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# Establishing a MAN access strategy for future broadband service: a fuzzy MCDM analysis of SONET/SDH and Gigabit Ethernet

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**Abstract**

Global Internet traffic growth continues to create a 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 purpose of this paper is to help telecom carriers evaluate and plan their future broadband MAN access strategy by employing the fuzzy MCDM method. An empirical formula can rationally examine the practicability and usefulness of this method. Results revealed that SONET/SDH technology scored higher than Gigabit Ethernet technology with regards to MAN access for future broadband service.


*Keywords:* Ethernet; SONET/SDH; LAN; MAN; WAN; Fuzzy; MCDM

## 1. Introduction

The rapid increase of Internet users throughout the world has resulted in exponential growth of Internet traffic in WANs (Wide Area Networks). Despite the recent telecom industry slowdown, Internet IP traffic has continued to quadruple each year through the first quarter of 2001 (Lawrence and Crump, undated). 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 with 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 MAN 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 leaped ahead of traditional voice

*Abbreviations:* AAL, 5: ATM Adaptation Layer 5; ADM:, Add-Drop Multiplex; ADSL:, Aynchronous 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; COA:, Center of Area; CSMA/CD:, Carrier Sense Multiple Access with Collision Detection; DCS:, Digital Cross-Connect System; DWDM:, Dense Wavelength Division Multiplexing; GR-253:, Generic Requirement-253; IEEE:, Institute of Electrical and Electronic Engineers; IP:, Internet Protocol; LAN:, Local Area Network; 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.

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traffic to become the dominant traffic type, the transmission throughput limitation of the MAN to handle data traffic has restricted the capabilities of the system. 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).

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 paper 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 practicability 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 paper employed 1985 Buckley’s ‘fuzzy AHP’ method to conduct alternative evaluation research. Survey questionnaires were distributed to two 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 paper is organized as follows. Section 2 of this paper reviews the evolution of Ethernet technology. Section 3 discusses the current MAN broadband service architecture. Section 4 takes a look at the benefits and challenges of using Ethernet technology in the MAN. Section 5 establishes the MCDM model for evaluating different MAN access technologies. Section 6 examines the practicality and usefulness of this method via an example and its empirical results. The last section gives conclusions and suggestions.

## 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 (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 optical 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 employed basic technology and simple protocol 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, undated). 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 area. 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) the WAN. However, as Ethernet evolves, a number of questions also arise about its true capability and role in the new market.

## 3. Current MAN broadband service architecture

With Ethernet being virtually ‘everywhere’ in the enterprise and desktop environments, there is a need to interconnect these LANs together for networking service and applications. To provide enterprises with broadband services, telecom carriers have deployed SONET/SDH rings in the MANs to address the LAN networking and Internet traffic issues. 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 (http://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 (64 kb/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 provide a 155 Mb/s SONET channel to carry it, thus wasting the remaining 55 Mb/s. This inefficiency is rendered obsolete with the 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 SDH/SONET 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.

To address the above business challenges, a solution with flexible bandwidth allocation, 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, and RPR (Resilient Protection Ring) are all emerging solutions for MAN networks. Based on the maturity and applicability of this technology, this paper will focus on exploring the feasibility of adopting Gigabit Ethernet (1 Gigabit and 10 Gigabit Ethernet) technology in the MAN environment (Clavenna, 2001).

## 4. Pros and cons of using Gigabit Ethernet technology for MAN access

### *4.1. Benefits of using Gigabit Ethernet technology*

Since Gigabit Ethernet delivers easy provisioning and bandwidth flexibility, telecom carriers can potentially 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, 2001).

#### *4.1.1. Simplified network architecture*

A telecom carrier, using existing SONET/SDH network architecture for conventional DS3 (45 Mb/s) broadband service, must deploy DCS (Digital Cross-Connect System) and ADM (Add-Drop Multiplex) rings in their network. With Gigabit Ethernet technology, a telecom carrier could conceivably provide broadband connection to users by deploying a series of Ethernet switches linked with leased fiber cables.

#### *4.1.2. Eliminate the need for 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, requiring an additional layer 2 of ATM and of layer 3 AAL5 protocol stack processing. Streamlining protocol conversion not only can reduce technical complexity, but also enhance the integrity of data transmission.

#### *4.1.3. Asynchronous network vs synchronous network*

Because the SONET/SDH network operates in synchronous mode, it requires highly accurate network timing. 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). Since Gigabit Ethernet operates in asynchronous mode, neither network synchronization nor sophisticated PLL in each line card is required. This can reduce overall network equipment costs as well as operating expenses.

#### *4.1.4. Ethernet equipment cost advantage*

A study conducted by the Dell'Oro Group (Clavenna, 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

Table 1
Dollar per gigabit of bandwidth in 2004, by Dell'Oro Group

| | Fast Ethernet | Gig Ethernet | 10 Gig Ethernet | SONET OC-3 | SONET OC-192 |
|---|---|---|---|---|---|
| 2004(Y) | $3116 | $838 | $485 | $26,367 | $3143 |

the bandwidth equivalent of a $1 million SONET network. As shown in Table 1, by 2004, the cost difference in deploying one Gigabit of bandwidth using 10 Gb/s Ethernet versus SONET OC-192 is estimated to be several thousand dollars.

#### *4.1.5. Technical and operations support*

With over 100 million installed Ethernet LANs in the world, a large group of users and skillful technicians are already familiar with Ethernet technology. The convenience of the 'plug and play' feature and the backward compatibility to lower speed Ethernet LANs hint at a smooth migration path for enterprise IT applications. This common capability and ease of use could enhance the demand for Gigabit Ethernet and eventually drive its cost down.

#### *4.1.6. 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. (www.appliancom.com).

#### *4.1.7. 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 deteriorating, 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 (http://www.appliancom.com).

### *4.2. Challenges of using Gigabit Ethernet technology for MAN access*

Although Gigabit Ethernet offers many unique capabilities and advantages to satisfy business needs in a metropolitan network, there are many challenging issues that need to be answered before Gigabit Ethernet can establish itself as the future mainstream MAN access technology. For example, can Ethernet technology evolve into a true 'carrier grade' technology? How will Gigabit Ethernet be deployed? How does Gigabit Ethernet inter-work with or replace the existing SONET/SDH and ATM networks? Some of these issues are briefly discussed in the following:

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

Unlike ATM, Gigabit Ethernet does not have admission control capability to regulate an individual user's traffic stream. Gigabit Ethernet can only rely on 'policy-based' QoS to manage the aggregated traffic.

#### *4.2.2. 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 this network performance monitoring information, carriers can detect network deterioration, localize fault, 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.

#### *4.2.3. Can Gigabit Ethernet provide the network protection switching and fault isolation capabilities that are currently provided by SONET/SDH and ATM?*

SONET/SDH frame structure contains signaling overhead bytes (e.g., the K1 and K2 bytes) that can be used to provide protection-switching functions within a 50 ms interval (GR-253). 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.

#### *4.2.4. How can Gigabit Ethernet scale up within a large carrier network?*

Because Ethernet is traditionally used as a LAN in private enterprise environment, the scale and size of any single Ethernet network is much smaller compared to a public telecom network. Scalability of the Gigabit Ethernet is a major concern for telecom carrier while evaluating different MAN access technologies.

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.

## 5. 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

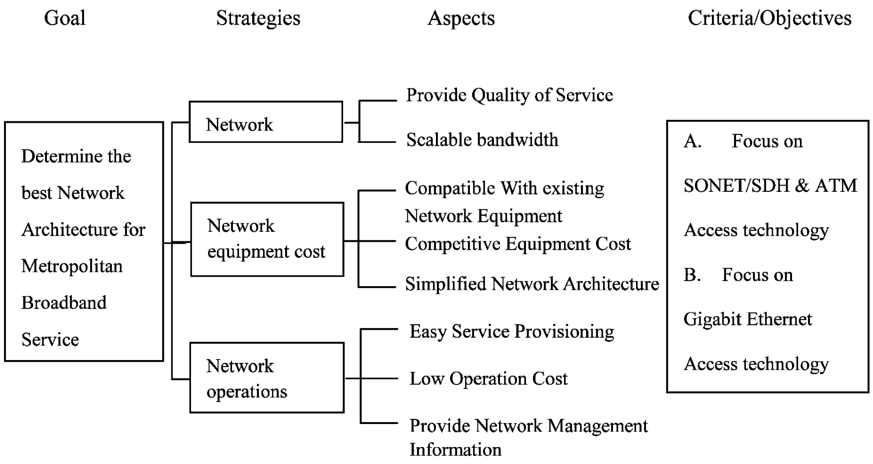


Fig. 1. Relevance system of hierarchy strategies for access technology.

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.

### 5.1. 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. According to 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 Fig. 1).

### 5.2. 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 2.

Table 2
MAN access strategies for the telecom carriers

| Criteria/Issues | Strategies |
|---|---|
| • Telecom carriers need to provide proven carrier's grade scalable broadband solutions and service for customers.<br>• It is critical to maintain the network operations through comprehensive network management information.<br>• Leverage existing SONET/SDH infrastructure to generate revenue is important, particularly during the telecom downturn.<br>• Telecom carriers should offer bandwidth flexibility to customers.<br>• The convergence of voice and data service will be the major business driver for future broadband services.<br>• 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. | *A: Focus on SONET/SDH and ATM access technology:*<br>Telecom carriers continue to enhance and improve existing SONET/SDH and ATM networks and their respective operations support systems to offer quality broadband services.<br><br>*B: Focus on Gigabit Ethernet access technology:*<br>To offer broadband service, telecom carriers will aggressively deploy Gigabit Ethernet in the MAN to take advantages of the potential benefits offered by Gigabit Ethernet. |

*5.3. Fuzzy MCDM method*

In a simple environment or using a single measurement index, the traditional minimum cost, maximum profit or the cost efficiency methods can be employed to conduct an alternate evaluation. 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 and 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 the possible adverse consequence, the evaluation is conducted in an uncertain and fuzzy environment. This fuzzy evaluation design allows evaluators to express their opinions in fuzzy expression manner. For these reasons, the Fuzzy MCDM was selected to conduct this evaluation.

*5.4. The process of evaluating the hierarchy strategies*

The evaluation process includes two steps.

*5.4.1. 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 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.

*5.4.2. Obtaining performance values*

The evaluators choose a score for each business strategy based on their subjective judgement. By doing this, we can use the methods of fuzzy theory to estimate the achieving 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 get the 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 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 product and technology leadership profit’ and ‘reduce employee churn rate’ represents a linguistic variable in the context of this study (see Fig. 2). 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. 2).
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 and Goving, 1991; Teng and 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.

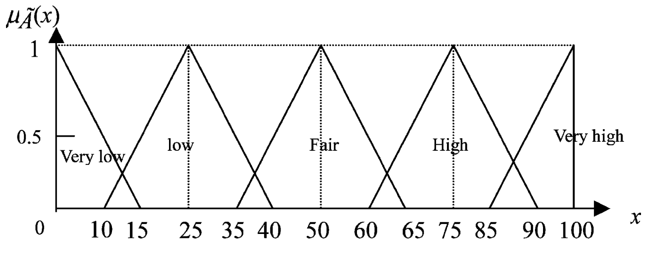


Fig. 2. The membership function of the five levels of linguistic variables (hypothetical example).

Table 3
The criteria weights for evaluating business strategies[a]

| 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.

## 6. Empirical study and discussions

We give an empirical study in Taiwan as an example to show the practicability and usefulness of the proposed method through 14 samples. The process of evaluating the business strategies can be expressed in the following:

### 6.1. 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 3. 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 the 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 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.

### 6.2. Estimating the performance matrix

The evaluators can define their own individual ranges for the linguistic variables employed in this study according to their subjective judgements within a scale of 0–100. Table 4 reveals a degree of variation in their subjective judgements on a scale from 0 to 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 eight criteria for two strategies, a performance matrix can be established for each eigenvector.

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.

$$\vec{S}_n = \begin{array}{c} \\ \text{Criterion1} \\ \text{Criterion2} \\ \cdots \\ \cdots \\ \text{Criterion12} \end{array} \begin{array}{c} \begin{array}{cccc} \text{StrategyA} & \text{StrategyB} & \text{StrategyC} & \text{StrategyD} \end{array} \\ \begin{bmatrix} s_{n1}^A & s_{n1}^B & s_{n1}^C & s_{n1}^D \\ s_{n2}^A & s_{n2}^B & s_{n2}^C & s_{n2}^D \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ s_{n12}^A & s_{n12}^B & s_{n12}^C & s_{n12}^D \end{bmatrix} \end{array}$$

### 6.3. Ranking the business strategies

From criteria weights obtained by AHP (Table 3) and the performance matrix for each evaluator, the BNP values for seven 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 5, namely, AB.

### 6.4. 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:

Table 4
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) |

Table 5
The evaluation results of MAN access strategies[a]

| 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.

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 good potential technology, 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 (http://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 two layers 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 focus' and not only focusing on technology.
5. Bandwidth scalability criteria (0.169) received the second highest score in all of criterion. 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 are 92.49 and 80.24, respectively. These two BNP values are relatively high scores compared with the 100 full 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 two strategies is only 12.25, possible suggesting that a combination of the two strategies to form an evolution approach is a viable way to address the MAN access technology issue.

Since June 2002, 10-Gigabit Ethernet technology has been standardized to be compatible with 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 how to work 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.

## 7. Conclusions and suggestions

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. Although the simple protocol of Ethernet 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 the 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 paper 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.

Given that this is a first attempt to address the qualitative issues while setting a access strategy 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 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, evaluating the weights for the hierarchy relevance system using ANP (Analytic Network Process), and different defuzzified fuzzy ranking methods.

## 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).

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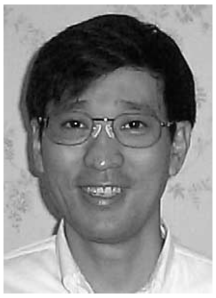

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