, it is important to understand the objectives and perspectives of the issue at hand while managing various access technologies.

Future growth and investment in telecommunications will depend on how well policy-makers can bring sustainable competition into the local loop. As the telecom industry continues evolving, it will be a challenge for regulators to set proper regulatory policies and guidelines to promote local loop competition.

6.2 Suggestions

Telecom industry provides the infrastructure for worldwide communications. Therefore, network to network connectivity, network coverage, network reliability and performance and service affordability are important criteria in establishing telecom networks. Because of the unique characteristics of the telecom network, it requires large capital investments and government licenses to conduct business and is, therefore, heavily influenced by government policy and regulation. Telecom deregulation is intended to introduce competition in the telecom carriers. However, without proper government guidance, telecom deregulation and policy (such as the European 3G license auction) could have a long-term negative impact on the local telecom industry. How to balance the forces between market demand and regulation is deemed a delicate issue. Furthermore, the speed and scope of telecom deregulation also impacts the survivability and sustainability of the telecom industry, particularly the carrier industry. A long-term sustainability phase approach for the telecom carrier industry coupled with a user centric strategy to balance supply and demand may be the best guideline for future telecom policy regulation. From a policy perspective, if a majority of the CLECs (Competitive Local Exchange Carriers) are unable to effectively compete with incumbent carriers, then a CLEC consolidation - leading to a well-controlled monopoly - could be a solid option for future local loop networks.

It is important to recognize the qualitative issues while managing emerging MAN and access technologies. Using the fuzzy MCDM method to quantify the qualitative issues while conducting a strategy evaluation is deemed an effective approach. This is may be of particular importance in managing emerging technologies in a complex business environment, since no deployment and proven benefits have been realized yet on these technologies. It is also found that in many cases, technology advantages are only one of the components in making a successful business. Other components, such as marketing and partnership strategies, as well as meeting user's demands, are equally important in overall technology management. A system view is deemed necessary to manage and capture the trend of the emerging technologies.

References

王乃弘 (民 89), 民眾偏好醫院類型之研究 法之應用, 管理學報, 第十六卷第四期, 頁 661-681。

汪美香, 許溪南 (民 89), AHP 應用於外幣選擇權投資策略之研究 -- 以國際金融業務分行(OBU)爲例, 企業管理學報, 第四十六卷第二期頁 115 - 134。

黃興進, 張仁雄, 李幸秋, (民 90), 群體支援系統環境中層級分析法與任務型態對群決策之影響, 中山管理學刊, 第九卷第二期, 頁 201 - 219。

Arthur W. B., Business 2.0, March 2002, Is the Information Revolution Dead?

Baker S., BusinessWeek Asia Edition, June 3, 2002, Tale of a Bubble, p46 –p52

Bellman, R.E., Zadeh, L.A., 1970. Decision-Making in a Fuzzy Environment. Management Science 17(4), 141-146.

Beranek L., 2000, Volume 2, The Massachusetts Historical Review, p56 -p72.

Buckley, J.J., 1985. Ranking Alternatives Using Fuzzy Numbers. Fuzzy Sets and Systems 15(1), 21-31.

Business Online, May 2000, volume 1, issue 7, Cover Story, E-volution –Trading Hubs Take Off, p26 – p35.

Business Online, May 2000, volume 1, issue 7, ASPs – Controlling the Chaos, p18 – p20.

Chen, T.C.,1997. Fuzzy theory application in selecting management strategy. 1997 toward new management era conference, Ming-Chian University, 715-720.

Cheng, C.H., Mon, D.L., 1994. Evaluating Weapon System by Analytical Hierarchy Process Based on Fuzzy Scales. Fuzzy Sets and Systems 63, 1-10.

Cheng, J.Z., Tsyu, J.Z., Yu, H.C., 2003. Boom and gloom in the global telecommunications industry. Technology in Society 25(1), 65-81.

Cheng, J.Z., Chen, P-T, Yu, H-C D. 2003, Establishing a MAN access strategy for future broadband service ; a fuzzy MCDM analysis of SONET/SDH and Gigabit Ethernet, accepted by Technovation.

Cheng, J.Z., Yu, H-C, Sincoskie, W.D. 2003, Meeting the broadband access infrastructure demands: the promise of Gigabit Ethernet, accepted by Technological Forecasting and Social Change.

Christodoulou K. & Vlahos K. 2001, Implications of regulation for entry and investment in the local loop, Telecommunications Policy, 25, PP. 743-757.

Clark R., February, 2002, Caught in the loop, telecom Asia, PP. 18- 21.

Clavenna, S., Mary Jander and Marguerute Reardon, August 2001, Metro Optical Ethernet, Business Communications Review: S12-S16.

Economides, N., September, 1998, The Telecommunications Act of 1996 and its Impact, presented at the Annual Telecommunications Policy Conference, Tokyo, Japan, December 4, 1997. available at www.raven.stern.nyu.edu

Economides, N., Spring/Summer, 2001, Coming Together: The AT&T breakup (round three) and the remonopolization of telecommunications, STERNbusiness, PP. 39-41.

Economides, N., Lopomo, G., & Woroch, G., September, 1996, Regulatory Pricing Rulesto Neutralize Network Dominance, available at www.raven.stern.nyu.edu

Elstrom P. with Timmons H. in New York, BusinessWeek, April 23, 2001, Telecom Meltdown, p 100 – p 110.

Ferreira P., Lehr W., McKnight L., 2002, Optical networks and the future of broadband services, Technological Forecasting and Social Change, 69(2002) PP 741-758

Finneran M., August, 2001, Optical Switching: The What, How and Why, Business Communications Review PP S19-S23.

Foroohar R., Newsweek, May 28, 2001, The Other Bubble, p19 – p22.

Gabelmann A., 2001, Regulating European telecommunications markets: unbundled access to the local loop outside urban areas, Telecommunications Policy, 25, PP. 729-741.

GR-253, September, 2000, Synchronous Optical Network (SONET) Transport Systems: Common Generic Criteria, Telcordia Technologies.

Henry D., BusinessWeek, February 19,2001, Deadweight on the Markets", p84 –85.

Hu C-W, Keys for future network industry growth, Chinatimes Business Newspaper, June 29, 2001.

IEEE Standard 802.3AE-2002, IEEE Standard for Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications-Media Access Control (MAC) Parameters, Physical Layer, and Management Parameters for 10 Gb/s Operation

Information Technology - LAN/MAN - Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer, Specifications 2000 IEEE 802.3 CSMA/CD (Ethernet) Standards.

Kerzner, H., 1989. A System Approach to Planning Scheduling and Controlling. Project Management, New York: Van Nostrand Reinhold, 759-764.

Lawrence, G..R., Crump, C., U.S. Internet IP Traffic Growth, available at www.caspiannetworks.com

Lashinsky A, TheStreet.Com, June 22, 2001, Cisco's Cash Cushion Keep It Riding High

Lynch G. April, 2002, Has the competitive carrier model failed?, Telecom Asia, PP. 38.

Masini, E.B. and Vasquez, J.M. 2000, Scenarios as Seen from a Human and Social perspective, Technological Forecasting and Social Change, 65(1), 49-66.

Metro Ethernet Networks – A Technical Overview, A Metro Ethernet Forum Whitepaper, www.metroethernetforum.org

Michalis M., 2001, "Local competition and the role of regulation: the EU debate and Britain's experience", Telecommunications Policy, 25, PP. 759-776.

Miller R. , Arndt M., Edwards C., Burrows P., Shinal J., Muller J., Zellner W., and bureau reports, February, 2001, Downturn in Fast-Forward. BusinessWeek.

NASA, PATTERN Relevance Guide (3 vols) 1965,. National Technical Information Service, U. S. Department of Commerce, Virginia.

NASA, PATTERN procedure manual. 1996, Honeywell Aero Report. National Technical Information Service, U. S. Department of Commerce, Virginia.

Perez, T. 1995, Some Comments on Satty's AHP, Management Science, 41(8), 1091-1095.

Rohde L., February 2002, Study warns local loop unbundling failing in Europe, IDG News Service, available at www.pcworldmalta.com/news/2002/Feb

Rosenbush S., March, 2002, Broadband Policy: Did somebody say oligopoly?, BusinessWeek, PP. 40.

Rosenbush S. and Elstrom P., BusinessWeek, August 13, 2001, 8 Lessons from the Telecom Mess, p 60 – p 67.

Rosenbush S. in New York, with Shinal J. in San Mateo, Crockett R. in Chicago, Baker S. in Paris, and Kunii I. in Tokyo, BusinessWeek, February 19, 2001, Bad Loans Rattle Telecom Vendor, p85 – p86.

Saaty, T.L., 1977. A Scaling Method for Priorities in Hierarchical Structures. Journal of Mathematical Psychology 15(2), 234-281.

Saaty, T.L., 1980. The Analytic Hierarchy Process, New York: McGraw-Hill.

Seifert, R., A Complete Guide to LAN Switching Technology. JOHN WILEY & SONS, INC.

Seifert R., A Complete Guide to LAN Switching Technology, JOHN WILEY & SONS, INC.

Shinak J., BusinessWeek, February 26, 2001, Can Mike Volpi make Cisco Sizzle Again? p102 – p104.

Tang, M.T., Tzeng, G..H., Wang S.W., 1999. A Hierarchy Fuzzy MCDM Method for Studying Electronic Marketing Strategies in the Information Service Industry. Journal of International Information Management 8(1), 1-22.

Telecommunications Industry Association, September, 2002, TIA White Paper: Fiber Optic Network Capacity and Utilization, Part II

Teng, J.Y., Tzeng, G.H., 1996, Fuzzy Multicriteria Ranking of Urban Transportation Investment Alternative. Transportation Planning and Technology 20(1), 15-31.

Tsaur, S.H., Tzeng, G..H., Wang, K.C., 1997. Evaluating Tourist Risks from Fuzzy Perspectives. Annals of Tourism Research 24(4), 796-812.

Tzeng, G.H., 1977. A study on the PATTERN Method for the Decision Process in the Public System, Japan Journal of Behaviormetrics 4 (2), 29-44.

Tzeng, G.H., Shiau, T.A., 1987. Energy Conservation Strategies in Urban Transportation: Application of Multiple Criteria Decision-Making. Energy Systems and Policy, 11(1), 1-19.

Tzeng, G.H., Shian, T.A., Lin, C.Y., 1992. Application of Multicriteria Decision Making to the Evaluation of New Energy-System Development in Taiwan, Energy (An International Journal) 17(10), 983-992.

Tzeng, G.H., Teng, J.Y., 1994. Multicriteria Evaluation for Strategies of Improving and Controlling Air-Quality in the Super City: A Case of Taipei City, Journal of Environmental Management 40(3), 213-229.

Tzeng, G.H., Tsaur, S.H., 1993, Application of Multicriteria Decision Making to Old Vehicle Elimination in Taiwan, Energy and Environment 40 (3), 265-283.

www.techguide.com, Building 10 Gigabit/DWDM Metro Area Networks, The Technology Guide Series.

www.extremenetworks.com, Building New-generation Metropolitan Area Networks, Extreme Network.

www.appliancom.com, Ethernet, The key to new service revenues. Appian Communications.

www.wimaxforum.org, WiMAX Overview, Worldwide Interoperability for Microwave Access Forum

www.xilinx.com

www.yipes.com

www.onfiber.com

Zadeh, L.A., 1965. Information and Control. Fuzzy Sets, 8(3), 338-353.

Zadeh, L.A., 1975. The Concept of a Linguistic Variable and Its Application to Approximate Reasoning, Parts 1, 2, and 3. Information Science 8(2), 199-249, 8(3), 301-357; 9(1), 43-80.

Zahedi, F., 1986, Analytic hierarchy Process: A Survey of the Method and its Applications, Interfaces, 16(4), 96-108.

Zhau, R., Goving, R., 1991. Algebraic Characteristics of Extended Fuzzy Numbers, Information Science 54(1), 103-130.

Appendix - Questionnaire

選擇都會區寬頻網路架構策略之評選問卷調查表

親愛的學者、專家、業界人士大家好：

　懇請撥出一分鐘勾選以下之比較表。您的寶貴意見將有助於都會區網路架構的規劃挑選出一較佳之政策模式。敬頌

教安

交通大學科技管理研究所
虞孝成　拜託
M-Phone：0933-695842
Fax Number：03-5726749
E-mail：pengting.mt90g@nctu.edu.tw

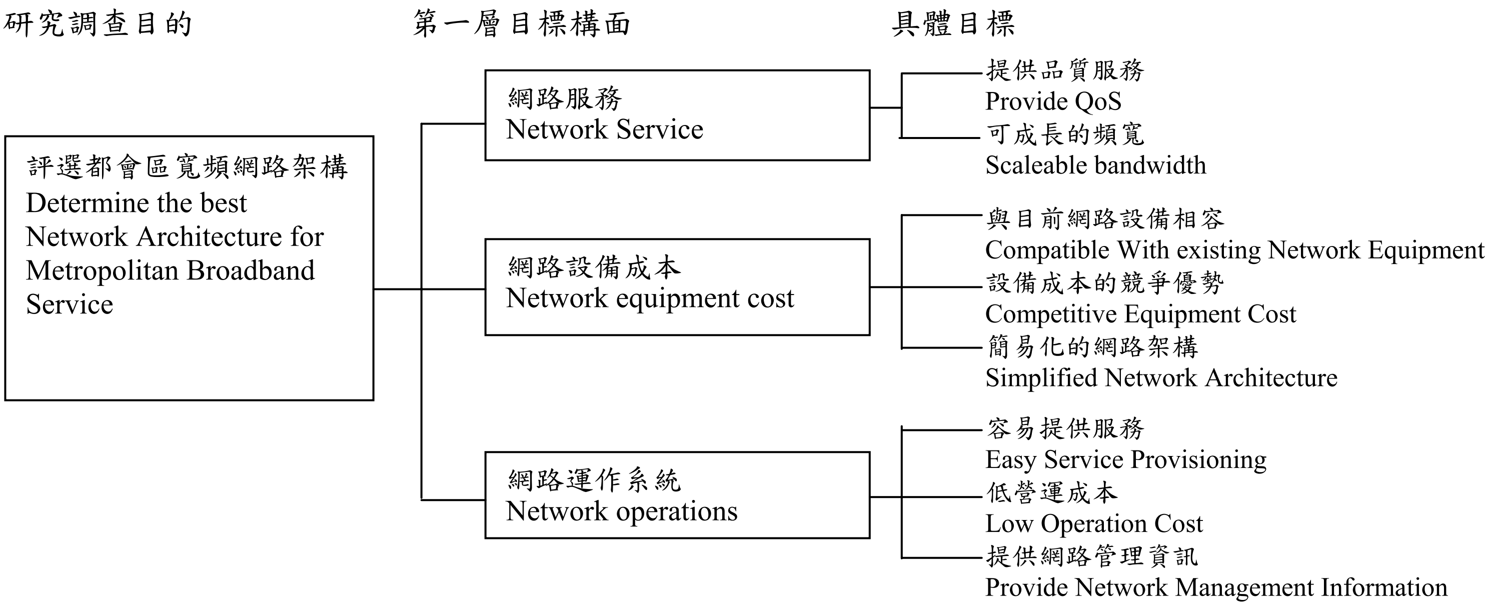
壹、基本資料填寫：(可複選，請在適當位置劃勾『V』)

工作機構：□大學學者 □研究單位 □行政部門 V□電信服務業者 □電信設備或零售業者
受訪者部門：□財務會計 □生產製造 V□研發 □行銷 □人力資源 □其它
需要本研究結果請留電子郵件地址：________@____________

貳、各類策略方案實務探討

本研究將針對以下兩種都會區網路架構政策進行分析：
I.「SDH Architecture」
II.「Gigabit Ethernet」

撰擇都會區寬頻網路架構最佳策略時，期望達到三個目標構面：網路服務構面、網路設備成本構面以及網路運作系統構面。然而在每一目標構面下又各有幾項具備目標。



一、各考量項目相對重要性之比較（每一行請選一個格子劃勾「∨」）

填寫範例

敬請兩兩相比，勾選以下各考量項目之相對重要性比例。

以下為例 9:1 表目前「網路服務」相對於「網路設備成本」重要性最強；反之，1:9 表目前「網路運作系統」相對於「網路服務」重要性最強，下量表越靠左，表「網路服務」相對越強。若置於中間(1:1)則表兩考量項目之重要性相等。

	相對重要性比例（9 最大、1 最小）																	
	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
網路服務	V																	網路設備成本
網路服務																	V	網路運作系統

問卷填寫開始

敬請兩兩相比，勾選以下各考量項目之相對重要性比例。

	相對重要性比例（9 最大、1 最小）																	
	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
網路服務												V						網路設備成本
網路服務												V						網路運作系統
網路設備成本														V				網路運作系統

針對「網路服務」下之第二層構面敬請兩兩相比，勾選以下各考量項目之相對重要性比例。

	相對重要性比例（9 最大、1 最小）																	
	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
提供品質服務																	V	可成長的頻寬

針對「網路設備成本」下之第二層構面敬請兩兩相比，勾選以下各考量項目之相對重要性比例。

	相對重要性比例（9最大、1最小）																	
	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
與目前網路設備相容			V															設備成本的競爭優勢
與目前網路設備相容			V															簡易化的網路架構
設備成本的競爭優勢															V			簡易化的網路架構

針對「網路運作系統」下之第二層構面敬請兩兩相比，勾選以下各考量項目之相對重要性比例。

	相對重要性比例（9最大、1最小）																	
	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
容易提供服務						V												低營運成本
容易提供服務												V						提供網路管理資訊
低營運成本												V						提供網路管理資訊

二、效用值設定

請給以下各種程度的效用區間一個評分，自 0 至 100 指示之低、中、高三個分數。例如您可能認為「效用很大」低、中、高評分各為(85, 90, 100)，但「效用大」的低、中、高評分各為(70, 80, 90)，其中低和高的分數可以重疊。

	低	中	高
1.「效用很大」	80	90	100
2.「效用大」	60	70	80
3.「效用中」	40	50	60
4.「效用小」	20	30	40
5.「效用很小」	0	10	20

三、評估準則及都會區網路寬頻網路架構政策間之效用值勾選

【1】請勾選每一種評估準則(構面)對「都會區網路寬頻網路架構政策」影響效果大小請在適當位置劃勾『V』。

評估準則 / 效果 / 都會區網路架構政策	提供品質服務 Provide QoS					可成長的頻寬 Scalable bandwidth					與目前網路設備相容 Compatible With existing Network Equipment				
	效用很大	效用大	效用中	效用小	效用很小	效用很大	效用大	效用中	效用小	效用很小	效用很大	效用大	效用中	效用小	效用很小
SDH Architecture		V							V			V			
Gigabit Ethernet				V			V					V			

【2】請勾選每一種評估準則(構面)對「都會區網路寬頻網路架構政策」影響效果大小請在適當位置劃勾『V』。

評估準則 / 效果 / 都會區網路架構政策	設備成本的競爭優勢 Competitive Equipment Cost					簡易化的網路架構 Simplified Network Architecture					容易提供服務 Easy Service Provisioning				
	效用很大	效用大	效用中	效用小	效用很小	效用很大	效用大	效用中	效用小	效用很小	效用很大	效用大	效用中	效用小	效用很小
SDH Architecture				V					V					V	
Gigabit Ethernet		V					V					V			

【3】請勾選每一種評估準則(構面)對「都會區網路寬頻網路架構政策」影響效果大小請在適當位置劃勾『V』。

評估準則 / 效果 / 都會區網路架構政策	低營運成本 Low Operation Cost					提供網路管理資訊 Provide Network Management Information				
	效用很大	效用大	效用中	效用小	效用很小	效用很大	效用大	效用中	效用小	效用很小
SDH Architecture				V			V			
Gigabit Ethernet		V							V	