CHAPTER 6

OPTICAL COMMUNICATIONS & BROADBAND INFRASTRUCTURE[1]

Keith Warble

INTRODUCTION

Optical technology has for decades offered an attractive means of communication because of its virtually unlimited bandwidth. A typical infrared laser source operating at 1.5 micron (1500 nanometers) wavelength has an equivalent RF operating frequency of 200,000 Ghz, which allows 200 Ghz channel bandwidth with just 0.1% modulation. In addition WDM (Wavelength Division Multiplexing) offers multiple channels in a single fiber, thus increasing the available "bandwidth" by up to 100 fold. As the optical communications technology has matured and become commercially viable, a rapid explosion of fiber-optic based telecommunications has both created a demand for broadband or multi-media information and also accelerated circuit/device R& D as competition increases for this lucrative market.

Leading the optical device development and commercialization is the sourcing of optical fiber itself, which has further fueled the deployment of several million miles of broadband routing worldwide. But in order to deliver the information carried by fiber-optics to regions, municipalities and dwellings, expensive nodes are needed to convert the optically modulated information into electronic form, and vice versa as drop-add junctions insert additional information into the vacated optical channels. These attractively priced and relatively high volume nodes have spurred research internationally for lower cost photonics devices, circuits and architectures. Asia is among the regions investing heavily in photonics research.

This chapter will first discuss the generic fiber-optic architectures which are being deployed globally, then briefly examine photonics research in Asia. Finally we will summarize the many last mile broadband access technologies being introduced to wirelessly deliver multi-media to the un-fibered consumers, including free space optical links.

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[1] Charles Cox of MIT & Photonic Systems Inc contributed to this chapter

FIBER-OPTIC ARCHITECTURES

Leaders in the installation of large fiber-optic backbones are the traditional telephone carriers and the cable television providers, both groups anticipating winning away the other service in their regional coverage. This has led to a phenomenon called over-building, or trenching of duplicate fiber-optic lines in the same route in order to "own" the neighborhood. A third group of players for multi-media carrier services is the communications satellite industry, but until recently this segment offered broadcast only service, thus limiting two-way multimedia services to highly asymmetric.

Recent addition of wideband uplink data services (DirecDuo) attempts to bring communication satellite players back into broadband contention, but their limited capacity and late start may handicap their ability to capture large global market shares..

This infrastructure competition depends upon improvements in laser sources for longer fiber runs prior to re-transmission, higher speed photo-detectors to support ever increasing data rates, and a myriad of passive devices to filter and modulate/demodulate the optical signal. Thus research in these areas as well as alternate fiber architectures (such as doped-fiber amplification which boosts submarine fiber signals) is growing as fast as engineering/scientific talent can be applied, both in the US, Asia and Europe.

Meanwhile the commercial broadband carriers/providers devise fiber-optic architectural strategies involving intersecting regional/municipal rings which minimize the cost of photonics devices/modules while maximizing the number of subscribers. Two such architectures are shown in Figures 1 and 2.

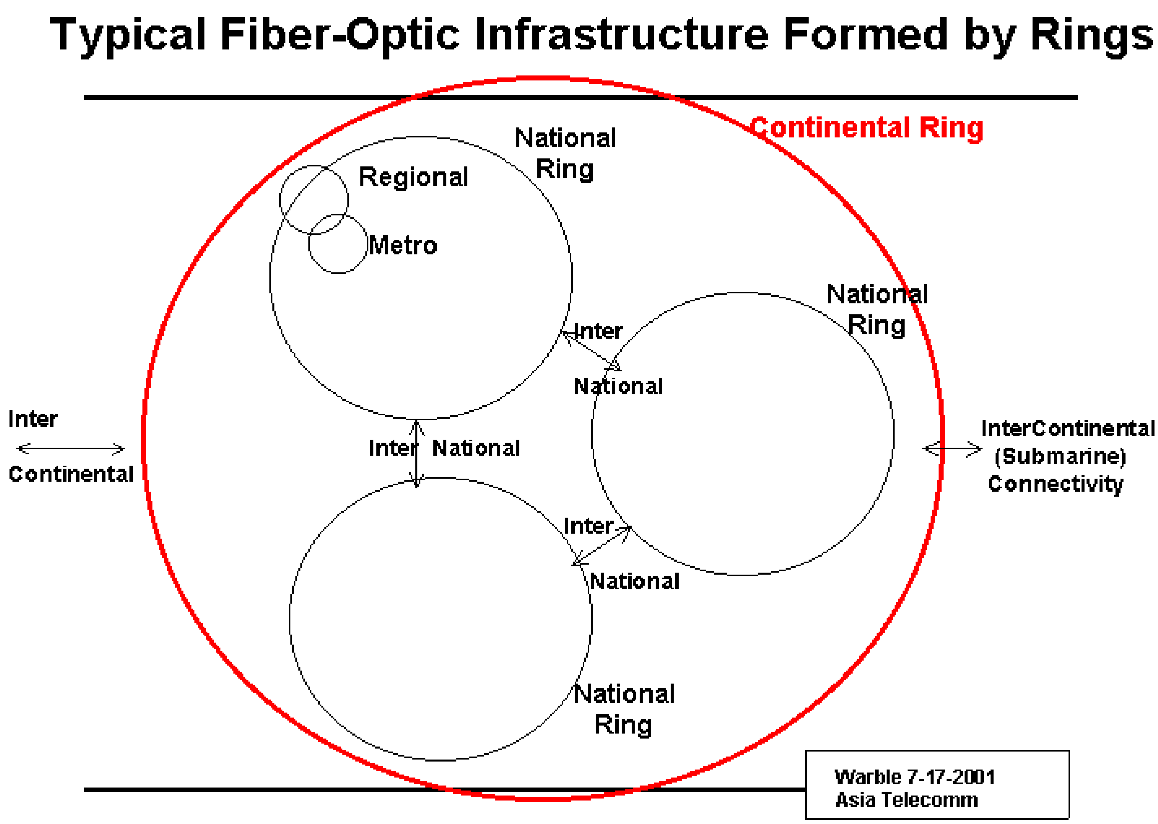

Figure 1

Another dynamic in the broadband carrier competition/deployment is the existence of 3 different standards for delivery to the home or office. The most aggressive standard, fiber to the home (FTTH) has stalled due to higher prices per consumer. The other two standards compete head to head from the telephone company side (fiber to the curb or FTTC) and the cable television side (hybrid fiber/coax or HFC). In order for the television providers to increase telephone and data subscriptions they are adding two-way HFC capability to their previously broadcast only networks. Since all three approaches are extremely price sensitive because of the volume market, one or two breakthroughs in photonics device manufacturing could disrupt the market, further stimulating international research.

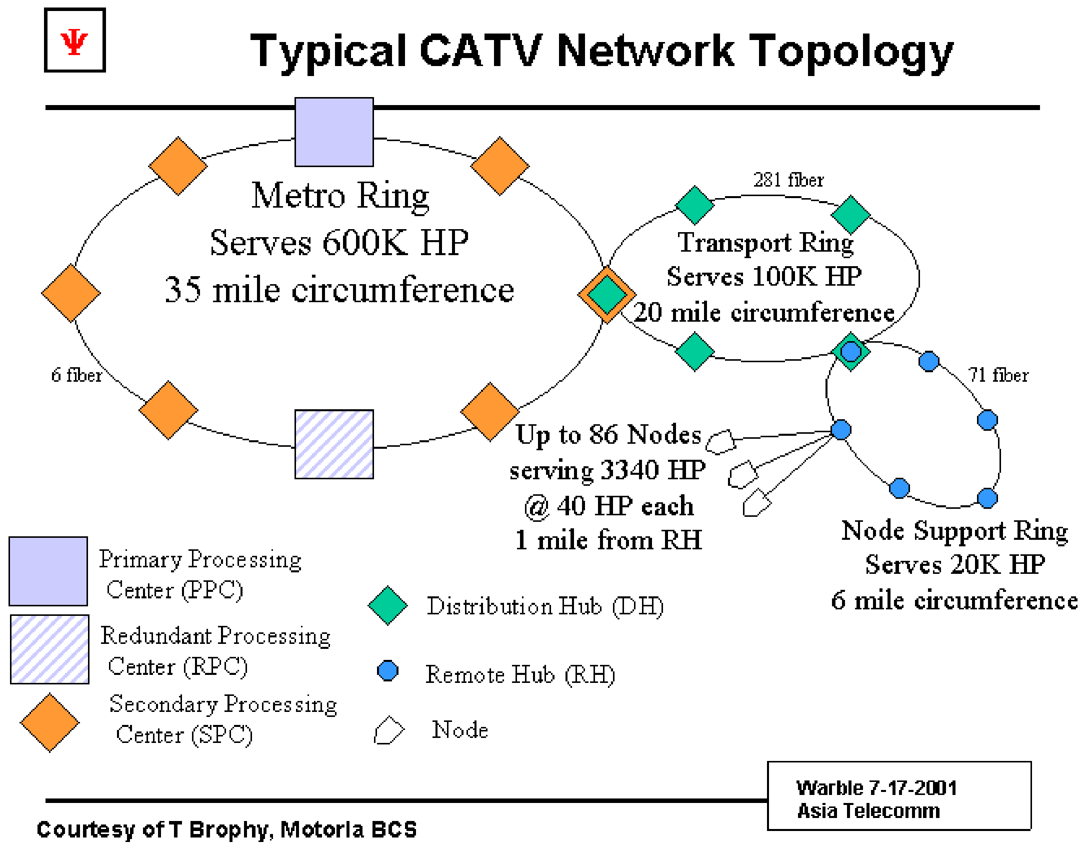

Figure 2

PHOTONICS RESEARCH

The early sources of photonics research were IBM and Bell Labs, illustrating the need for complex, multi-disciplinary research teams covering fields from optics to semiconductors to data processing. These labs made significant progress in developing practical fiber, fiber amplifiers, lasers, photo-detectors, filters and modulator/demodulators before “computer wars” and telephone company fragmentation took place. This progress was sufficient to launch fiberization in distributed computing and long haul telecommunications hubs, but not sufficient to introduce fiber-optics in mainstream telecommunications channels. It remained for spin-offs of this early research, in both private practice and universities, to make practical the explosive growth of fiber-optic backhaul being experienced today. In the US and Asia these photonics research centers continue to grow rapidly, with the distinction being that Asia's centers are orchestrated by national programs while the US's photonics centers of excellence are primarily stimulated by opportunistic free enterprise. A common theme in the US is to see a university research park be the host to several photonics start-up companies. It is more likely in Taiwan for a photonics research center to start up inside a university campus, funded by a multi-year national program. Japan appears to be somewhere in between, since industry and universities are typically orchestrated nationally. Because of the limited time the panel spent with mainland China researchers, it was unclear what the China photonics research model is, but the predominate influx of Chinese researchers to the US come from university (national) sponsored research parks off campus.

Taiwan's photonics research programs appear to be a spin-off from their silicon wafer fabrication approach, which has been highly successful. An ambitious new photonics research center was viewed at National Central University, a relatively small school with selective leadership research programs. They are currently installing an advanced semiconductor processing lab geared toward fabricating advanced wide bandgap and photonics devices. This ambitious program, called the "Micro-Optoelectronics Device and System Project" is nationally funded through 2003 at US$3.4 million.

A more conventional center at National Chiao Tung University includes photonics and millimeter wave devices with their submicron silicon research. NCTU became extremely active in nano devices in 1988 when a national program in "Submicron Technology" was launched. This led to a Semiconductor Research Center at NCTU and a National Nano Device Laboratory at nearby Science-Based Industrial Park in Hsinchu. A new national program, "National Science & Technology Program for Telecommunications" (NTP) began in 1998. This program has catapulted NCTU's semiconductor research into compound semiconductors (GaAs, InP, etc) because of the need for high frequency devices and integrated circuits (monolithic microwave integrated circuits called MMICs). A natural progression from MMIC research is photonics R&D, whose active devices are typically Indium or Gallium based. All the tools to support photonics device fabrication were apparent during our visit to the Semiconductor Research Center. This capability will be stimulated by a new NCTU research project called "Optical Fiber Communication Systems” which explores DWDM transmission and HFC access technologies with 160 Electro-optic graduate students and 13 faculty.

BROADBAND ACCESS

Despite the apparent glut of fiber-optic infrastructure, the low and high density areas of the world remain unreached by fiber routing. This is because low density areas do not have the subscriber potential to attract investment in this still expensive operation, and in high density areas, except for the few cities which planned for future underground utilities, the trenching and laying of cable/fiber is extremely expensive and disruptive.

Therefore these areas will obtain broadband access wirelessly, typically a few kilometers (commonly called the last mile or the last 10K) run to the fiber backbone. A variety of techniques have come into play, from RF to millimeter wave to free space optical. None of these approaches have met with instant success, primarily because they all suffer from quality of service (QoS) handicaps compared to fiber, which consistently delivers data with less than 1 error in 10exp9 bits (1 in 1 billion BER). Once these impairments are overcome in a cost competitive manner, we are likely to see another rapid spurt of broadband mobility services.

FREE SPACE OPTICAL COMMUNICATIONS

Just as the equivalent operating frequency of optical communications technology creates compelling bandwidth advantages for fiber-optics, it also adds beamwidth/power density advantages for free space optical links. Figure 3 compares the beamwidth of a 1.5 micron wavelength transmitting through a 6 inch aperture versus a 20 Ghz (LMDS) Ka band RF signal. The nearly 40 db advantage in power density allows transmit power sources of under 1 watt to carry >1Gbs signals a few kilometers and at the same time avoid the interference of other broadband signals, both because of the narrow beam and the percent bandwidth resulting from the optical carrier. The 40 db advantage (50 db compared to 3G broadband spectrum in the 2Ghz region) quickly diminishes, however, as fog and rain weather conditions become frequent. Figure 4 illustrates the problem of severe optical signal fade in even light fog for ranges over 1 kilometer. This may be a compelling reason why little research in free space optical communications appears in Asia, with only some limited industrial experiments in Tokyo appearing in the literature.

Meanwhile heavy free space optical communications experimentation goes on in North America, with operating links in Seattle (TeraBeam), Newark (Lucent), San Diego (AstroTerra) and Vancouver (NanoWave). By limiting the range to a few kilometers, fSONA has been able to attain .9999 availability in the field, even in extreme rain & fog regions. Whether any of these offerings will become mainstream last mile broadband access products will depend on cost, location, quality of service afforded by the installation range and weather, and the inevitable luck factors of new ventures.

Dramatic Power Density/Beamwidth Advantage

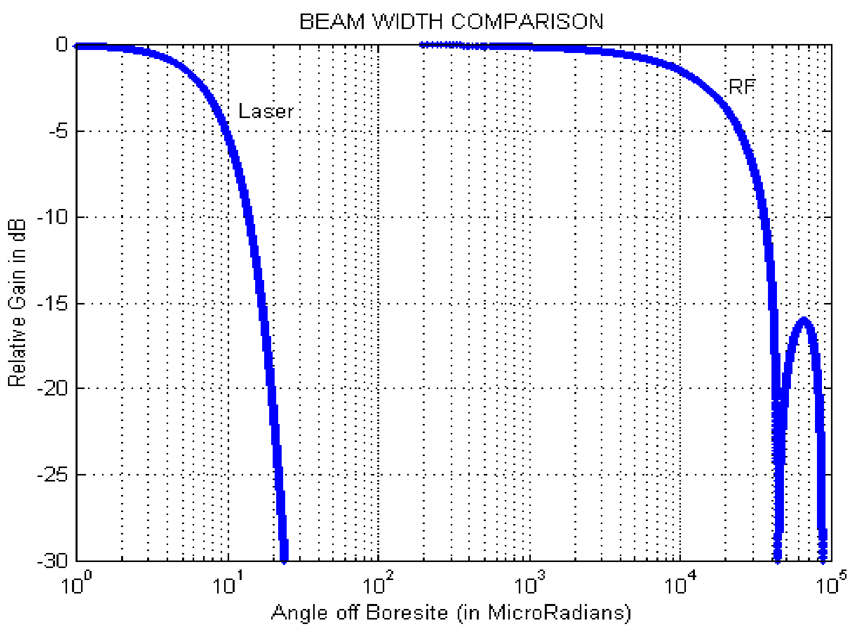

Figure 3

Large Haze and Fog Power Fades

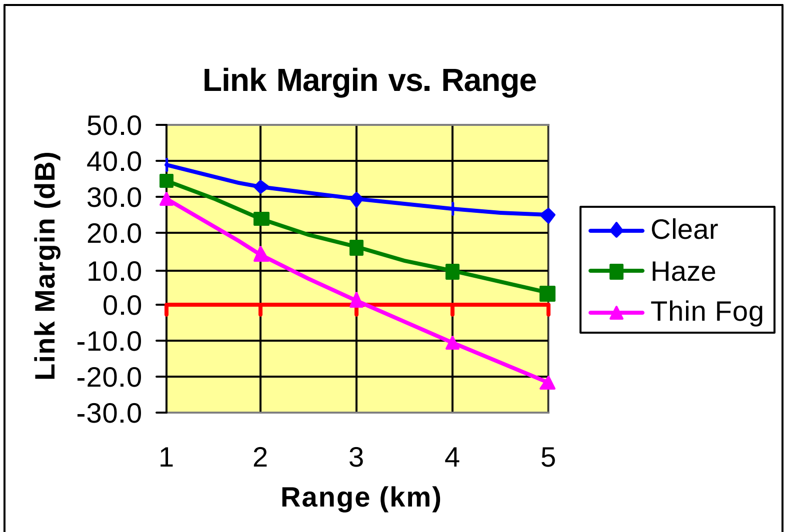

Figure 4. **Assumptions: Date rate = 100 Mbps, 1 x 10-9 BER, wavelength 785 nm, 500 mW, 15 cm aperture, APD detector**

CONCLUSIONS

Asia has kept up with the broadband explosion and in many ways is competitive with the rest of the world in optical communications technology. Each region of Asia has its own strategy for improving its position in the race for broadband access market share. For instance Hong Kong does not keenly participate in product R&D but is a world leader in developing fiber-optic infrastructure to offer advanced multi-media telecommunications services. Taiwan is not as far along in fiber-optic infrastructure (although an optical communications program was just being started during our visit) but is a world class competitor for the photonics and semiconductor device market.

Table 1 illustrates the relative position of each Asian region surveyed for key optical communications technologies (scale 1 to 5). Japan and South Korea were not compared during this assessment, but both would obviously do well because of their high levels of R&D investment and strong national commitments to telecommunications.

Table 1. Optical Communications Competitive Assessment

	Hong Kong	China	Taiwan
Fiber Capacity	4	2	4
Broadband Systems	4	4	3
Free Space Optical	2	3	3
Photonics	2	4	4
Semiconductors	2	5	3