# Future Directions of Networking Technologies

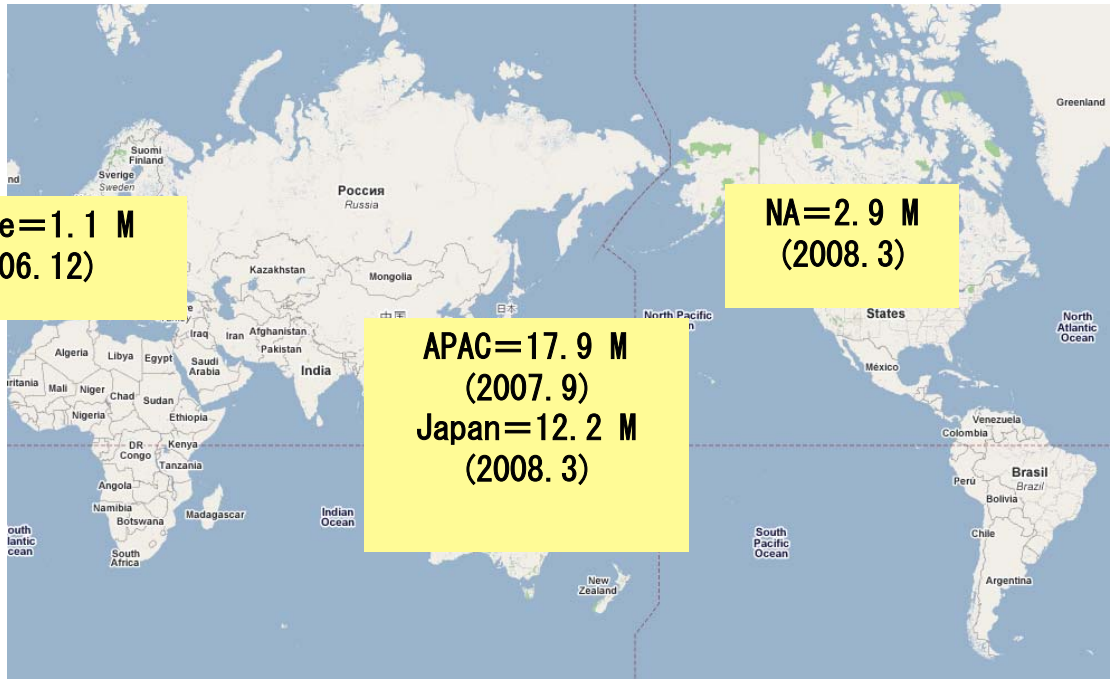
August 26, 2008
FISC 2008

**Ken-ichi Sato**
sato@nuee.nagoya-u.ac.jp
Nagoya University





## *Number of FTTH Subscribers in the World*

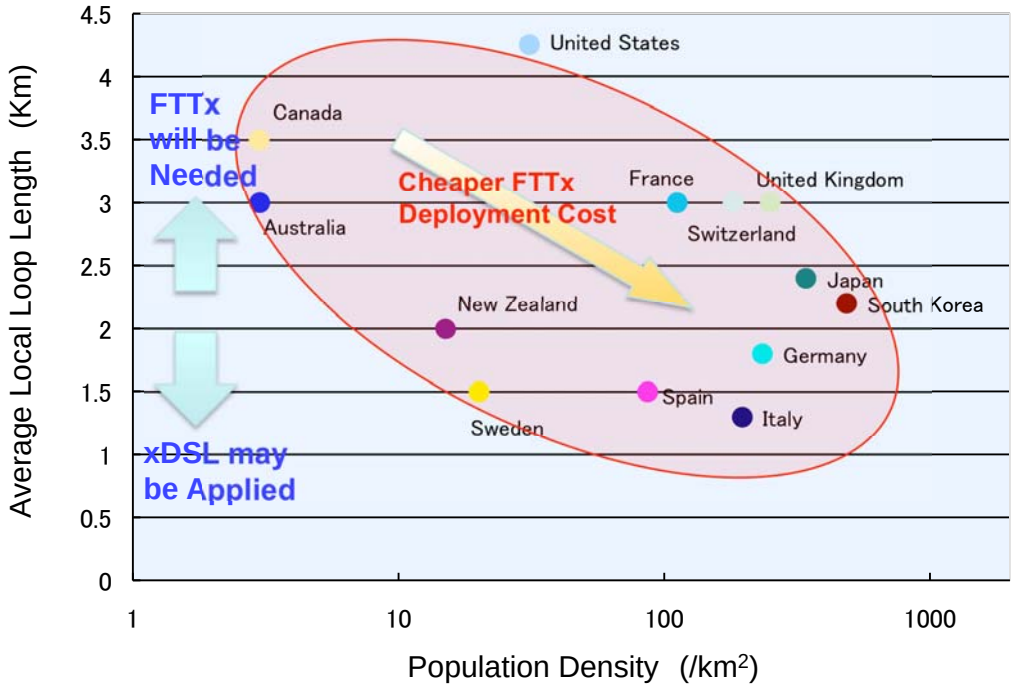



Europe＝1.1 M
(2006.12)

NA＝2.9 M
(2008.3)

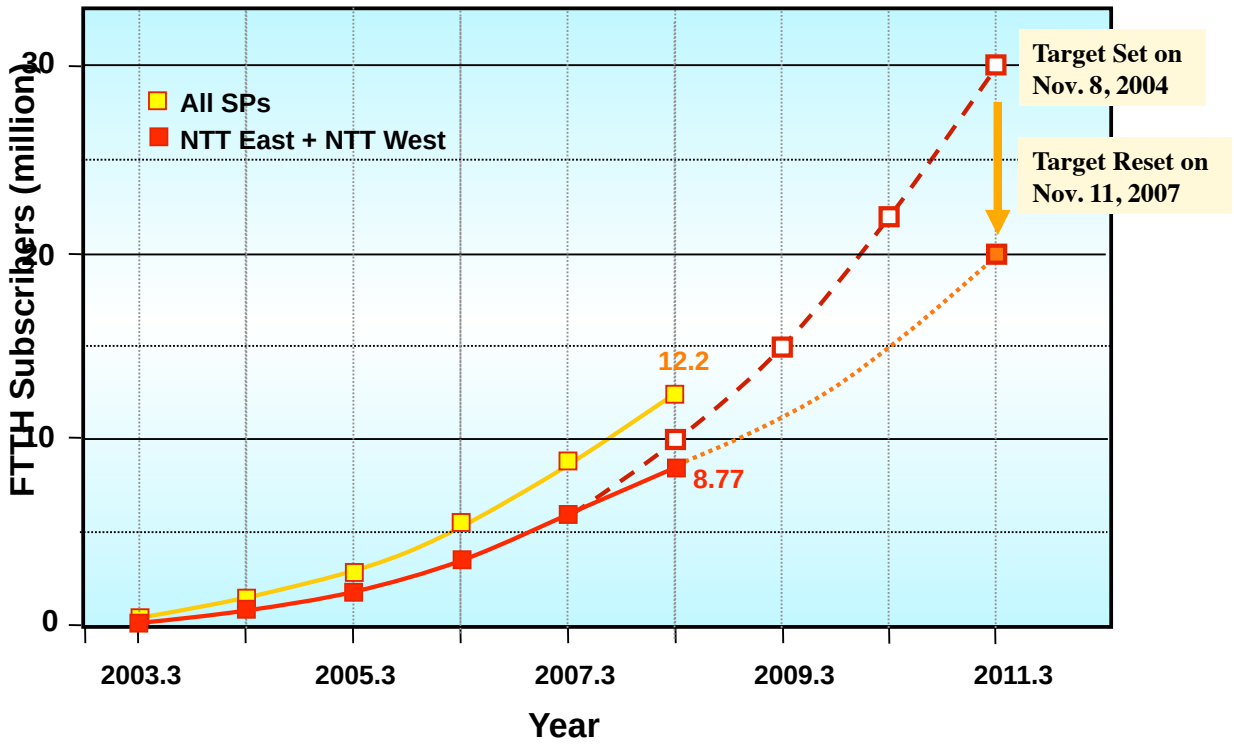
APAC＝17.9 M
(2007.9)
Japan＝12.2 M
(2008.3)

# Average Loop Length and Population Density



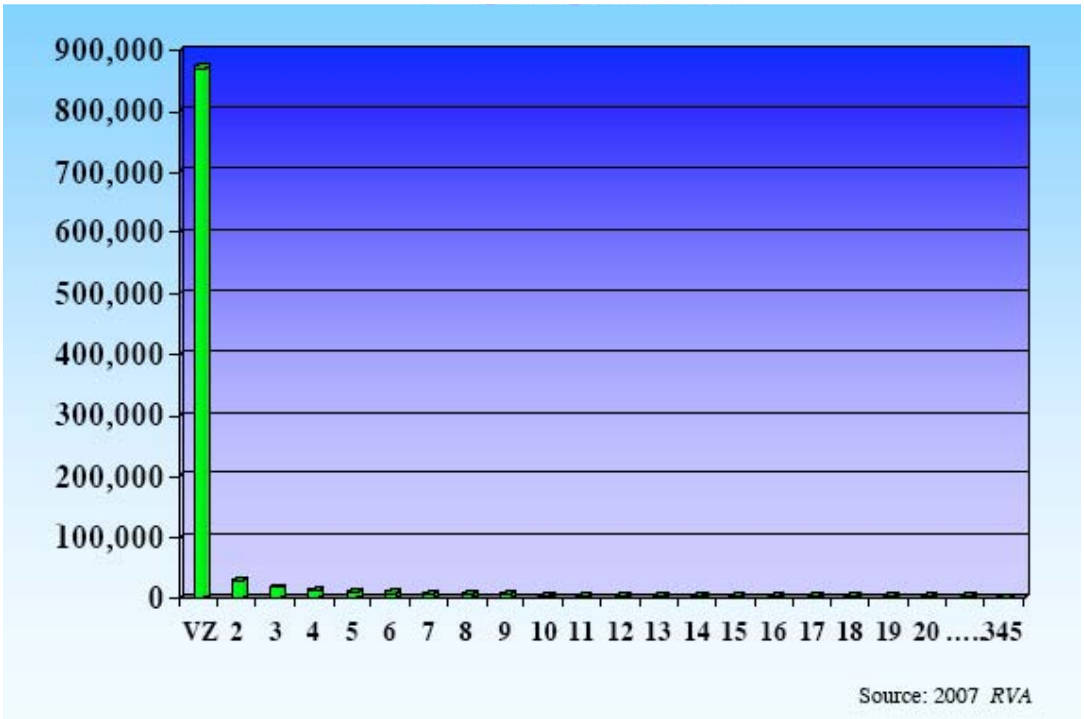



# Number of NTT's FTTH Subscribers toward 20 Million




Source: M. Ii, OFC/NFOEC 2007, March 28, 2006

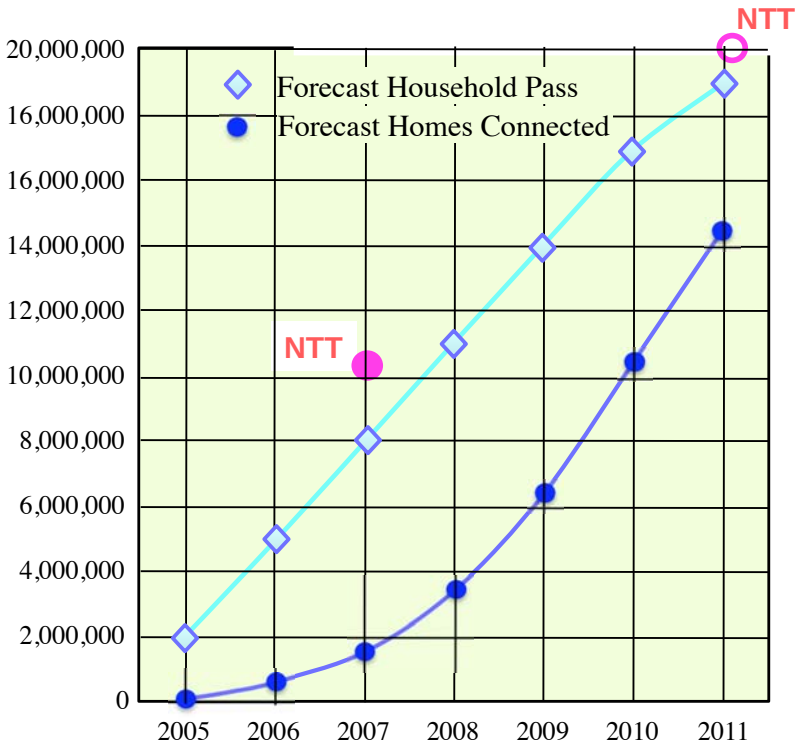
# FTTH Providers in North America: Long Tail




Source: Render, Vanderslice & Associates, April 2007

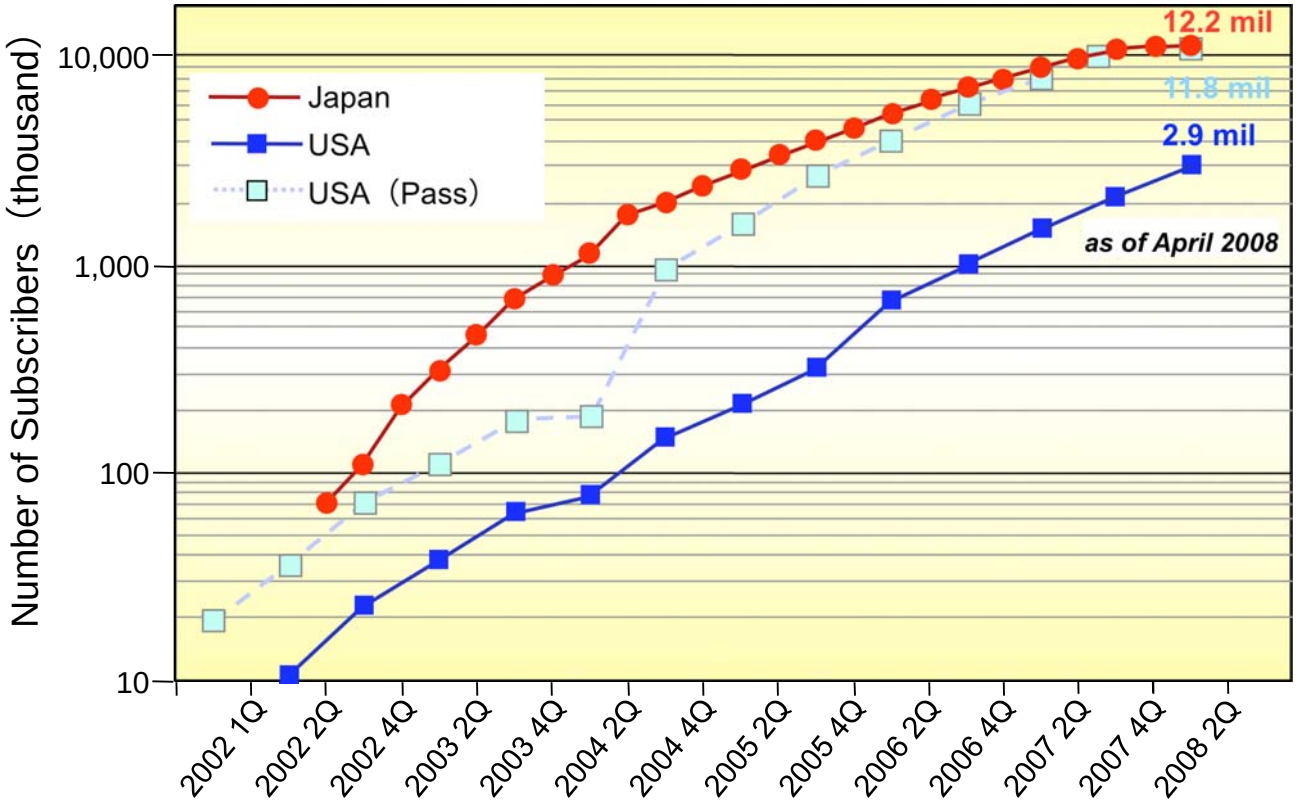


# Number of Verizon's FTTH Subscribers



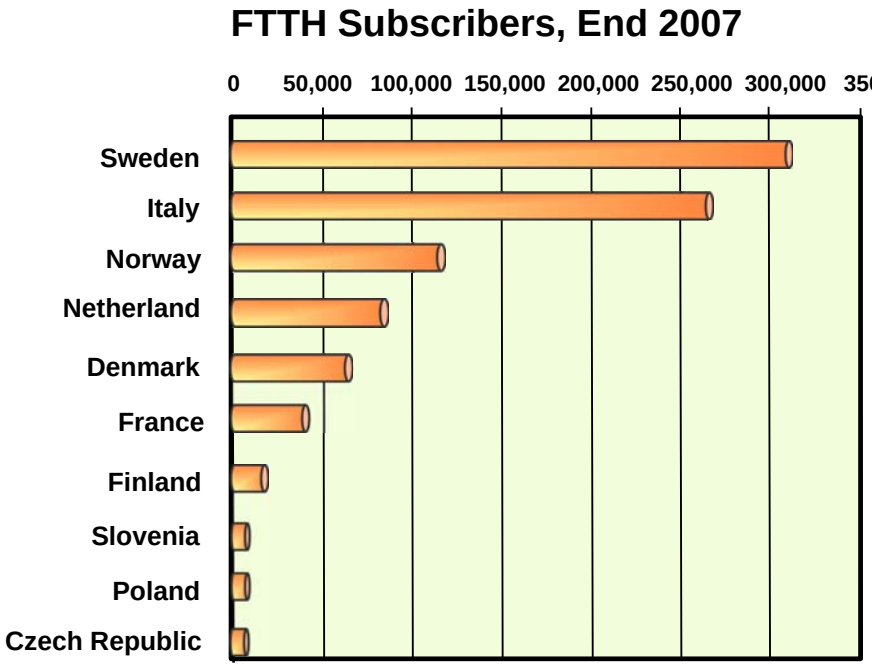

*Source: IGI, Second Qtr, 2007.*

# Number of FTTH Subscribers






# FTTH in Europe




**Strong public support. City- or Municipality-wide optical networks.**

**Private initiative. FastWeb.**

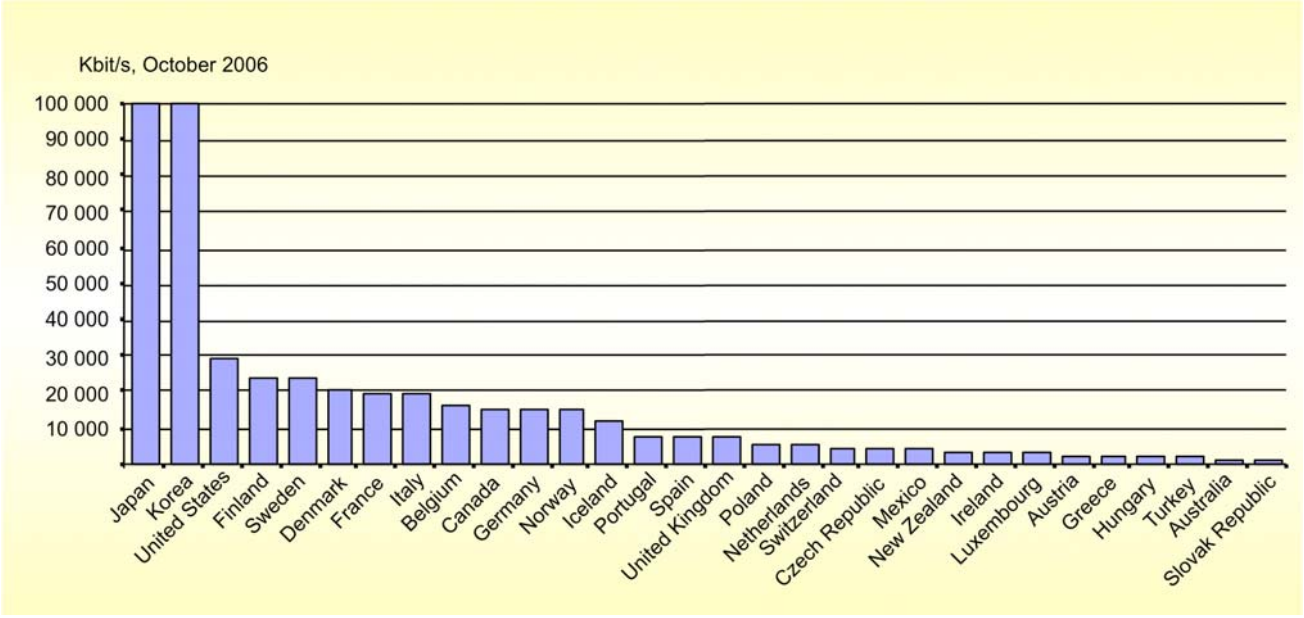
**Power utility company, Hafslund (Oslo municipality owns the dominant share.) Very high population density. Competition between cable pushes higher speed service.**

**Electrical power company plays a dominant role.**

**Situations depends on each country**
**Four countries make up more than 80 %**

Source: FTTH-Council Europe/IDATE 2008

# Fastest Broadband Download Speeds Offered by the Incumbent Telecommunications Operator

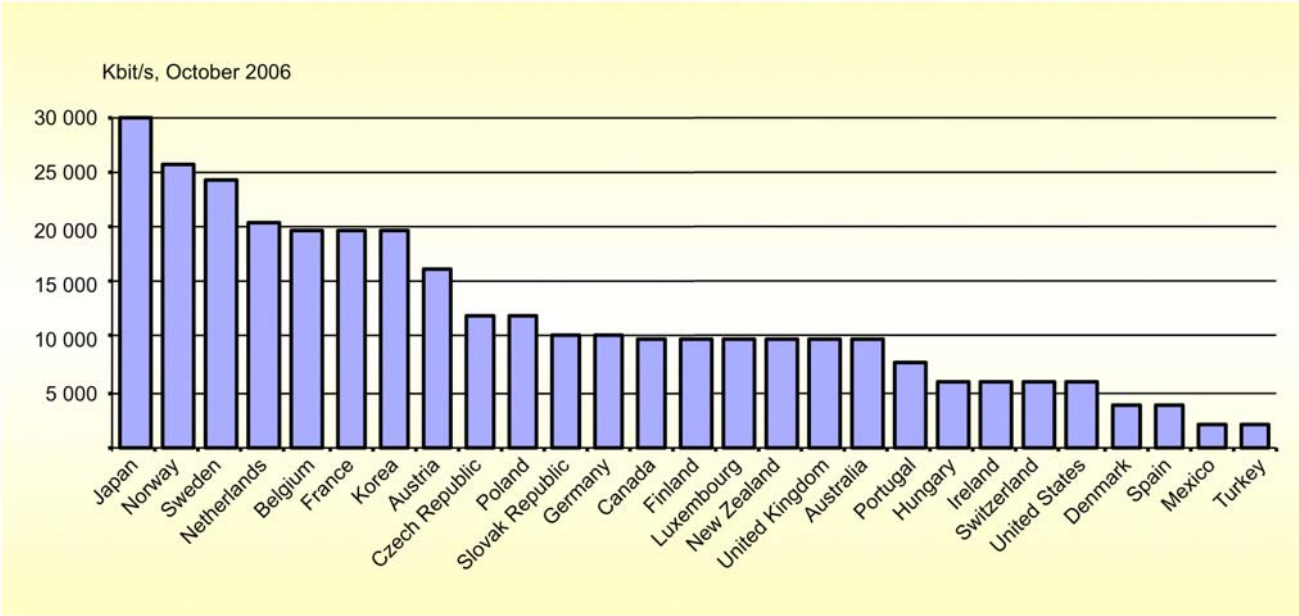



Note: The connections represented are either over DSL or fibre and they refer to the fastest consumer speed available in October 2006 from the incumbent operator on the date the data was gathered.

Source: OECD, - Last updated: 14/05/2007

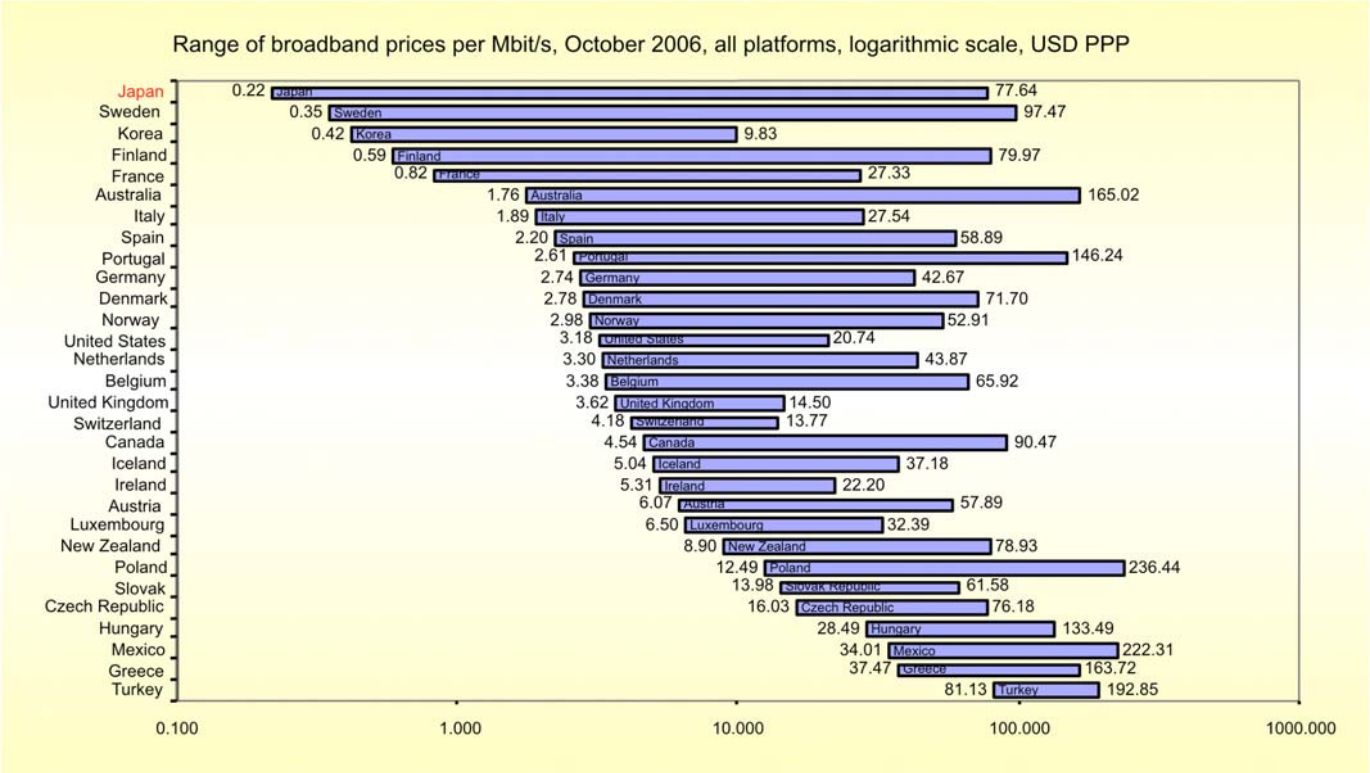


# Fastest Broadband Download Speeds Offered by the Largest Cable Operator




Source: OECD, - Last updated: 14/05/2007

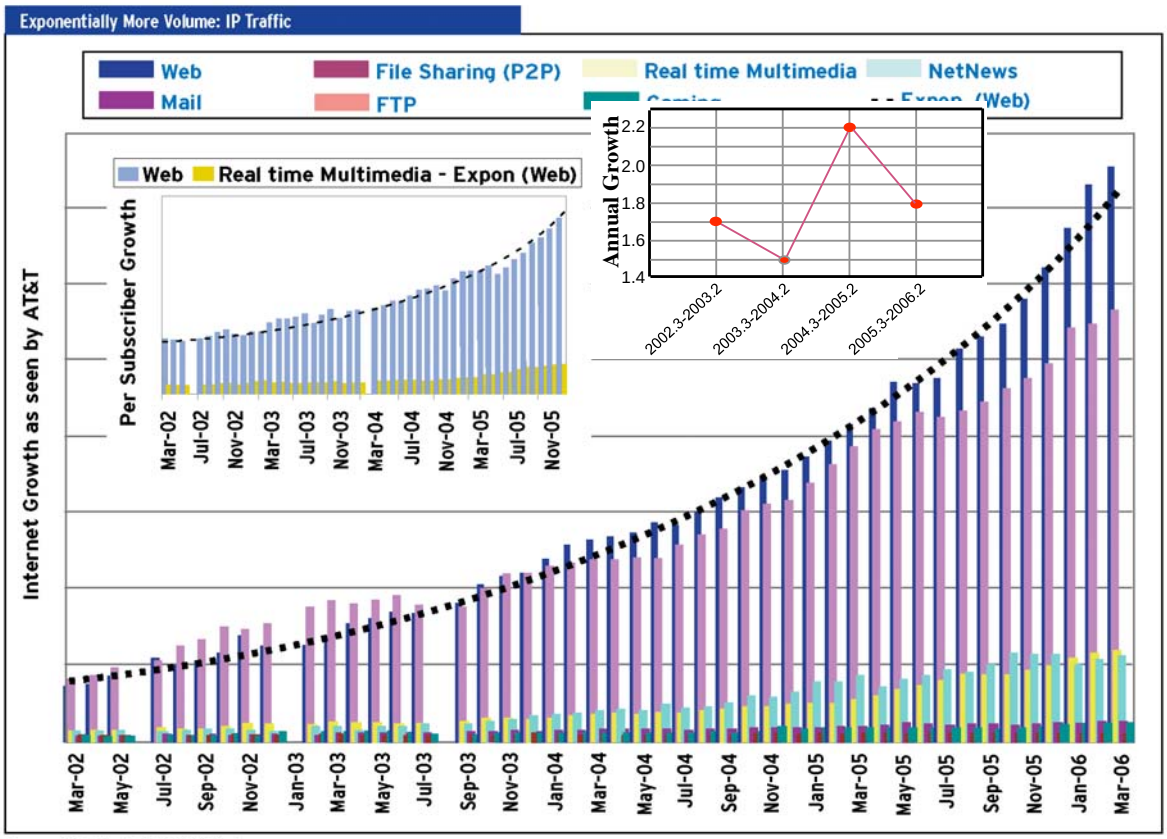
# Range of Broadband Prices per Mbit/s, October 2006, USD




Source: OECD, - Last updated: 14/05/2007



# Internet Traffic Growth as Seen by AT&T

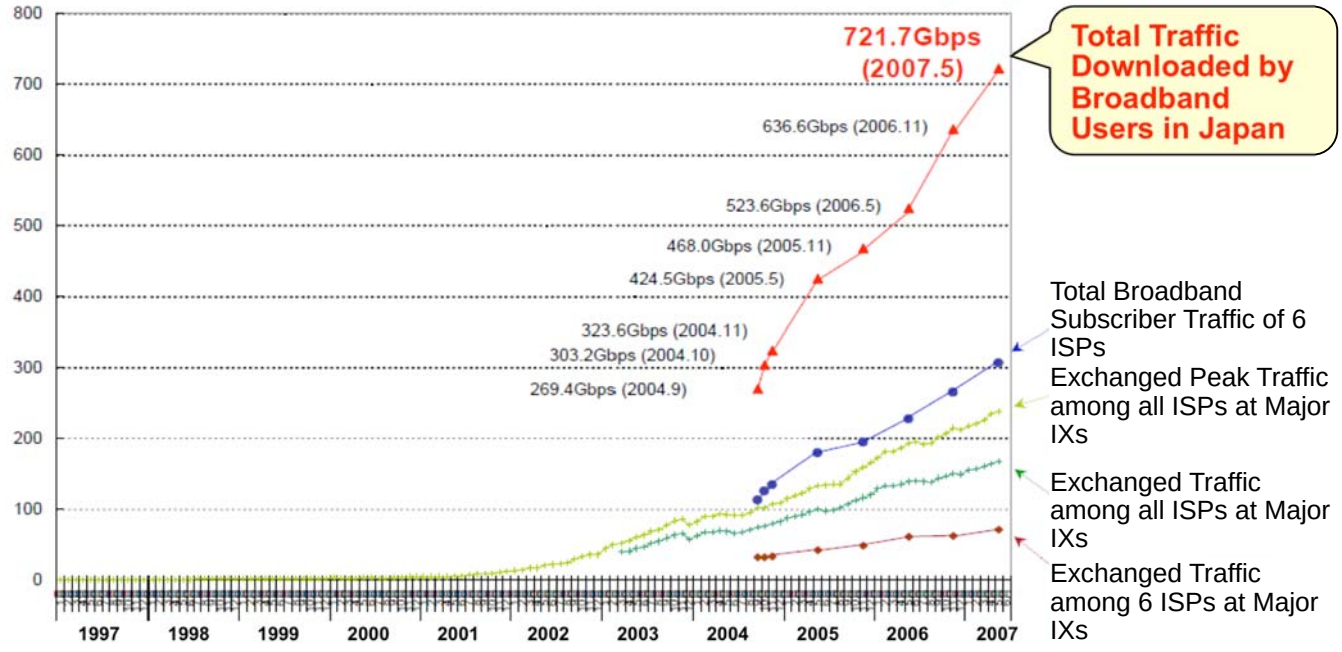



Source: AT&T, March 2002-2006 Data.
Internet Innovation Alliance, 2008

# Internet Traffic Growth in Japan

**Monthly average of day average traffic (Gb/s)**

**1.4 times increase per year**

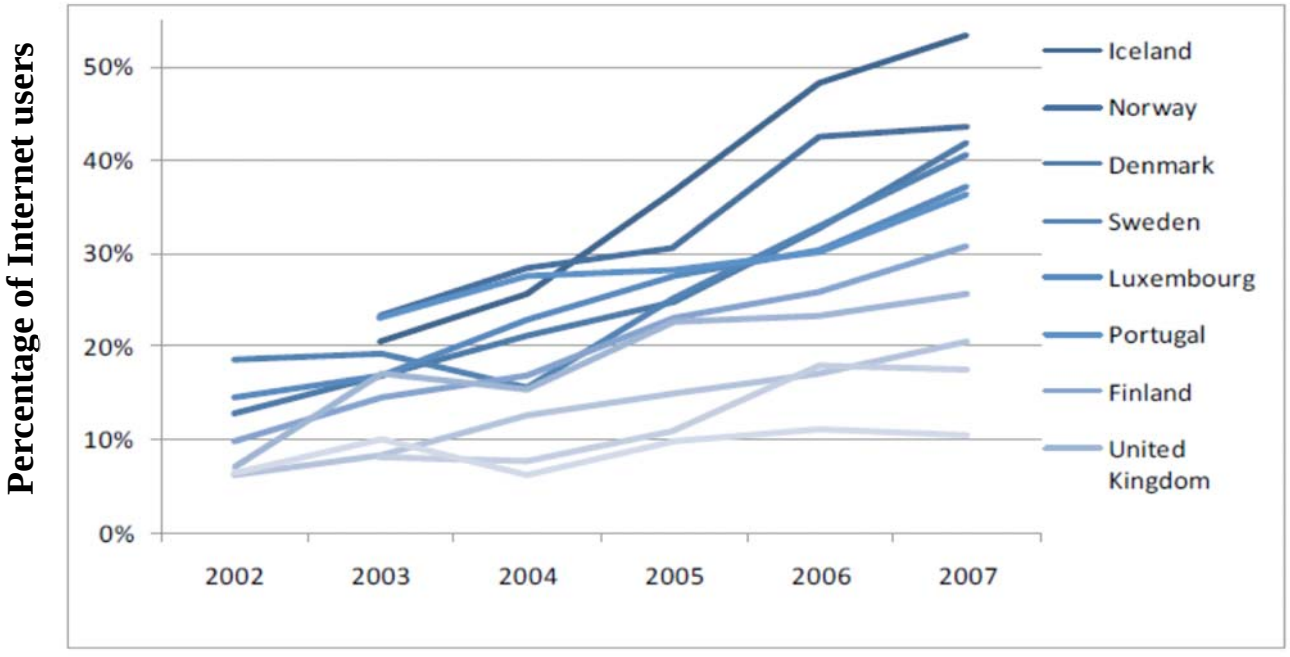



Source: Ministry of Internal Affairs and Communications



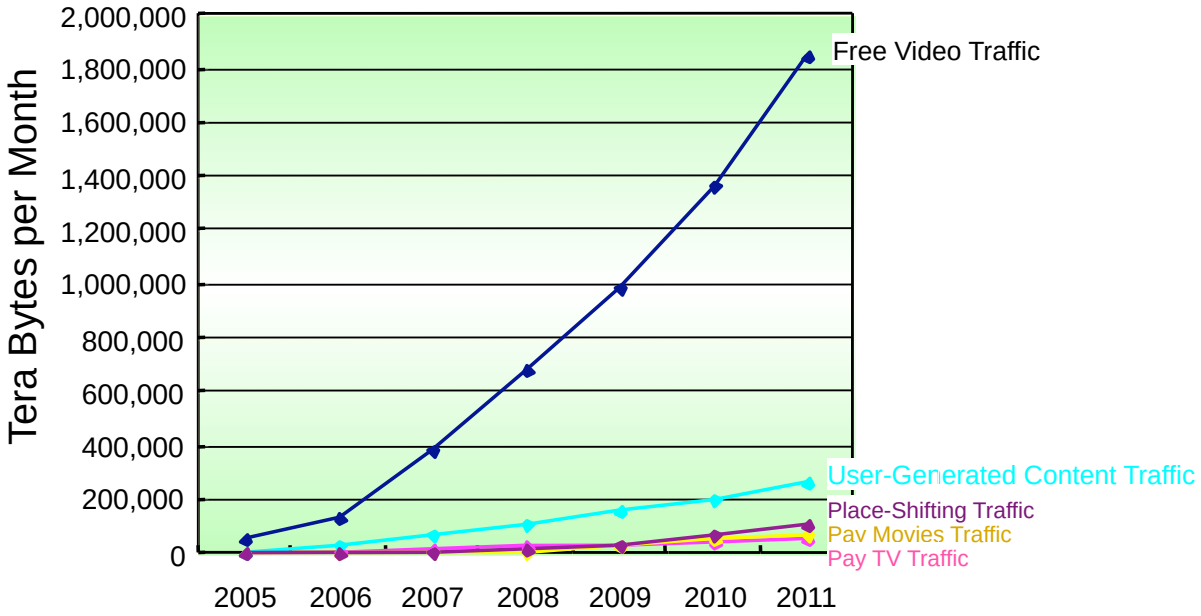
# Internet Users Listening to Web Radios/Watching TV

## Selected OECD Countries, 2002-2006




*Source*: OECD, 2008

# Global Consumer Internet Video-to-PC Traffic



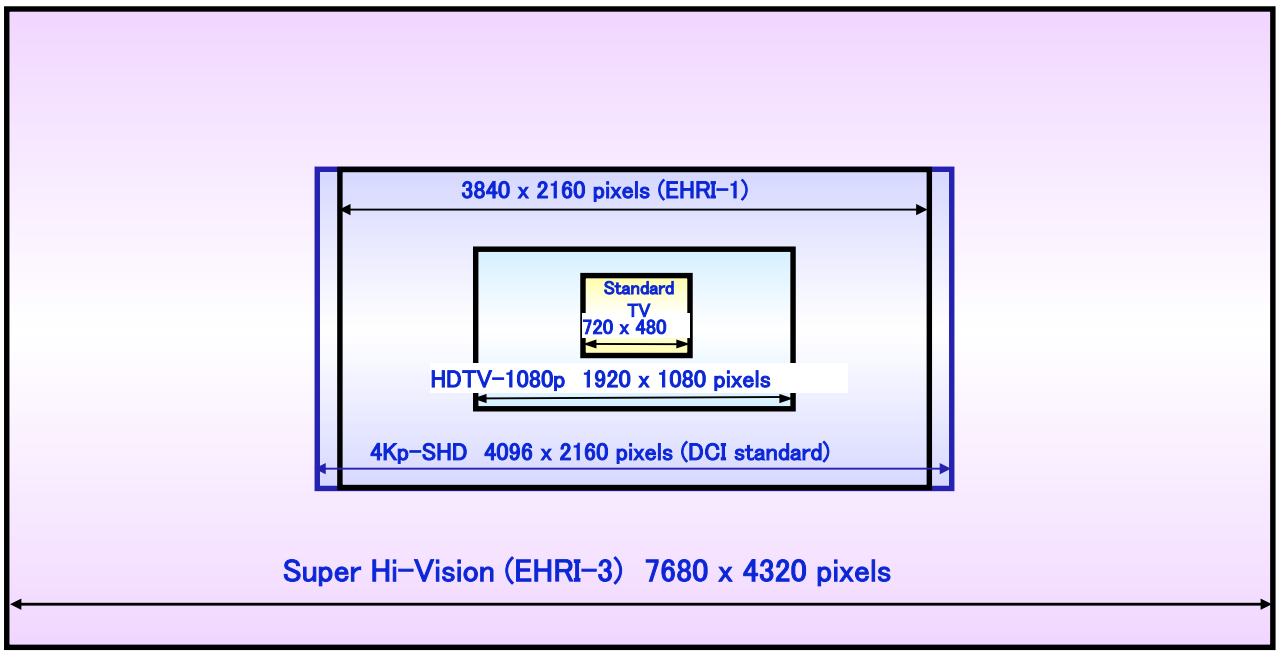

**Free Video Traffic – traffic generated by the viewing of free or ad-supported content offered by content providers**
**Pay TV Traffic –traffic generated by the purchase and viewing of full-length television content**
**Pay Movies Traffic – traffic generated by the purchase and viewing of full-length film content**
**User-Generated Content Traffic – content that has been posted by an individual to a video-sharing site. The content itself is either generated or edited and compiled by the individual (Global YouTube trafficはこのカテゴリー、2006年に55ー75%を占めると予測.)Place-Shifting Traffic - the streaming or download of commercial video content from a person's home to a remote PC or TV**

Source: CISCO, Updated January 14, 2008



# Resolution comparison

## HDTV-1080p/24 vs. 4K-SHD Digital Cinema with 8M pixels vs. Super Hi-Vision (EHRI-3) with 32M pixels



# Standardization in ITU

ITU-R SG6

- LSDI : Large Screen Digital Imagery, TG6/9
  - Draft New Recommendation 'Parameter values for an expanded hierarchy of LSDI image formats for production and international programe exchange'
- EHRI: Extremely High-Resolution Imagery, WP6J
- Multi-channel sound system for LSDI, TG6/9

| Hierarchies | EHRI-0 | EHRI-1 | EHRI-2 | EHRI-3 |
|---|---|---|---|---|
| No. of Pixels | 1920x1080 | 3840x2160 | 5760x3240 | 7680x4320 |

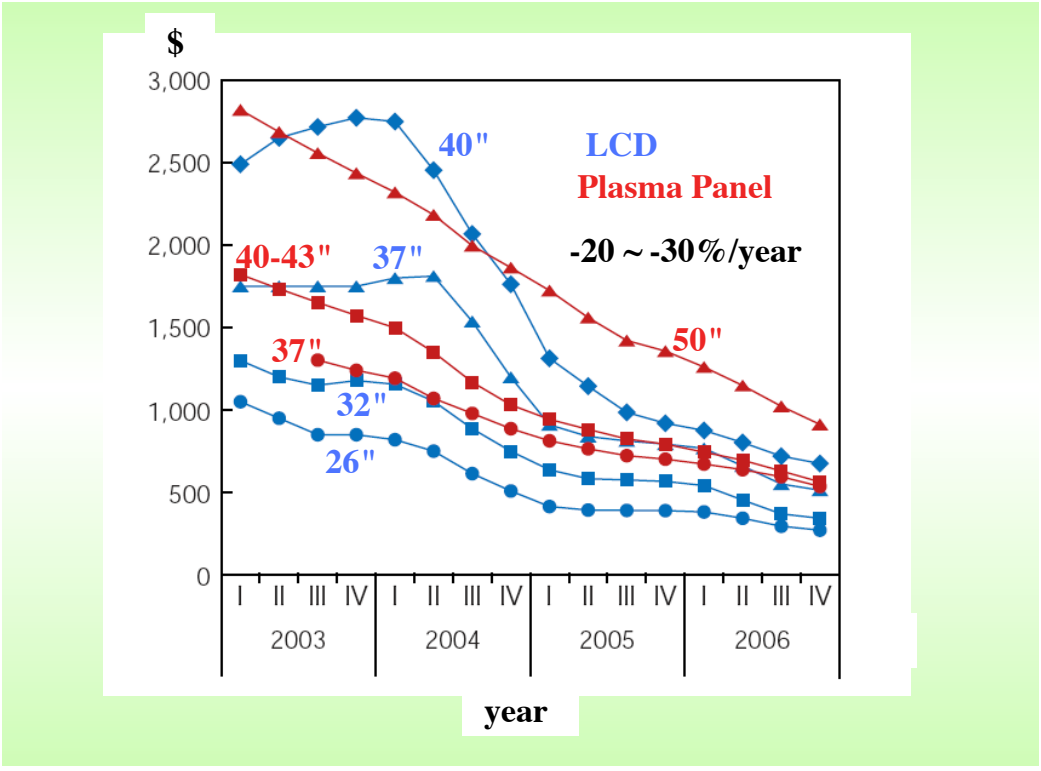
ITU-T SG9

- Cable transmission of LSDI

Courtesy of Dr. Yoshihiro Fujita, Presented at NAB2006 Broadcast Engineering Conference



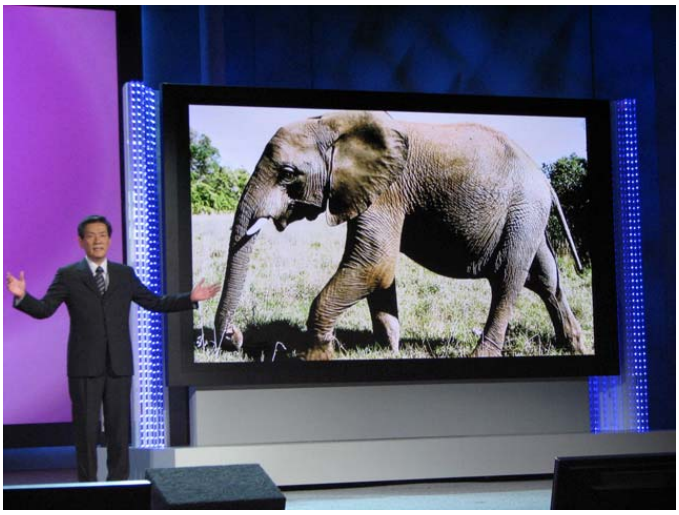
## Price Trend of LCD and Plasma Panel for High Definition TV (in Japan)




White Paper, Information and Communication Systems in Japan, Ministry of Internal Affairs and Communications, 2007

# Screen Size is Getting Bigger

## Large Screen TV,
## 100″ is already available,
## 150″ is already presented



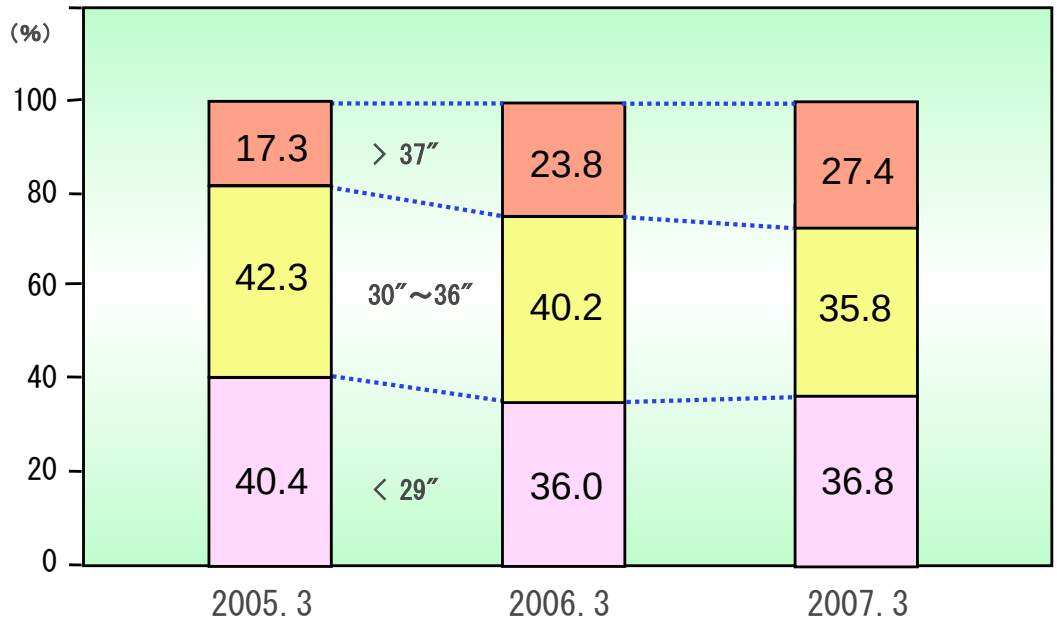
2006, 102 inch, Samsung and LG
2007, 103-inch plasma TV, Panasonic (commercially available)
2007, 108-inch LCD TV, Sharp (commercially available)
2007, 110-inch Projection TV, Victor (commercially available)
2008, 150-inch plasma TV, Panasonic (presented at 2008 CES, expected to be available in 2008)

150″ PDP presented at 2008 International CES
Expected to be commercially available in 2009



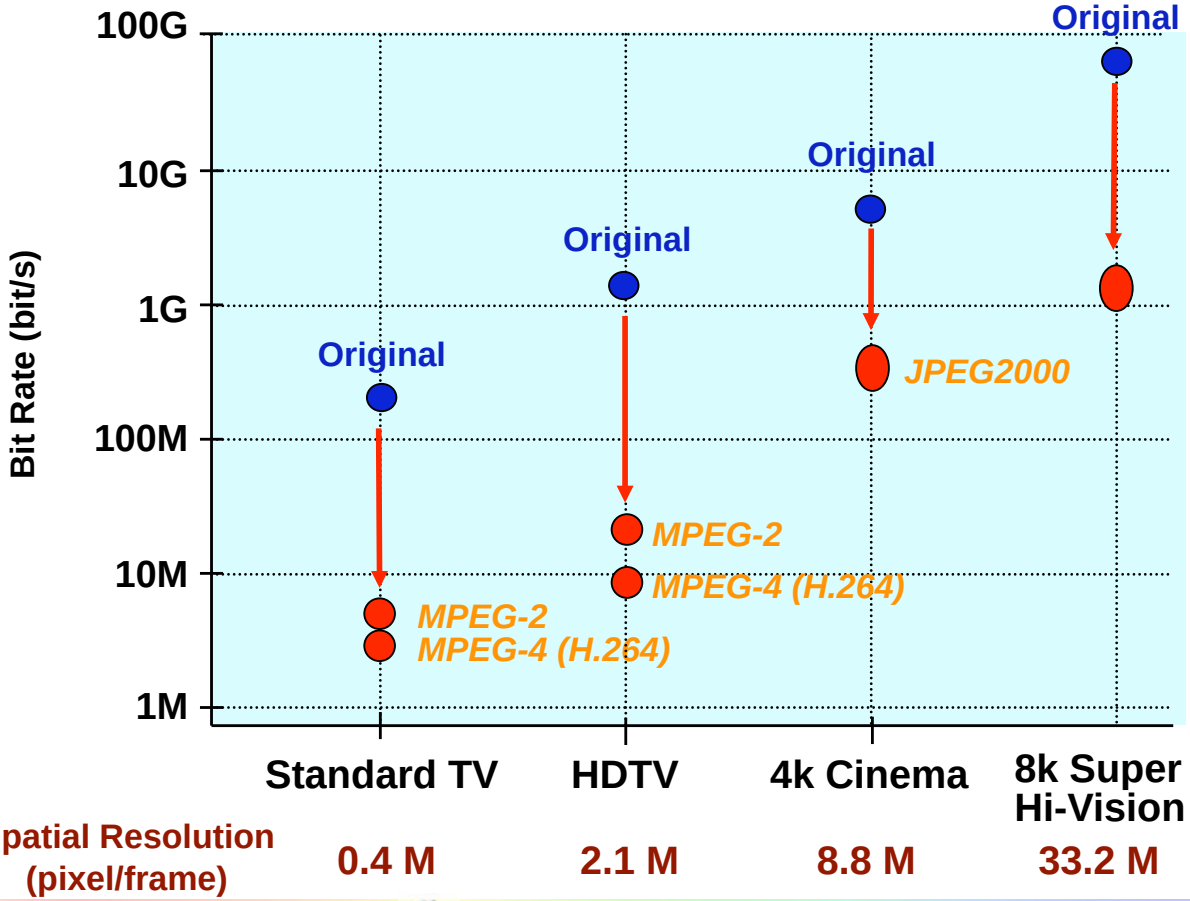
# Screen Size of TV (Japan)

### Shipping of LC-TV (16:9) in Japan




Source: Japan Electronics and Information Technology Industries Association

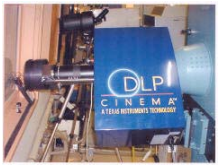
# Bit Rate of Different Video Format






# Digital Cinema

## 2K Cinema (2048×1080)



DLP Cinema developed by TI. Barco, Christie, and NEC are now licensed.

- The first film presented by 2K Cinema was "Star Wars Episode I" conducted by George Lucas, shown in June 1999 in USA. Digital Cinema Projector System that uses DLP (Digital Light Processing) Cinema developed by TI. More than 190 movies have been presented using the DLP Cinema.
- The number of theaters that have adopted DLP Cinema technologies was about 400 as of December 2005. It is expected to now exceed more than 3,000. The adoption rate should rise; 5,000 screens out of the 100 thousand screens in the world are renewed every year.

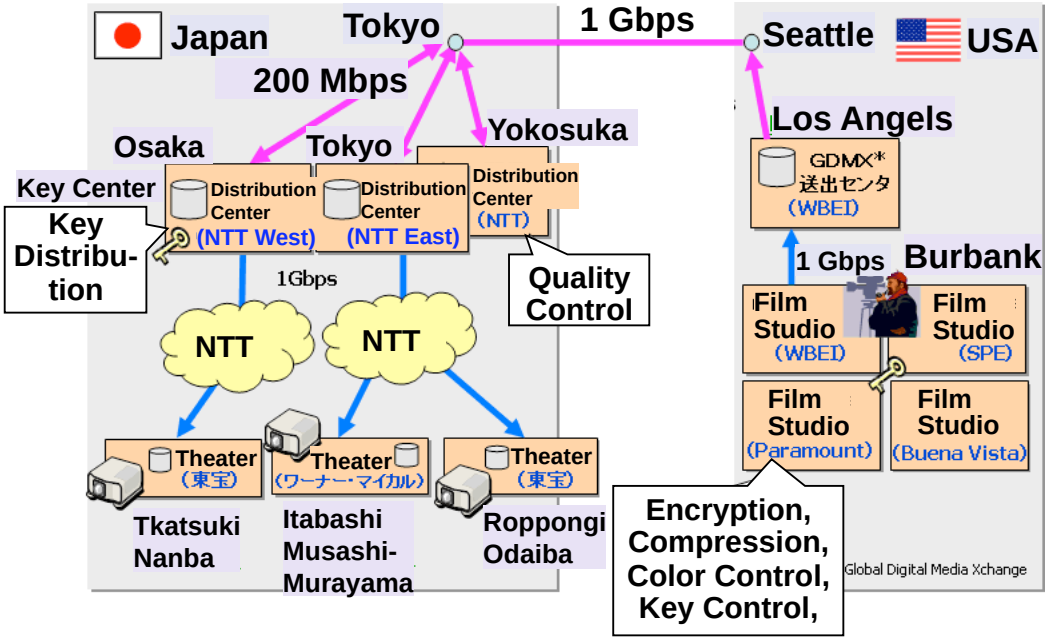
Christie **CP2000** WORLD'S MOST DEPLOYED DIGITAL CINEMA PROJECTOR

## 4K Cinema (4096×2160)

- Trial presentation started in October 2005 in Japan. Twelve films have been shown in Japan at six theaters as of May 2007.

SONY "4K" DIGITAL CINEMA PROJECTOR, SRX-R220,
- 4096 x 2160 pixel resolution
- 18000 ANSI Lumens
- 2000:1 Contrast Ratio

# Trial System Configuration of 4K Pure Cinema Distribution




Digital Cinema Server

SRX-R220 projector make it possible to realize its extremely high 4K (4096 H x 2160 V pixels) resolution, which is stipulated by the Digital Cinema Initiatives, LLC (DCI).



# Imbalance, with far more storage (processing power) than transmission?

- **Huge potential sources of traffic -far more storage, processing power, and broadcast video than Internet transmission capacity**

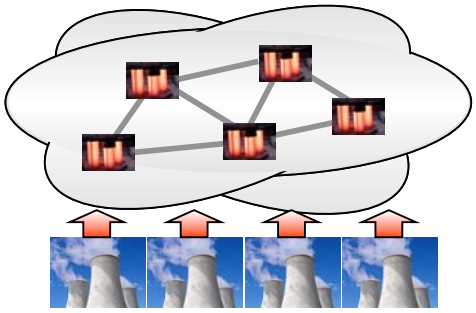
Presented by Dr. Andrew Odlyzko, "Internet economics, Internet evolution and misleading networking myths," ECOC 2007, Berlin.

- **YouTube has 20M unique users, >100M visitors per day, accounting for 60% of videos watched online. (Jun 2006).**
- **MySpace has > 45M unique users in Jun 2006**
- **FaceBook has almost 10M unique users, >1.7 M visitors/day, US $ 1 M/week**
- **Flickr has >500K visitors/day, >900K uploads/day, >230M photos**
- **60−70 IP-TV providers in US alone**

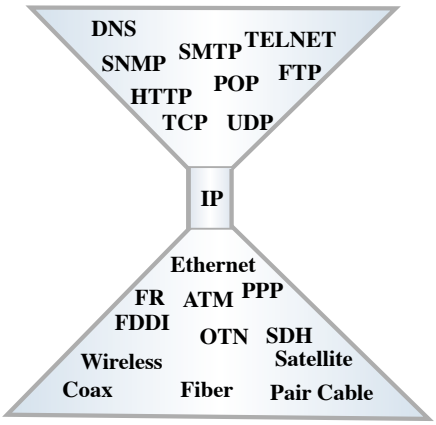
Presented by Dr. Stephan Scholz, "Challenges of Future Broadband Network," ECOC 2007, September 17, Berlin.

# Bottleneck of TCP/IP-based Internet

- **Energy Bottleneck of Internet**



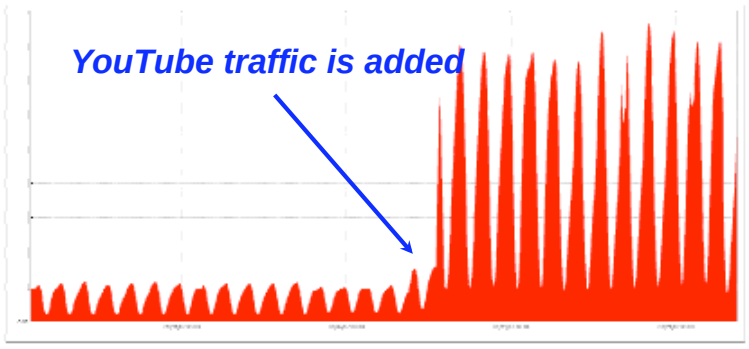
- **Throughput Bottleneck of IP Transport**






# Impact of Internet Video Traffic

**Traffic volume at a Google data center**




One Month

**Internet datacenter demand in units of one switch chassis**

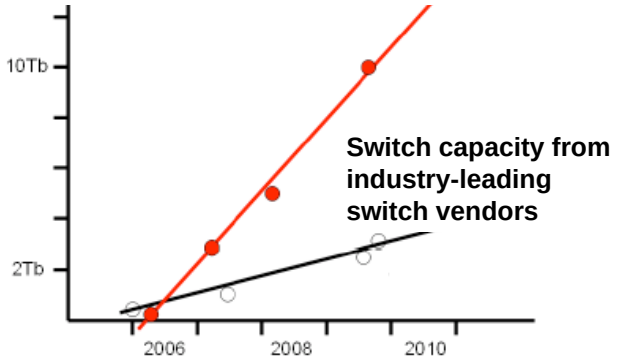



Figure 3: Demand vs. switch/router R&D

D. C. Lee, OFC/NFOEC 2008

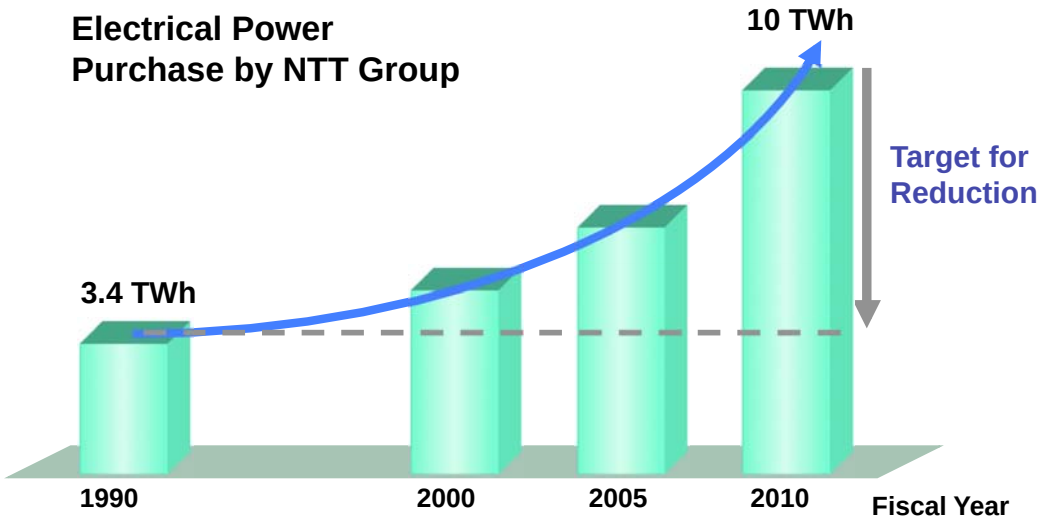
# Google's New Data Center, The Dallas, Oregon

**Power Consumption > 100 MW?**

Google Inc. plans to spend $600 million to build a data center in western Iowa, the latest site in a massive network of server farms holding the hundreds of thousands of computers which run its Web services. MidAmerican Energy Co., which will supply the electricity to the facility, would not say how much electricity the data center will consume, citing a confidentiality agreement with Google. The energy company recently completed the expansion of its coal-fired plant in Council Bluffs, which can produce over 1,300 megawatts.

June 19, 2007, Reuters, Google to build $600 million data center in Iowa
http://www.reuters.com/article/internetNews/idUSN1916606420070619?feedType=RSS&rpc=22

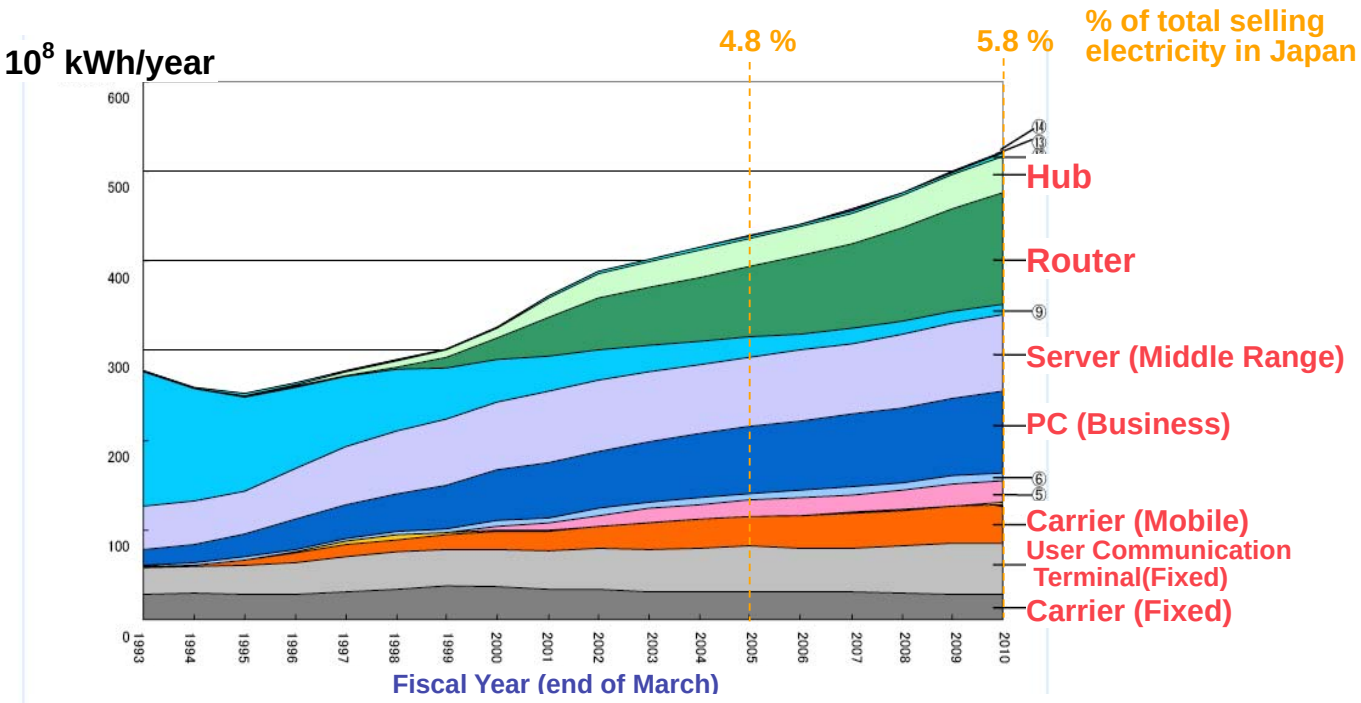
# Consumption of Electricity by Telecommunication Carriers is Rapidly Increasing




**Power Dissipation by NTT Group in the Fiscal Year of 2003 was 7.4 Tera Wh, One Percent of the Total Electrical Power Purchased in Japan.**

http://www.ntt-west.co.jp/corporate/2010-e/

# Prediction of Electricity Consumption on IT (Japan)




Report on ICT systems and networks that will contribute to the reduction of environmental load, March 2007, Ministry of Internal Affairs and Communications, Japan.



# Power Consumption will Limit Internet Growth

The energy bottleneck could eventually limit network growth.

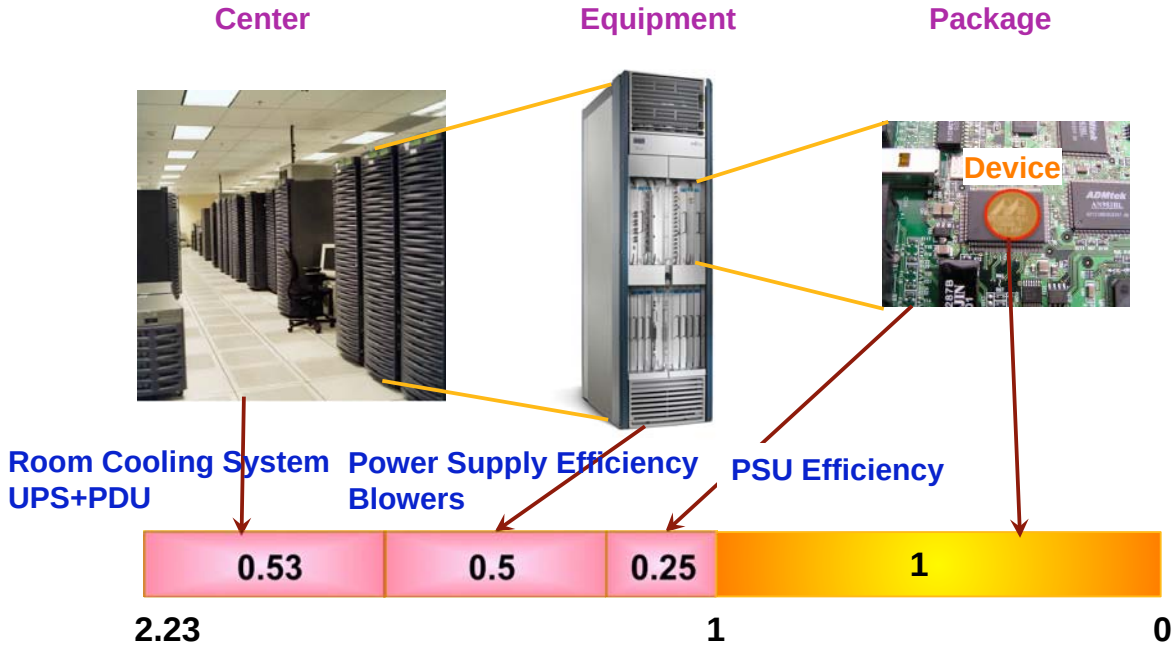
| Access Rate | 1 Mbps | 10 Mbps |
|---|---|---|
| Power Consumption | 100 GW | 1 TW |
| Percent of World Power Supply | 5 % | 58 % |

World Population: 6 Billion
Broadband Access Take Rate: 33 %

J. Baliga et al., COIN-ACOTF 2007, July 24-27 2007

# Device Power Consumption will be Multiplied

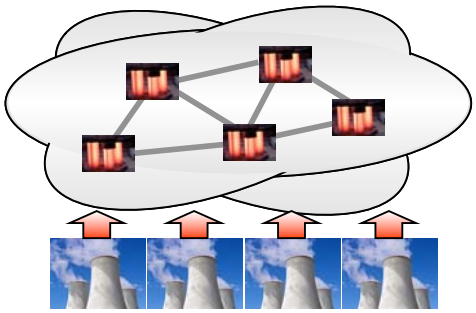
***Power Consumption of Each Device will be Multiplied by more than 2.***



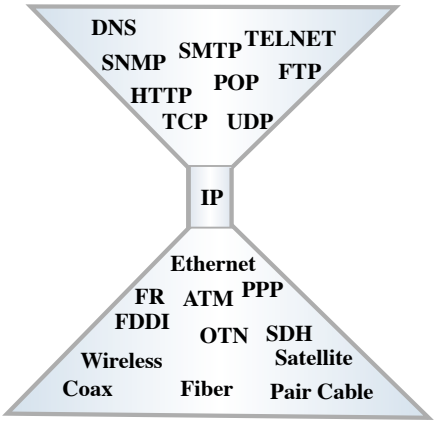



# Bottleneck of TCP/IP-based Internet

- **Energy Bottleneck of Internet**

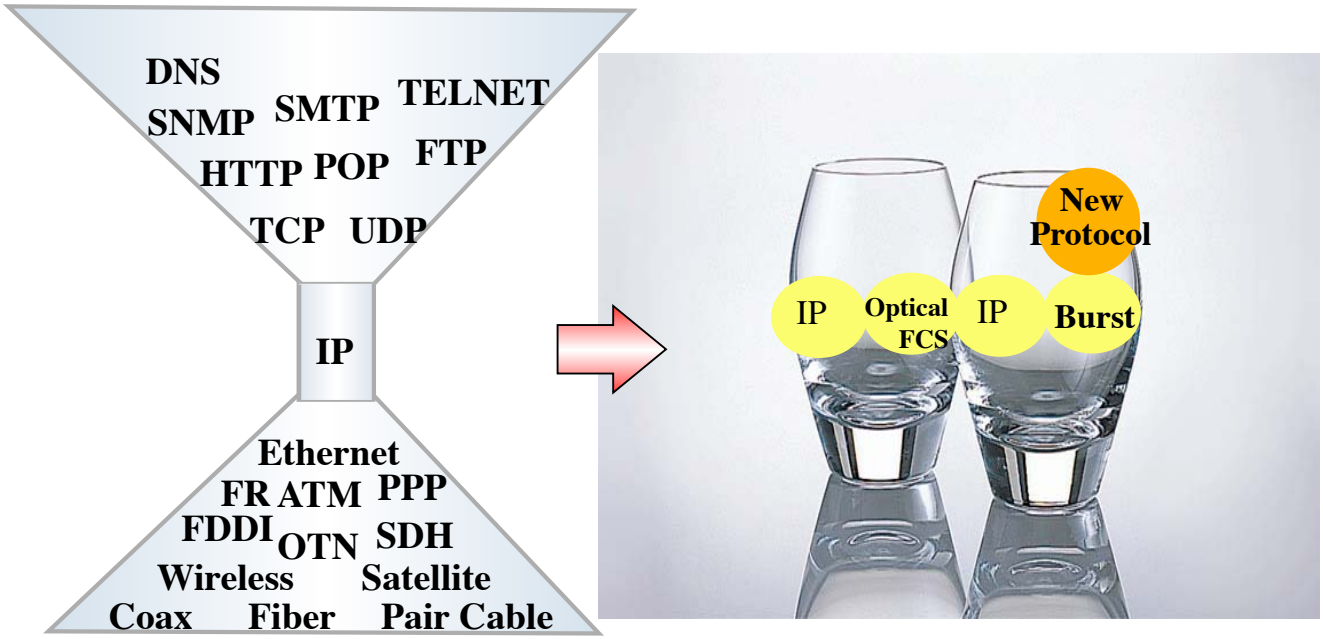


- **Throughput Bottleneck of IP Transport**



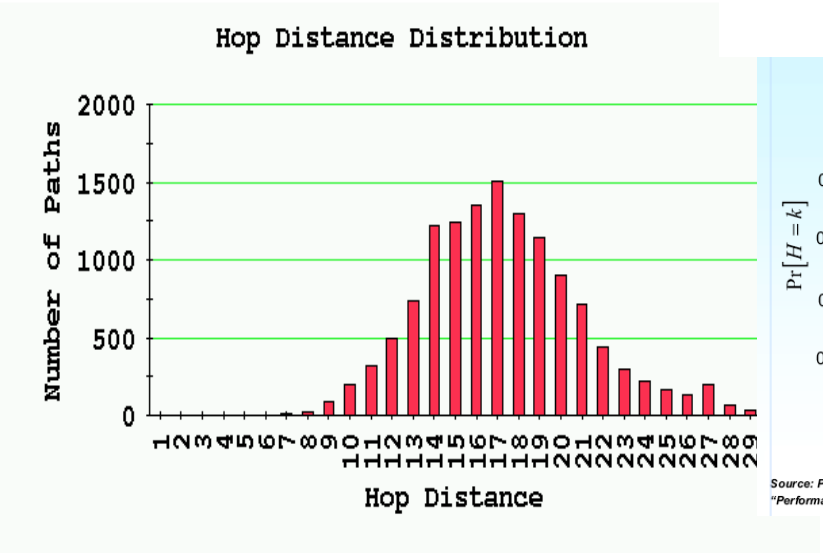
# Introduction of OBS - Solving IP Bottleneck? -

## *IP convergence will cause IP congestion.*

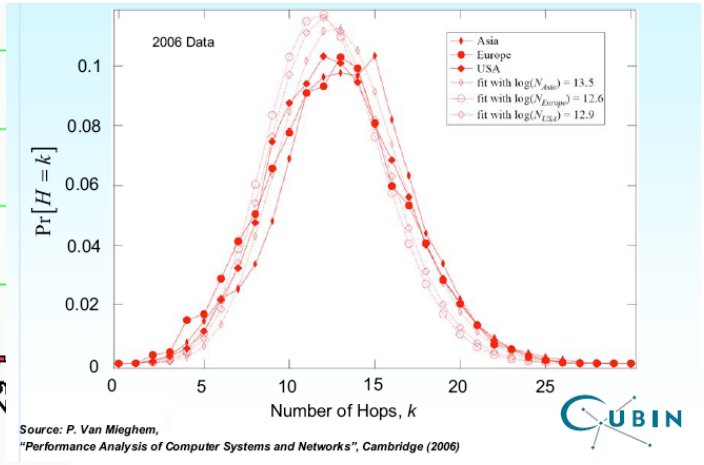





# *Internet Hop Distance Distribution*



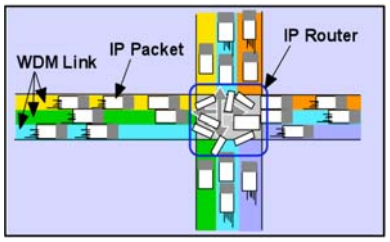

http://www.caida.org/outreach/presentations/nanog9806/




R. Tucker, "Optical Packet-Switched WDM Networks: a Cost and Energy Perspective," OFC/NFOEC 2008, OMG1, San Diego, February 2008.

# Wavelength Routing on Photonic Superhighway

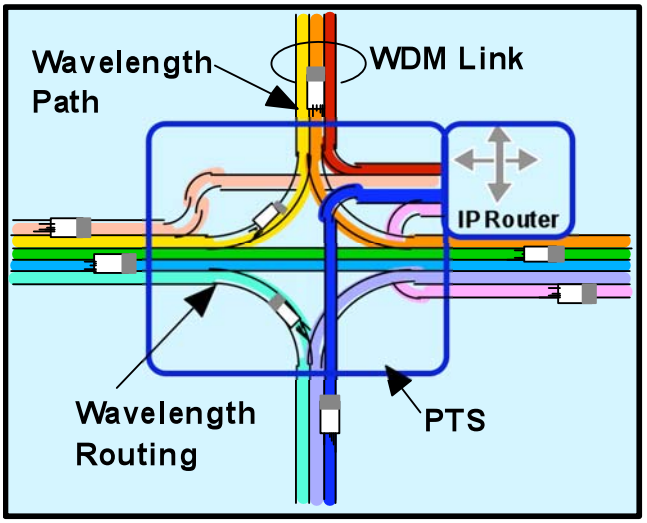
WDM + (electrical) IP Router




*Traffic Jam at Node*

Photonic MPLS

*Existing Network*

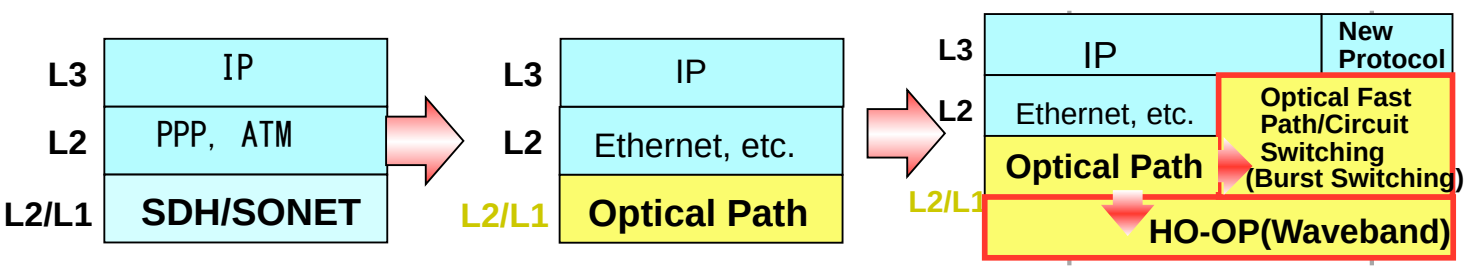



*Photonic Network*



# Direction towards Network Throughput Expansion and Total Power Reduction

**Traditional IP Networks** **New IP Networks（after 2004）** **Future Networks**




Electrical Processing

Optical Processing

**IP Layer Cut-through on Optical Path**

(1) Introduction of HO-OP (Waveband)

(2) Introduction of Optical Fast Circuit/Path Switching (Burst Switching)

~5 years ~10 years

**~ 1 Tb/s Electrical Router**

**~ 10 Tb/s Photonic Router**

**~ 100 Tb/s Photonic Router**

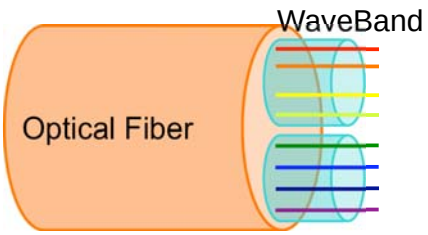
# Hierarchical Optical Path Networks

■ WaveBand:

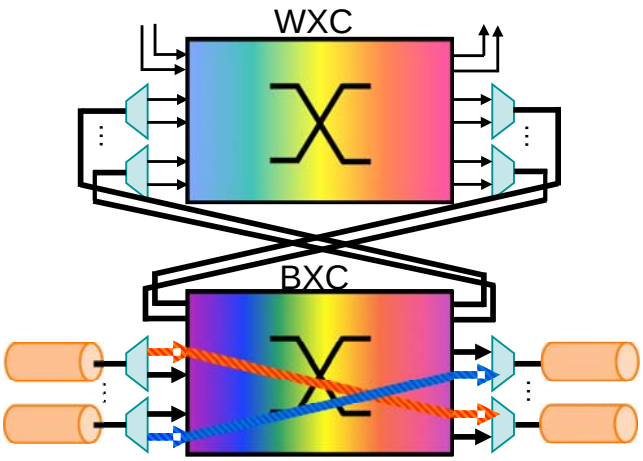
Grouped optical path to be treated as a higher order path

Merits

- Large Capacity Optical Path is Realized by Multiplexing Multiple Optical Paths




- Routing is done as a WaveBand; cut through of wavelength level routing processing




⇨
- Reduction of necessary number of switch ports
- Reduction of switch size

**Node cost reduction**

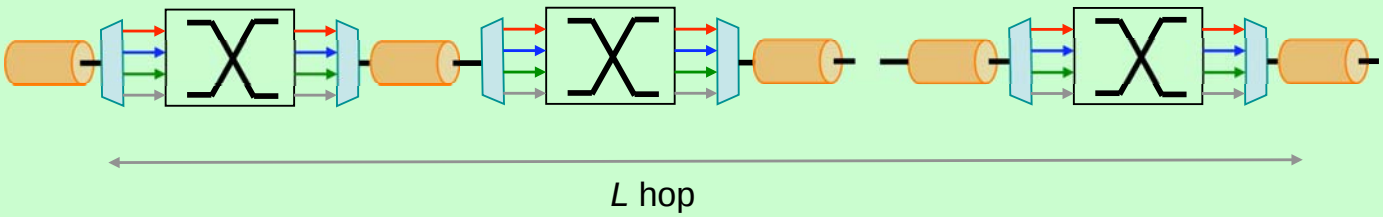


# Comparison of Cross-Connect Switch Port Number

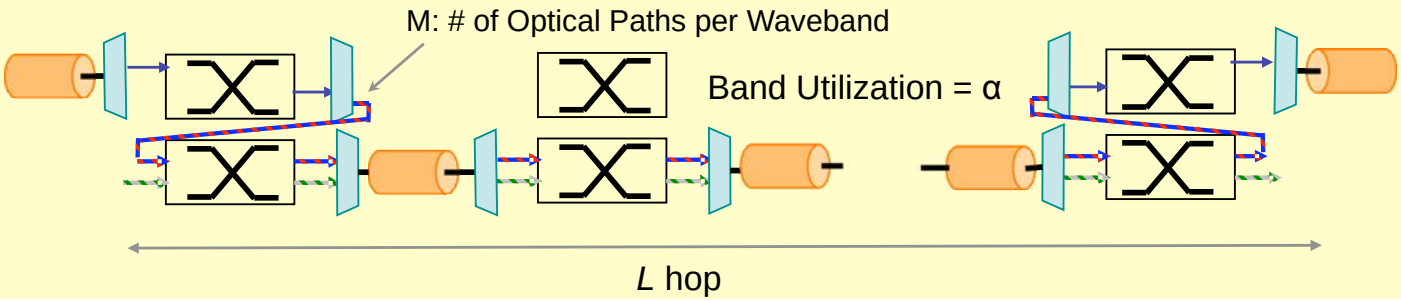
Ratio of total cross-connect switch port (Multi-layer／Single Layer) = $\frac{(M+(L+1)+M)/\alpha}{Mx(L+1)}$

Example: M=8, L=4, α=0.9 R=0.58, M=16, L=4, α=0.9 R=0.51, M=16, L=6, α=0.9 R=0.39

*Single Layer Optical Path Network*

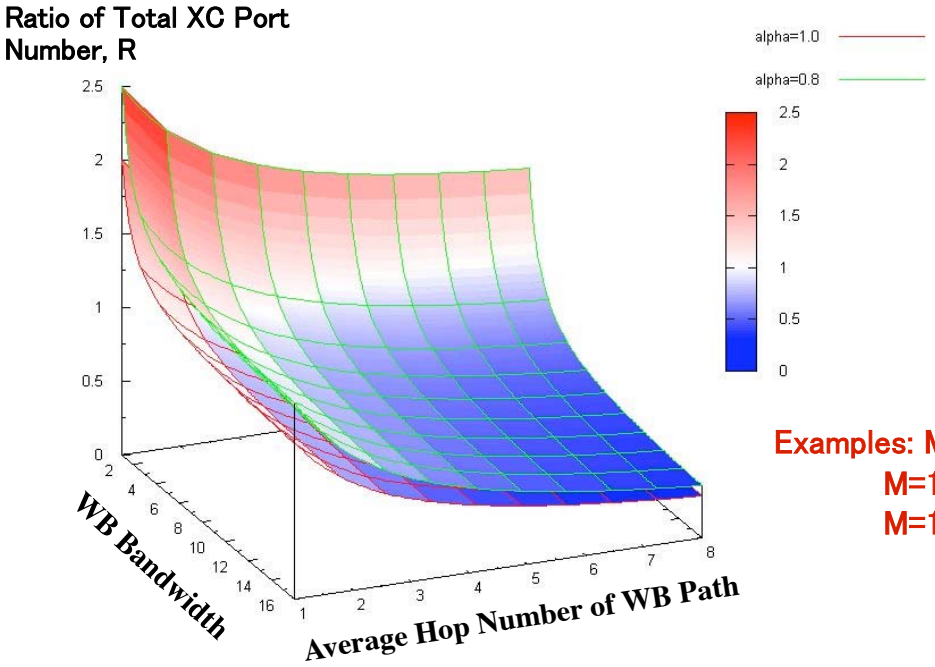



*Multi-Layer Optical Path Network*



# Reduction in Switch Port Number

Ratio of the total number of switch ports in the networks
( R: Multilayer/Single Layer)

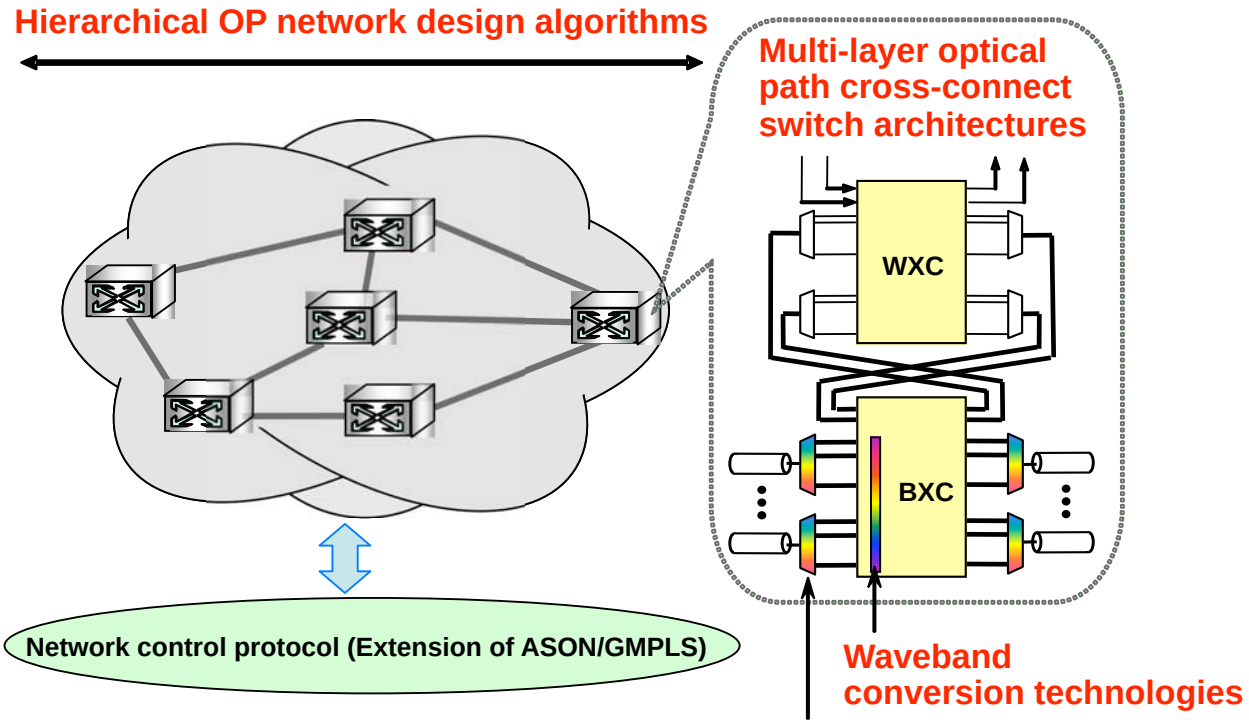



Examples: M=8, L=4, $\alpha$=0.9 R=0.58
M=16, L=4, $\alpha$=0.9 R=0.51
M=16, L=6, $\alpha$=0.9 R=0.39

Ref. [2, 34]

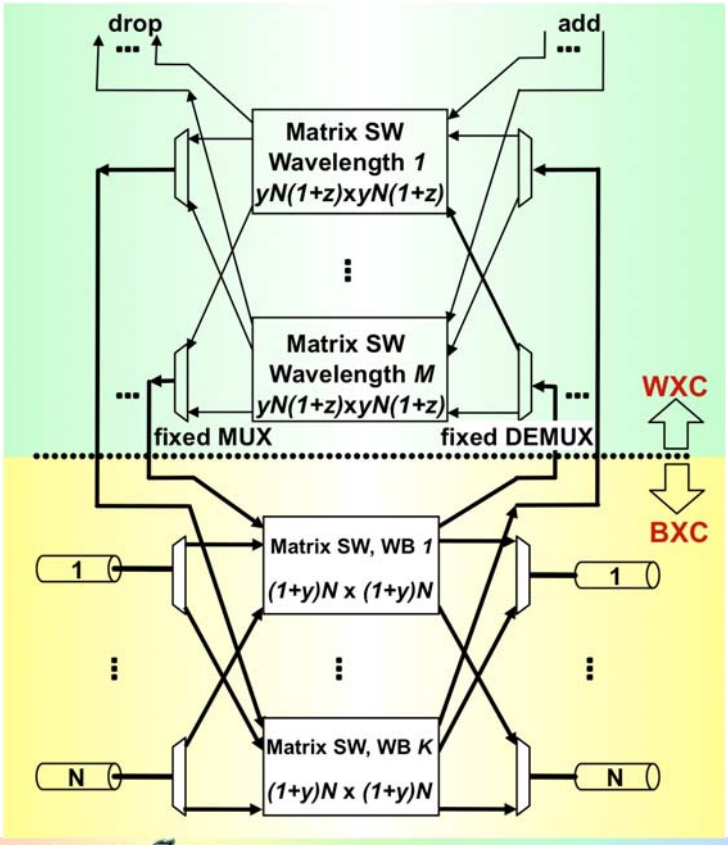


# Hierarchical Optical Path Network Technologies




WXC: Wavelength path cross-connect
BXC: Waveband cross-connect

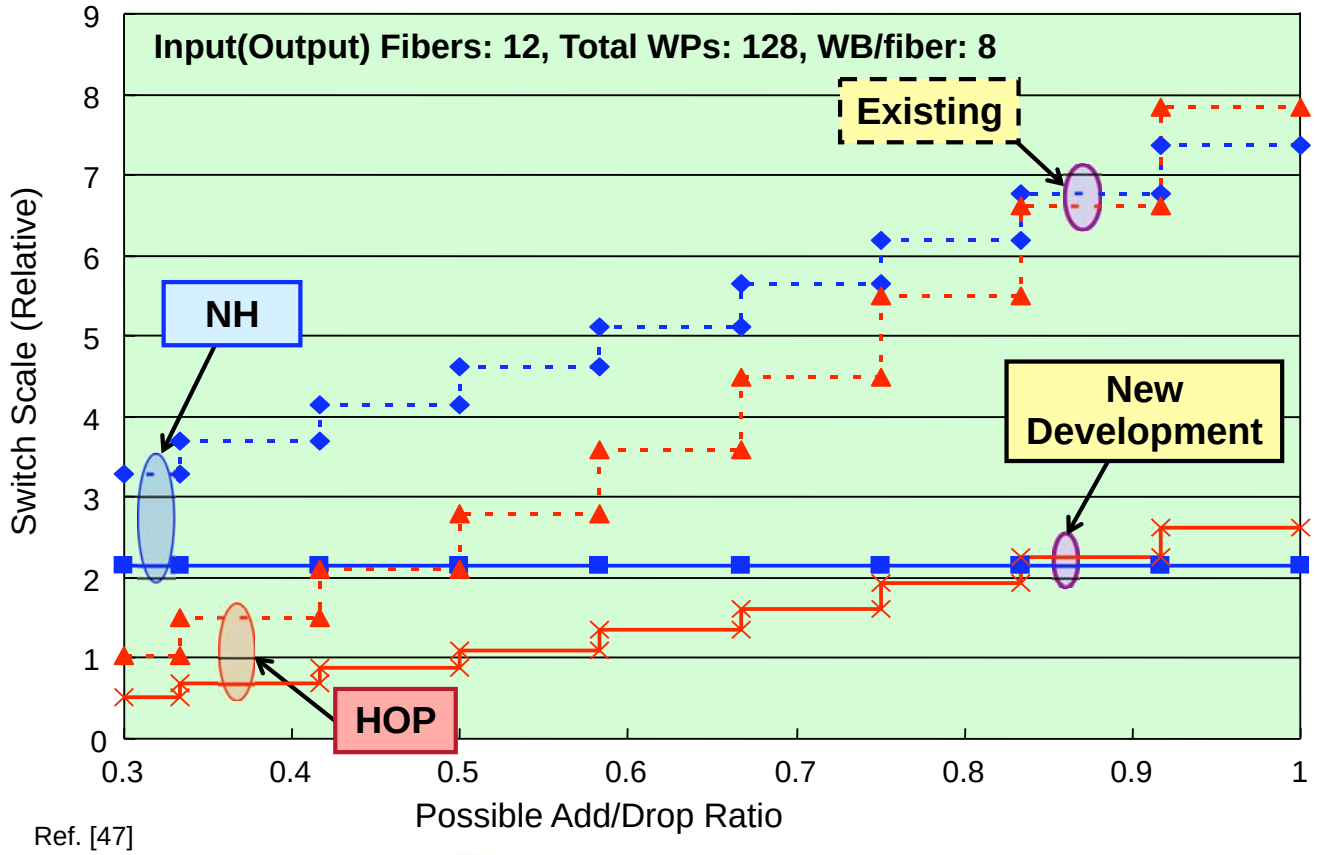
# Hierarchical Optical Path Cross-connect Switch Architecture -Space Switch Based-




Ref. [47]



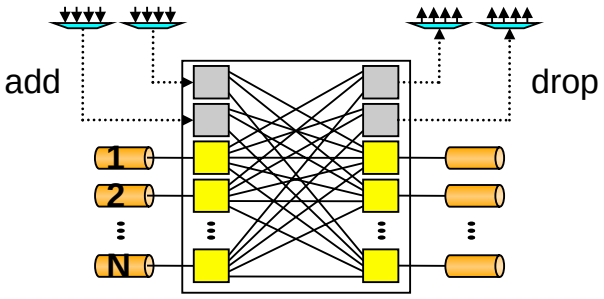
# Comparison of Switch Scale



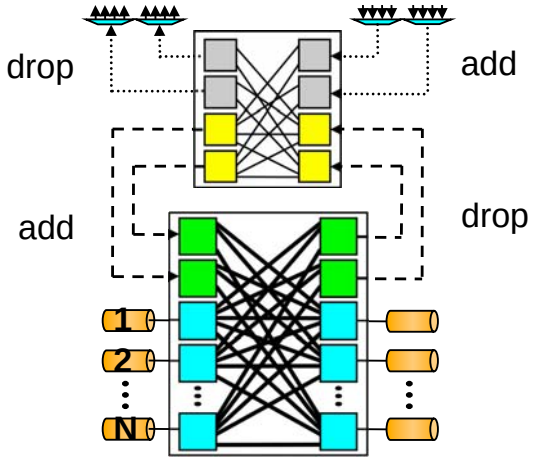

Ref. [47]

# Single Layer and Hierarchical OXCs based on WSS/WBSS

## WSS based Single Layer OXC




## WBSS based Hierarchical OXC

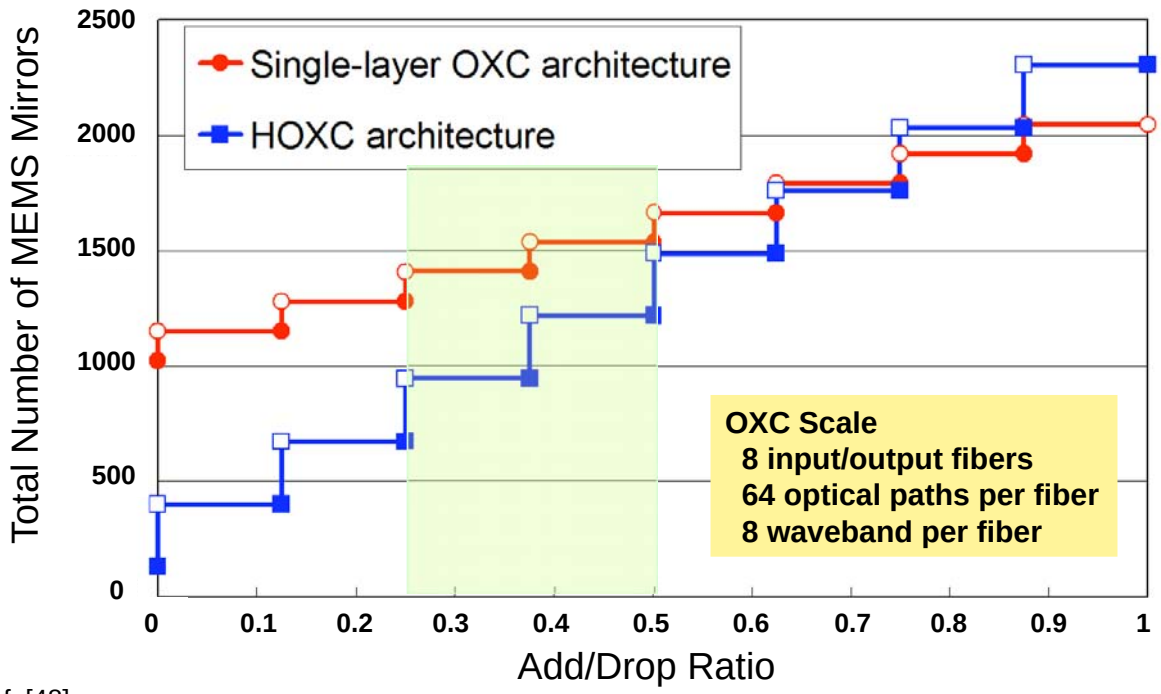



Ref. [48]



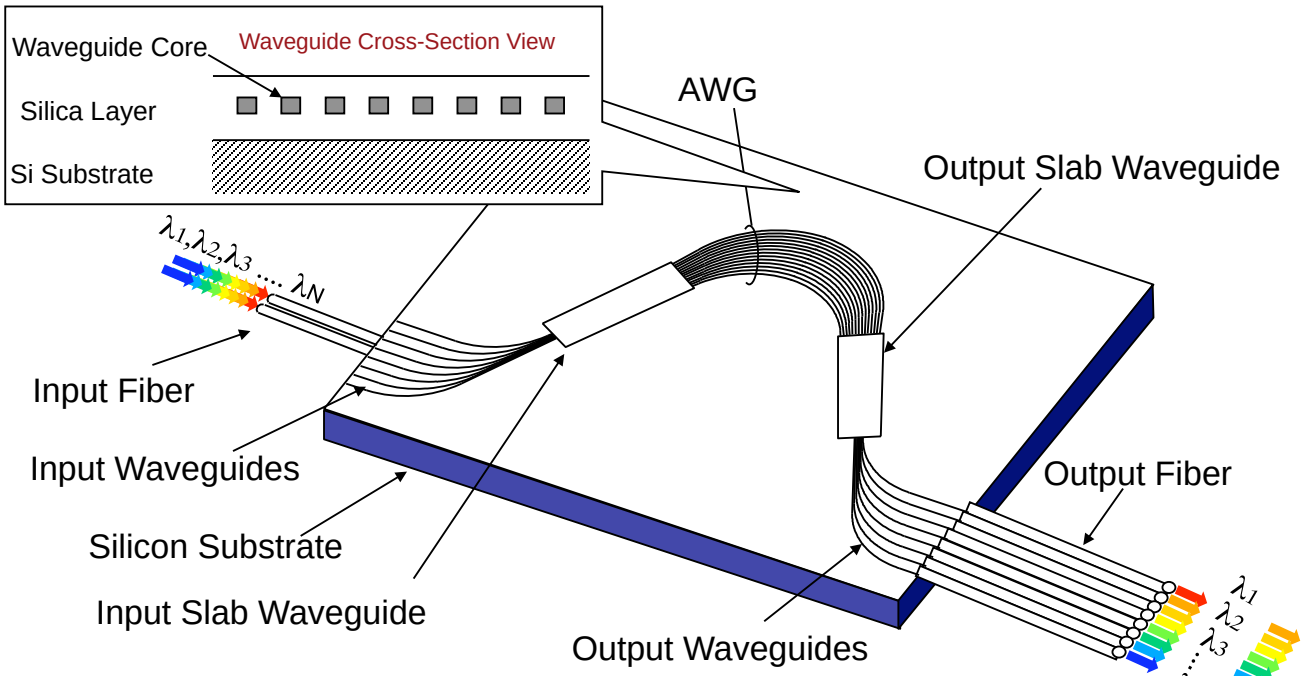
# Single-layer OXC vs. HOXC

**Total number of mirrors can be reduced by 48% to 21% over an area where the add/drop ratio is between 0.25 and 0.5.**




Ref. [48]

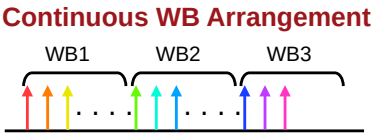
# Arrayed-Waveguide Grating (AWG)

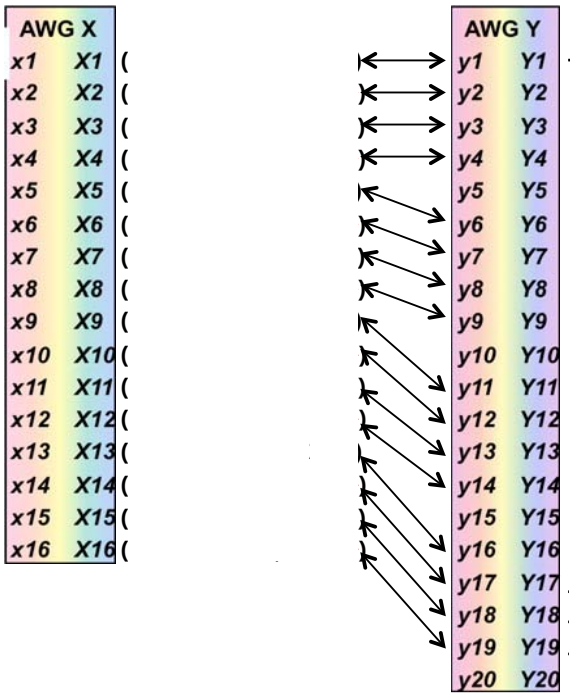



- Input optical channels are demultiplexed and output from each output port channel by channel
- When input optical fiber is shifted by one port, the output port of each channel will shift by one port.



# Newly Developed WB MUX/DEMUX
# - Continuous Waveband Arrangement -




Ref. [40, 41]

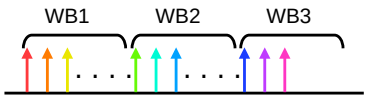
# Formulation of Waveguide Connection for Waveband MUX/ DEMUX

- **The relation ship of # $X_{out}$ of AWG X and # $y_{in}$ of AWG Y:**

$$\#\, y_{in} = \#\, X_{out} + j\left[(\#\, X_{out} - 1)/D\right] + i$$
$$\left(1 \le \#\, X_{out} \le M, 1 \le \#\, y_{in} \le N\right)$$

**where [ $z$ ] is the largest integer such that [ $z$ ] $\le z$, and $i$, $j$ are integers satisfying,** $i + j(B-1) + DB \le N, i \ge 0, j \ge 1$

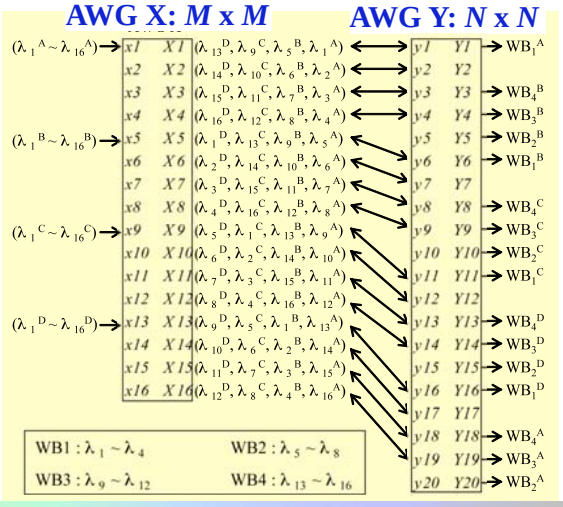
**Continuous WB Arrangement**




- **Input fiber connection ports to AWG X can be determined as**

$$\#\, x_{in} = 1 + sD \quad \left(1 \le \#\, x_{in} \le M\right)$$

**where $s$ is an integer satisfying,** $0 \le s \le B-1$




**$k$-th waveband $WB_k$ ($k$ = 1, ~, $B$) accommodates $D$ wavelength paths $\lambda_{kD+1}$, ~, $\lambda_{(k+1)D}$**

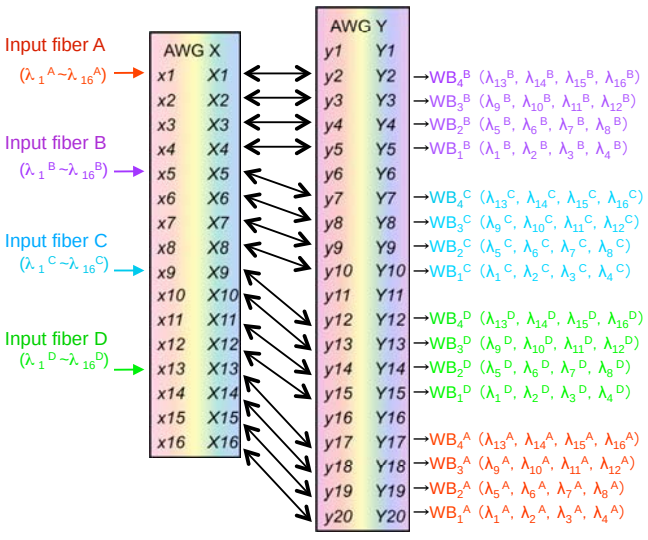
**($N \ge M+B$)**

Ref. [41]

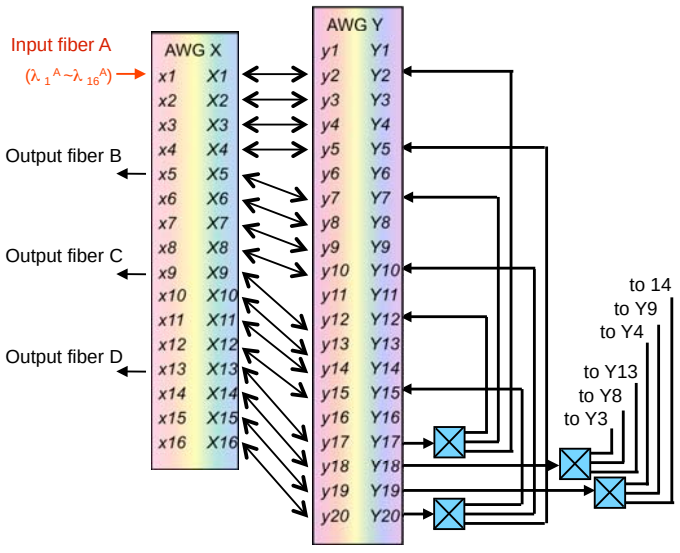


# Development of Waveband Selective Switch

WB MUX/DEMUX




1x3 WBSS
for continuous channel allocation

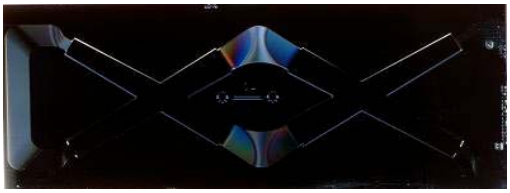



Shoji Kakehashi, Hiroshi Hasegawa, Ken-ichi Sato, Osamu Moriwaki, Masayuki Okuno, "Waveband Selective Switch Using Concatenated AWGs," to be presented at ECOC 07.

# Prototype of 1 x 5 Waveband-Selective Switch

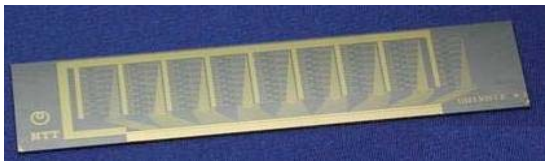
We fabricated Prototype of 1 x 5 Waveband-Selective Switch using PLC technology; two chips were connected by fibers.

3 x 7 $cm^2$



connected with fibers

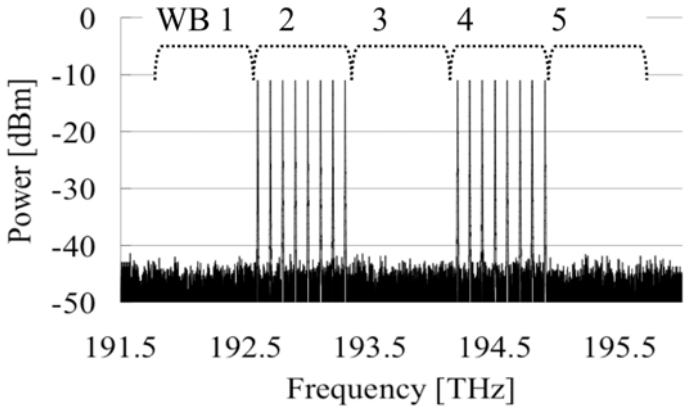
3 x 11.5 $cm^2$



1 x 5 Waveband-Selective Switch

- The device accommodates one input fiber and five output fibers.
- The input fiber carries 40 channels (8 channels x 5 continuous WBs).
- Average loss is 6.1 dB

Ref. [50, 49]






# Government-Funded R&D Programs

# Government-funded R&D programs until 2006

**All-optical transport**
(1996～2005)

**Photonic node enabling broadband access**
(2000～2005)

**Optical burst switching network**
(2001～2005)

**Control plane for terabit-class network**
(2001～2005)

Photonic Phase I

**Ministry of Internal affairs & Communs. (MIC)**

**Devices for photonic network**
(2002～2006)

**Femtosecond technology**
(1995～2004)

**Ministry of Economy, Trade, and Industry (METI)**

PHOTONIC INTERNET FORUM

# Current photonic NW R&D programs

Photonic Phase II

***Photonic node with multiple granularity switching capability***
(2005～2009)

***λ Access***
(2006～2010)

***λ Utility***
(2006～2010)

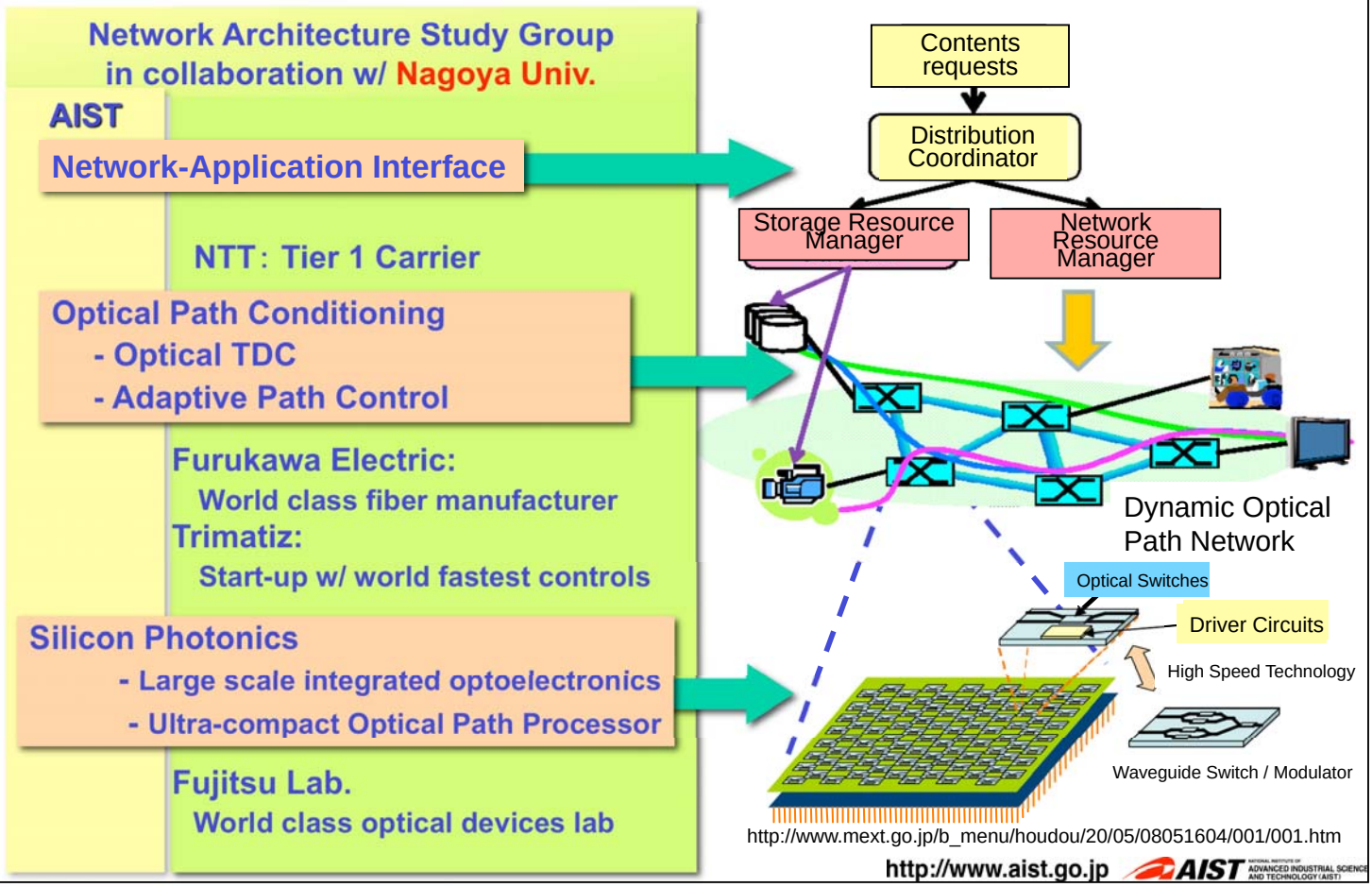
***Optical RAM for all-optical packet switching***
(2006～2010)

**Note 1: National Institute of Information and Communications Technology (NICT), affiliate of the Ministry of Internal Affairs & Communications (MIC)**

**Note 2: λ refers to a large-capacity and transparent information channel, identified by the wavelength value**

PHOTONIC INTERNET FORUM

**AIST has launched a MEXT Project, "VICTORIES"**
**"Vertically Integrated Center for Technologies of Optical Routing toward Ideal Energy Savings"**




# *Conclusions*

- IP convergence is now on-going, and at the same time the divergence of architectures and technologies is seen. Recent technology advances allow us to develop optimized networks that match each country's or region's or carrier's situation.
- It is very difficult to predict future services, however, video is expected to be the king media used for bit rate demanding services. High-quality video technologies are rapidly advancing.
- TCP/IP bottleneck is becoming more and more tangible. It will limit the future envisaged network expansion -the energy bottleneck and throughput bottleneck need to be resolved.
- Fast optical circuit/path switching will play the key role to create cost effective and bandwidth abundant future networks.
- Hierarchical optical path network and the node technologies are very important, and hence they need to be fully developed soon.

# Thank you.