Broadband Local Network Evolution to All-Optical Implementation

Member Yoshitaka Takasaki (Toyo University)

Non-member Ki-ichi Yamashita (Central Research Laboratory, Hitachi, Ltd)

Evolution of optical broadband local networks from near term systems to future higher grade systems is studied. Direct transmission, wavelength division multiplexing (WDM), time division multiplexing (TDM) and photonic TDM (P-TDM) are considered. These four systems are compared from the standpoints of economy and upgradability. Methods for analyzing costs and upgradability investigated in a previous paper[5] are modified to make it possible to include WDM systems in the analysis.

The results of numerical analyses by using representative examples revealed that the TDM system with copper distribution is most economical for lower capacity applications. The photonic TDM system is shown to be most economical for higher capacity later phase applications. When upgrading costs are taken into consideration, however, photonic TDM can be most economical even for lower capacity systems from earlier phase of deployment. The sensitivities of results to cost assumptions are also studied.

Keywords: Broadband local network, Upgradability, All-optical network.

1. Introduction

Broadband ISDN (B-ISDN) is expected to provide extremely large capacities to evolving multimedia systems as a next generation common carrier network. In early development of B-ISDN, a fiber to the home (FTTH) strategy was mainly considered, which was supposed to attain a direct and big jump, in a decade or two, from existing telephone networks with a capacity of 64 kb/s to a B-ISDN capacity of 150 Mb/s or 600 Mb/s. A bottom line conclusion in a paper read that "Fiber to the home" indeed can be a reality. The question now is "Who will pay for it?"[1].

It has been suggested that this problem can be alleviated by gradually upgrading of subscriber capacities[2-4]. Optimization of upgrading strategies was also studied and it has been shown that upgrading in the order of, (1) fiber to the curb (FTTC), (2) hybrid FTTC and FTTH, and (3) pure FTTH, is one of the optimum solutions [5].

Upgrading strategies mentioned above are based on hybrid electro-optical technologies. That is, optical technologies are used for transmission of signals, and electronic technologies are used for processing such as multiplexing and demultiplexing. Recently applying all-optical technologies to broadband networking is increasingly investigated [6,7]. It is expected that all-optical technolo-

gies can improve the flexibility and economy of broadband networking.

The influence of such new technologies on upgrading strategies will be studied in this paper. Both wavelength division multiplexing (WDM) and photonic time division multiplexing (P-TDM) technologies [8, 9] will be taken into consideration.

General trends of evolution from existing narrowband network to future super-broadband all-optical networks will be overviewed in Section 2. Models of subscriber transmission systems will be defined in Section 3. Some numerical examples will be provided in Section 4 and optimization of upgrading strategies will be investigated in Section 5.

2. Evolution to all-optical networks

Some people argue that the penetration of ISDNs (broadband and/or narrowband) should prove very quick once deployed, by extrapolating the trend of penetration from such examples as optical fibers and compact discs. Studying Fig.1 reveals that such an argument could be misleading so long as ISDNs cannot be classified as components: the penetration of a network type service would take much longer time than a component type product. It

should also be reasonable to conclude that the penetration of such a complicated network as B-ISDN will take more than a century, since even the telephone network that has much simpler architecture required almost 100 years.

Let us assume that the penetration of B-ISDN will take the same process as telephone network, which could be rather optimistic. It is interesting to speculate the evolution of switching systems for B-ISDN by referring to the history of switching systems for telephone networks as shown in Fig.2. Note in the figure that today's ATM switching corresponds to manual switching 100 years ago.

It is possible that an improved version of ATM switching (version 2) will appear in ten years or so as was the case with manual telephone exchange 100 years ago, since ATM is a completely new technology of switching and many people argue that major improvements and/or re-designing are required. It is also predicted that a photonic transfer mode (PTM) based on all-optical switching systems will be deployed in thirty years or so after the introduction of version 2 ATM switch, since the investigation of photonic switching has already been started and making a considerable progress. On the other hand, new transfer mode (NTM) in Fig. 2 which corresponds to crossbar switch of telephone system is still studied as basic research.

Next, let us try to predict the evolution of subscriber loop capacities. Let the discussion be based on the capacity trend of trunk line deployment shown in Fig.3 which is empirically known to be predictable with a considerably high reliability. It is seen that 100 Gb/s to 1 Tb/s capacities will be required between the years 2000 and 2010 where all-optical technologies should prove very applicable.

Applying all-optical technologies to trunk line systems has been mainly considered, since subscriber loop capacities seem to be too small to consider all-optical implementation. It will be shown, in the succeeding Sections, that such observations are not necessarily appropriate.

3. Models of subscriber loops

Let us consider subscriber capacities of 150 Mb/s and 600 Mb/s which are expected to become necessary in the 21st century. Four types of subscriber transmission systems are defined in Fig. 4 for a standard type network model explained in Section 4. Only down-stream systems are shown here for simplicity. Up-stream systems are supposed to have much smaller capacities [5]. Note that three types of optical fibers are defined in the figure.

Fig. 1 Dependence of required penetration time on applications

Fig. 2 Examples and prediction of switching system evolution.

Fig. 3 Capacity trend of trunk line deployment.

Fig. 4 Models of subscriber transmission systems.

In Fig. 4a, the optical fiber cable in the feeder line is defined as "Fiber", where the cable sheath is shared by multiple optical fibers. In Fig. 4b–d, each optical fiber in an optical cable defined as "FIBER" is shared by multiple subscribers by means of multiplexing technologies. Optical cable in distribution lines are defined as "fiber" where the number of optical fibers that share a cable sheath is supposed to be smaller than that in "Fiber" cable.

In Fig. 4c, not only optical cables but also copper cables can be applied in distribution lines as opposed to other systems that need optical distribution. In super-broad-band applications, it is expected that P-TDM that uses a remote photonic demultiplexer can contribute in reducing system costs (Fig. 4d) [10].

Note that the wavelength multiplexing system shown in Fig. 4b utilizes different wavelengths for respective

subscribers. While this system is promising as a broad-band passive optical network (BPON), it may require some additional costs as compared with other systems that utilize only a single wavelength. That is, the cost of optical source can be higher, the stabilization of wavelength can lead to costly implementation, and the identification of wavelength for respective subscribers can generate extra-costs.

Excess cost factor $e_c(n)$ for WDM systems is defined as

$$C_{trxW} = e_c(n) C_{trx}, \quad (1)$$

where n is the number of wavelengths multiplexed, and C_{trxW} and C_{trx} are costs of transmitter receiver pairs for WDM and single wavelength systems, respectively.

The dependence of WDM filter cost C_{WDM} on n is

expressed as

$C_{WDM}(n) = w(n) C_{WDM}(1).$ (2)

More details of $e_c(n)$ and $w(n)$ will be given later.

4. Numerical examples

Three types of network models, with high, average and low subscriber densities, are studied in [2]. They have distribution areas of 1, 5 and 20 km square and door to door spacings of 25, 75 and 200 meters, respectively. Let us assume the use of average density model for numerical analyses, since results for other types of models can be extrapolated from the results for the standard model. That is, in lower (higher) density models, only the cost of optical fibers becomes larger (smaller). Average transmission distance from a sub-center to a distributing point and that from a distributing point to a subscriber in Fig. 4 are based on the standard model mentioned above (Fig. 3 of [2]).

Three phases of evolution are studied in [2, 5], where each phase is assumed to have five to ten years duration. This may corresponds to a period between the year 2000 and 2030 in Fig. 2. Cost analysis for phases 1 and 3 based on Table 1 will be carried out, since including the second phase is considered to be too early to obtain any useful results. Cost assumptions in Table 1 were obtained by applying minor modifications to Table V of [5].

It is assumed that the cost of a transmitter-receiver pair for WDM transmission (WDM TX-RX) is twice as large as that of an optical TX-RX for non-WDM systems. This means that $e_c(n)=2$. The value of e_c depends mainly on the cost of laser diodes for WDM and is not still sufficiently reliable. Sensitivity analysis will be carried out in Section 5 to alleviate this problem. It should be reasonable to assume that the cost of WDM filter is proportional to the number of wavelength utilized ($w(n)=n$). It is also assumed that the cost of optical fibers for distribution lines assumes type γ cost trend in Table 1, since the cost of cabling is dominant with such a case as opposed to feeder line cables. The costs of cables in Table 1 do not include installation costs. Also the costs of interface and service equipments are not listed in Table 1. This is because such costs do not have influence on the relative comparison of transmission system costs.

5. Cost analysis

The results of per-subscriber analyses for phases 1

Table 1. Cost Trend Example (Arbitrary Unit)

System Components	Phase 1	Phase 3	Trend Types*
Remote Mux. (600 Mb/s)**	2500	1000	$\beta + \gamma$
Opt. TX-RX (50 Mb/s)**	400	50	α
Elec. TX-RX (50 Mb/s)**	100	20	β
WDM TX-RX (50 Mb/s)**	400 $e_c(n)^\dagger$	50 $e_c(n)^\dagger$	α
WDM Filter	250 $w(n)^{\dagger\dagger}$	25 $w(n)^{\dagger\dagger}$	α
Optical Fiber (1m)			
Feeder Line	1	0.2	β
Distribution Line	1	1	γ
Copper Cable (1m)	0.75	0.75	γ

* Phase 3 cost/Phase 1 cost : ($\alpha=1/10, \beta=1/5, \gamma=1/1$)
** Costs are assumed to be proportional to square root of clock rates.
 $\dagger$ excess cost factor : $e_c(n)=2$ (n: number of wavelengths)
 $\dagger\dagger$ multiplexing factor : $w(n)=n$ (n: number of wavelengths)

Fig. 5 Phase 1 example cost analysis.

and 3 are shown in Figs. 5 and 6 for capacities of 150 Mb/s and 600 Mb/s. It is seen that the TDM system with copper distribution (TDMc) is most economical for 150 Mb/s transmission in both Phase 1 and 3 applications. On the other hand, for the 600 Mb/s capacity, the photonic TDM (P-TDM) is most economical. This is because an optical TDM pulse stream can be directly

converted to demultiplexed optical signals with the help of a photonic demultiplexer as shown in Fig. 4d. It is assumed that the cost of a photonic multiplexer-demultiplexer pair is the same as that of electrical one.

Note that different result can be obtained when we consider upgradability. That is, when we take upgrading costs into consideration, using 150 Mb/s P-TDM from phase 1 can be more economical than TDMc that use copper cable, since with P-TDM we can use existing "fiber" in upgrading to 600 Mb/s P-TDM for phase 3.

Now let us proceed to analyze the sensitivities of the results to cost assumptions by referring to Figs. 5, 6 and 7. Note that the cost of WDM system is very sensitive to the cost of optical transmitter-receiver pair (otrx), and therefore, to excess cost factor $e_c(n)$ (see Fig. 7). This is especially true in later phases of deployment. It seems that the cost reduction of otrx is most important for making WDM system applicable. Note that WDM can be more economical than P-TDM in phase 3, if $e_c(n)$ can be made smaller than 2 (Fig. 7b). However, sacrificing system design flexibility due to the use of different wavelengths with respective subscribers could be a fatal problem with WDM which has to be solved before commercially viable systems can be realized.

On the other hand, the cost of direct transmission (DT) is very sensitive to the cost of optical fiber especially in later phases of deployment (Fig. 6). It is very important to reduce not only the cost of optical fiber itself, but also the cost of such technologies as splicing, cabling and wiring (fibering) for making DT systems applicable.

The cost of the photonic TDM (P-TDM) is sensitive to the cost of photonic multiplexer-demultiplexer pair, especially with later phase larger capacity systems. Such photonic processing technologies as those overviewed in [10] should prove useful in reducing the P-TDM cost.

6. Conclusions

Evolution of optical local networks from near term systems to future higher grade systems has been studied. A method for evaluating and comparing local transmission systems has been investigated.

The efficiency of the method has been checked by using numerical examples, which have revealed that TDM with copper distribution and photonic TDM are most economical in earlier and later phases of applications, respectively. On the other hand, upgradability analyses have suggested that employing P-TDM from earlier phases can

Fig. 6 Phase 3 example cost analysis.

Fig. 7 Sensitivity of WDM cost to excess cost factor $e_c(n)$.

be most economical when upgrading costs are taken into consideration.

The sensitivities of the results to cost assumptions have also been analyzed. It has been shown that the costs of WDM, DT and P-TDM systems are sensitive to the costs of transmitter-receiver pair, optical cables and photonic multiplexers, respectively, especially in later phase large capacity systems.

The results obtained in this paper are expected to be useful for reducing system costs and improving the system upgradability in designing local broadband networks.

(Manuscript received Mar. 7, 1997, revised Dec. 9)

References

- [1] S. A. Esty, "Fiber to the home" activity in the United States, Conf. Rec. Globecom '87, pp.1995-1999, Tokyo, Japan, Nov. 15-18, 1987.
- [2] Y. Takasaki, "Fiber-optic broadband distribution strategies toward the year 2000," Conf. Rec. Globecom '86, Houston, TX, Paper 11.5, December 1-4, 1986.
- [3] A. Brosio, et al., "A modular approach to broadband ISDN over optical fibers," Conf. Rec. Globecom '87, pp.1473-1476, Tokyo, Japan, Nov. 15-18, 1987.
- [4] M. O. Vogel and R. C. Menendez, "Fiber-to-the-curb systems: architecture evolution," Conf. Rec. Globecom '90, pp.125-130, San Diego, Ca., Dec. 2-5, 1990.
- [5] Y. Takasaki, "Upgrading strategies for B-ISDN subscriber loops", IEEE J. Lightwave Tech., Vol. 7, no. 11, pp. 1778- 1787, Nov. 1989.
- [6] Special Issue on Broad-band Optical Networks, Journal of Lightwave Technology, vol. 11, no. 5/6, May/June 1993.
- [7] Special Issue on Multiwavelength Optical Technology and Networks, Journal of Lightwave Technology, vol. 14, no. 6, June 1996.
- [8] C. A. Brackett, "Foreword-Is there an emerging consensus on WDM networking?" Special Issue on Multiwavelength Optical Technology and Networks, Journal of Lightwave Technology, pp.936-941, vol. 14, no. 6, June 1996.
- [9] R. A. Barry, et al., "All-optical network consortium-Ultrafast TDM networks," IEEE Journal on Selected Areas in Communications, pp.999-1013, vol. 14, no. 5, June 1996.
- [10] Y. Takasaki, "Multiplied block codes for all-optical transports", Special Issue on Broad-band Optical Networks, Journal of Lightwave Technology, pp. 829-835, vol. 11, no. 5/6, May/June 1993.
- [11] Y. Takasaki, "Applicability of fiber to the distributing point strategy", Conf. Rec. ICC '91, pp. 918-922, Denver Colorado, June 23-26, 1991.

Yoshitaka TAKASAKI (Member) was born in Ibaraki, Japan, on November 21, 1938. He received the B.S. and Ph.D degrees in electrical engineering from the University of Tokyo and the Tokyo Institute of Technology, both Tokyo Japan, in 1962 and 1979, respectively.

After joining Central Research Laboratory, Hitachi, Ltd., Kokubunji, Tokyo, Japan in 1962, he has been responsible for the research and development of digital transmission systems, interactive video distribution systems, fiber optic transmission and video distribution systems, broadband ISDN systems and broadband information distribution networks. He moved to Toyo University, Saitama, Japan, in 1994 and is doing research on next generation multimedia systems and future super-broadband network and systems.

Dr. Takasaki is a member of The Institute of Electrical Engineer of Japan, The Institute of Electronics, Information and Communication Engineers of Japan, and The Institute of Image Information and Television Engineers of Japan. He is also a Fellow of IEEE.

Ki-ichi YAMASHITA (Non-Member) was born in Shizuoka, Japan, on May 30, 1944. He received the B.S., M.S. and Ph.D degrees in electronic engineering from Shizuoka University, Shizuoka, Japan, in 1969, 1971 and 1987, respectively. After joining Central Research Laboratory, Hitachi,

Ltd., Kokubunji, Tokyo, Japan in 1971, he has been responsible for the research and development of digital transmission systems, interactive video distribution systems, fiber optic transmission and video distribution systems, broadband ISDN systems and cellular radio systems. Currently, he is responsible, as a Chief Researcher, for the research and development of mobile radio and fiber optic networks and systems.

Dr. Yamashita is a member of The Institute of Electronics, Information and Communication Engineers of Japan. He is also a member of IEEE.