HITACHI
Inspire the Next

June 20th 2007

Optical Access System
Implementation
- ITU-T G-PON Technology-

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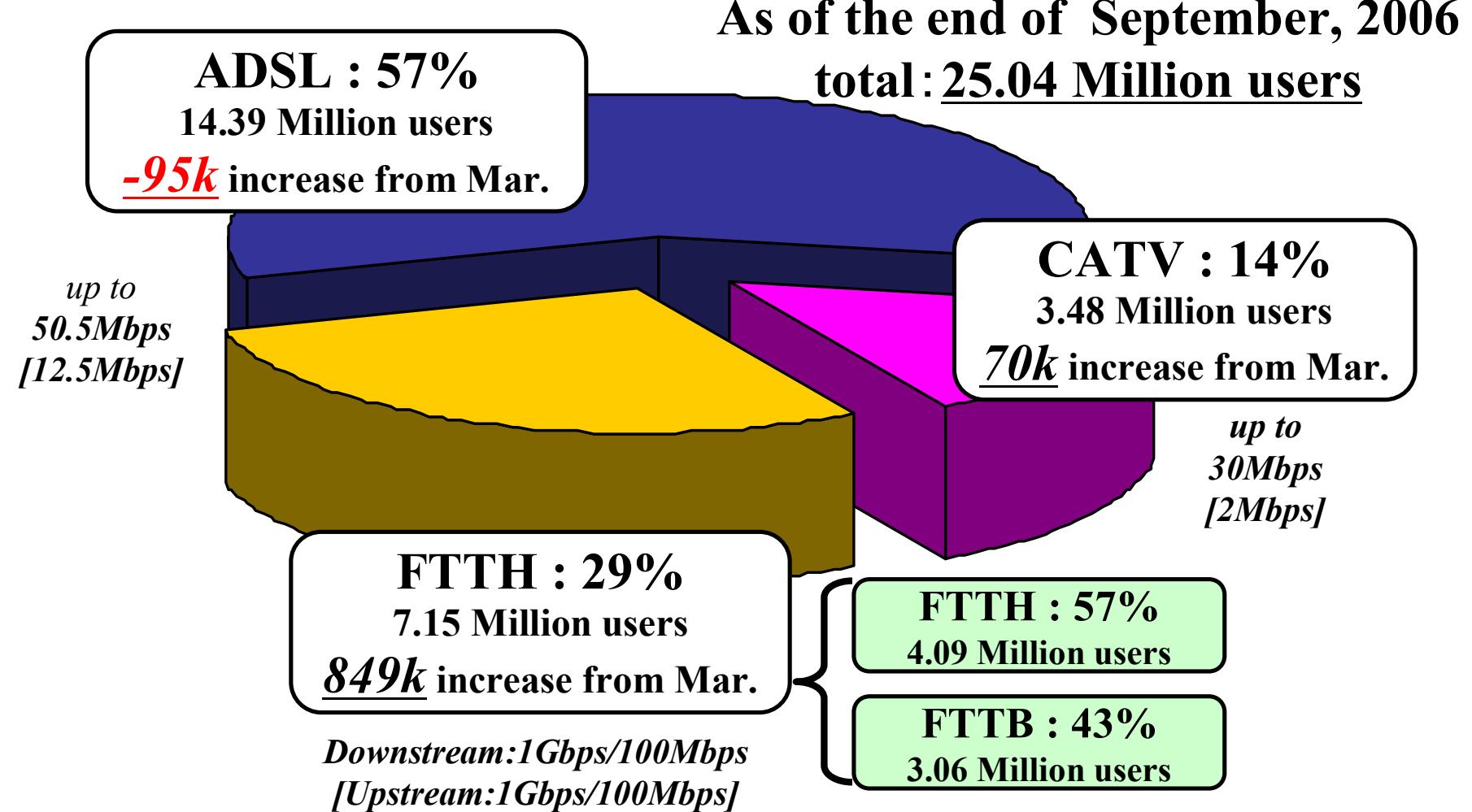
Contents
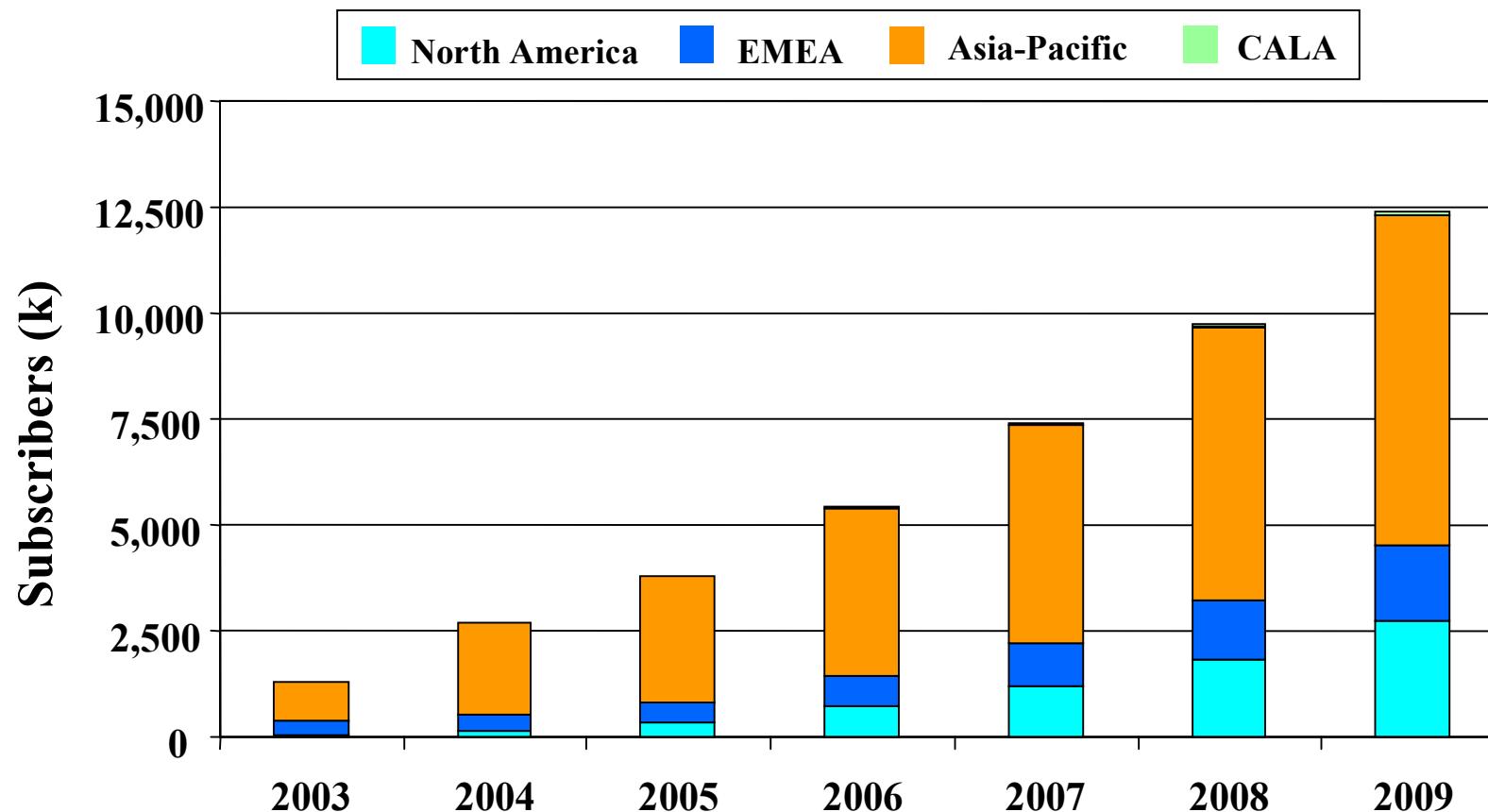
Broadband Users in Japan

As of the end of September, 2006
total : 25.04 Million users

ADSL : 57%
14.39 Million users
-95k increase from Mar.

up to 50.5Mbps [12.5Mbps]

CATV : 14%
3.48 Million users
70k increase from Mar.

up to 30Mbps [2Mbps]

FTTH : 29%
7.15 Million users
849k increase from Mar.

Downstream:1Gbps/100Mbps [Upstream:1Gbps/100Mbps]

FTTH : 57%
4.09 Million users

FTTB : 43%
3.06 Million users

* Source: Japanese Government numbers
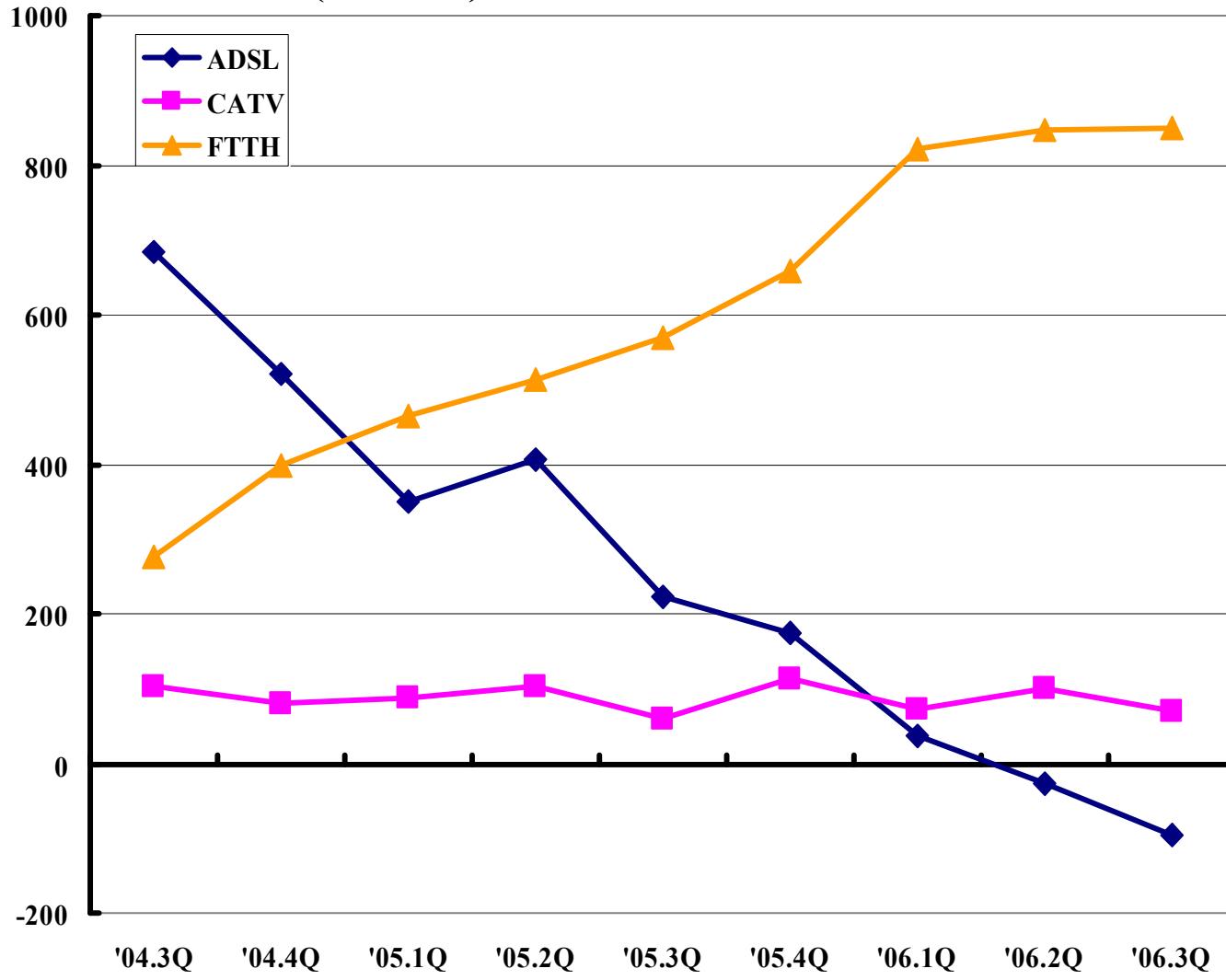
# Global FTTH Market

Source : Ovum-RHK

FTTH Growth in Japan
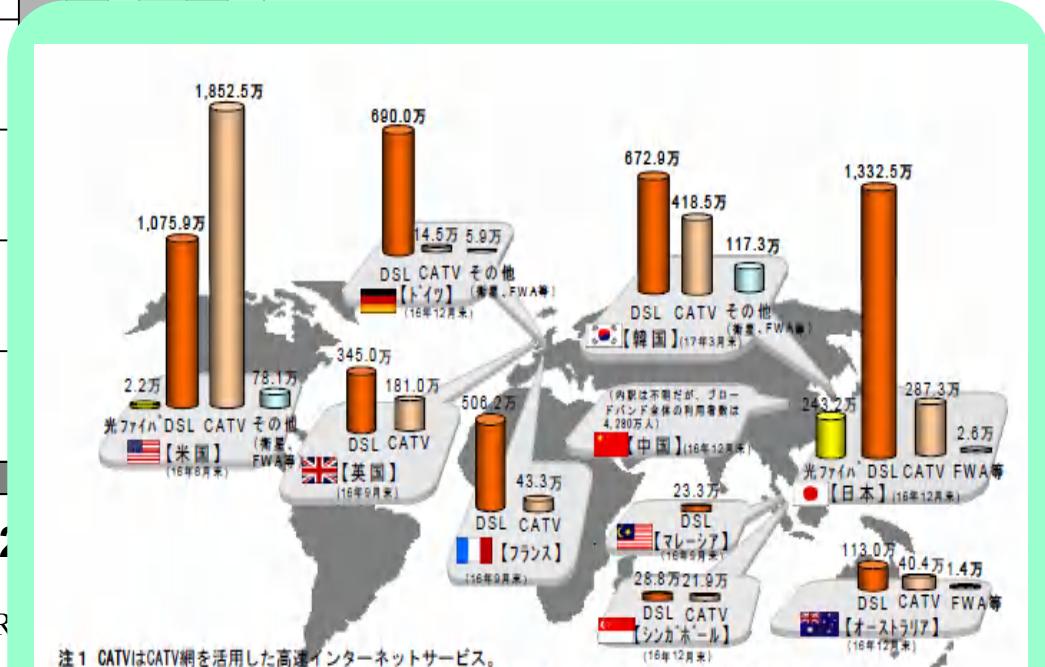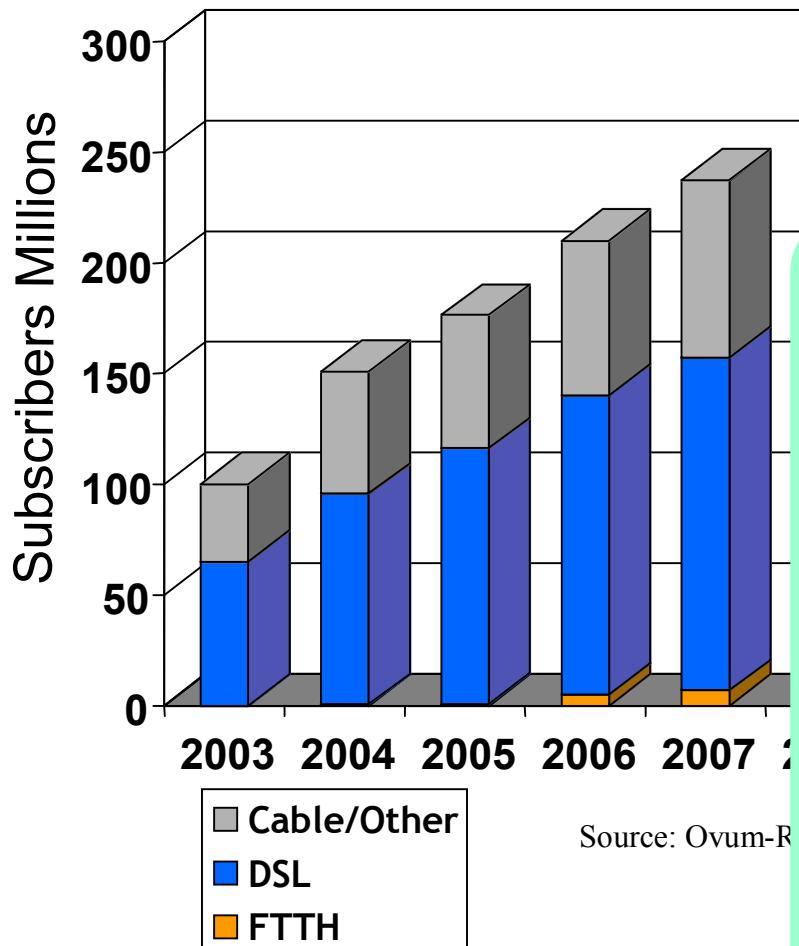
Number of Subscribers (k users)

Source: Ministry of Internal Affairs and Communication (Japan)

Global Broadband Services

Source: Ovum-R
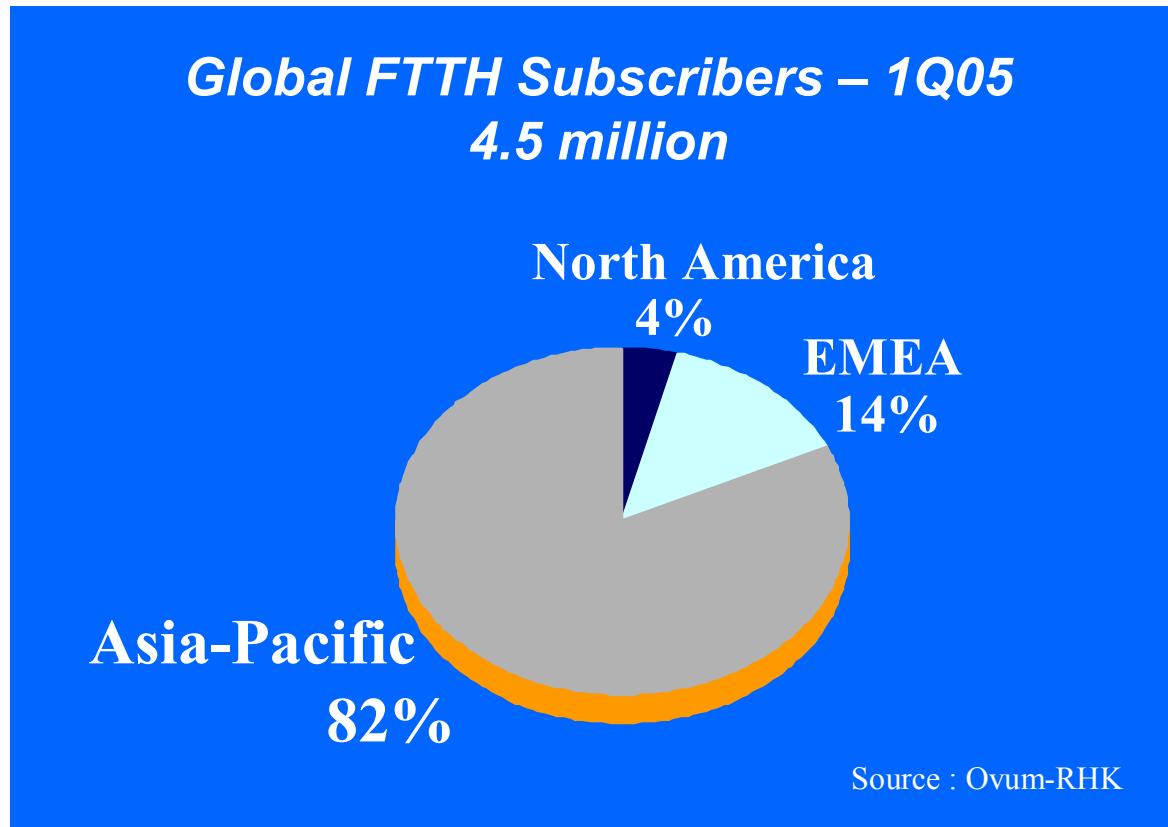
Source ： 総務省報告書「次世代BB構想2010」(05.5)

Global FTTH Market Segmentation

Global FTTH Subscribers – 1Q05
4.5 million

North America
4%

EMEA
14%

Asia-Pacific
82%

Source : Ovum-RHK

US FTTH Market

- **Activity**

  Aggressive Incumbent builds
   (Verizon, SBC, BellSouth)
  Numerous Community-Utility,
   Property Developer builds

- **Competitive Situation**

  Cable-TV operators providing
   telephony competition

EU FTTH Market

- Europe is late

- 500K subscribers, 2.6M homes passed by the end of 2004

- More than 90% of FTTH-subscribers concentrated in just 5 countries
  - Sweden : 200K, Italy : 185K, Denmark : 85K, Netherlands : 50K, Norway : 15K

- 167 FTTH-projects – most of them small and/or pilots

- Only modest growth in next years

- G-PON is gaining momentum

Asia-Pacific FTTH Market

"See The Light" : **Asia-Pacific is unique**

■ **Market Leaders : "lighthouses on the coast"**

- Japan
  - More than 3M FTTH subscribers
- Korea
  - Extremely high broadband penetration and FTTB
- Hong Kong

■ **Potential and Rising Market : "bright future"**

- China
- India
- South-East Asian Countries

Korea FTTH Market

Activity
- Most mature broadband market in the world 95% penetration of broadband services via DSL, HFC or Apartment LAN
- Incumbent (Korea Telecom) trials in Pusan & Guanju
    - 50K users of WDM-PON trials underway in Guanju City
    - 2K users GE-PON trials

Competition
- Extremely competitive environment

Government/Regulatory
- Government has moved from e-Korea (2002) to u-Korea ("ubiquitous" integration)
- Plan to build BcN (Broadband Convergence Network) as core network for U-Korea

BcN Vision
- 50-100Mbps services, HDTV, Video phone
- 1.5M subs 2005, 4.5M subs 2007, 10M subs 2010

China FTTH Market

- **Activity**
  - 15-16 pilots and regional rollout commenced in 2004 Pilots from China Netcom, China Telecom & China Railcom
  - Yongfeng Park Beijing : 1700 users in 2005, target 40-50k
  - 3TNET Yangtze Triangle : 5000 subs in 2005, target 60k by 2007 Chuangye Street Wuhan
  - 1000 subs in 2005, target (all Wuhan) 500k-1M subs

- **Government/Regulatory**
  - Government has announced goal of 75M broadband by 2008
  - Regulatory position unclear; risks for new carriers

- **Carriers/Vendors**
  - Carriers looks like to use GPON.
  - GPON under development in Major vendors such as Huawei

FTTH Market Driving Factors

- **Government Policies and Influence**
  - Korea and China : Initiatives and Support
  - Japan : Unbundling

- **Housing and Population Density : High Profitability**
  - MDU : Apartment houses and Condominium
  - Smaller Houses
  - MDU in China : > 85 %
  - Back to Tokyo downtown

- **Access Loop Network : Efficient CAPEX**
  - Asia loop length average is 2-2.5 km, vs. 3.5 to 4 km in U.S.

- **Some Competitive Areas : Japan**
  - Multiple FTTH service providers

- **Cultural Issues**
  - Speed is a key in Korea
  - Status Symbol in Japan

Contents

GPON Characteristics

- **Broadband**

- **Multi-service**

- **OAM**

- **Interoperability**

PON Bandwidth(Physical bitrate)

	B-PON	ITU G-PON	IEEE E-PON
Downstream Bitrate	**622.08 Mb/s** 155.52 Mb/s	**2.48832 Gb/s** 1.24416 Gb/s	**1.25 Gb/s**
Upstream Bitrate	622.08 Mb/s **155.52 Mb/s**	2.48832 Gb/s **1.24416 Gb/s** 622.08 Mb/s 155.52 Mb/s	**1.25 Gb/s**
Transmission coding	Scrambled NRZ	Scrambled NRZ	8B10B
Splitting ratio	16, 32	16, 32, 64	More than 16
span loss	20 dB (Class A) **25 dB (Class B)** **28 dB (Class B+)** 30 dB (Class C)	20 dB (Class A) 25 dB (Class B) **28 dB (Class B+)** 30 dB (Class C)	**20 dB (PX10)** **25 dB (PX20)**

Bandwidth Requirements for IP-TV

	Category（not exclusive）	characteristics	Number of TV channel Over PON	Channel bandwidth	PON downstream required BW
1	All TV program Broadcasted	Simple and end-to-end broadband network	e.g. 100ch～200ch	SDTV:6Mbit/s	600Mbit/s ～1.2Gbit/s
				HDTV:20Mbit/s	2～4Gbit/s
2	Requested TV program Multicasted	IGMP-based Rich equipment (further study For channel selection speed)	e.g. 4chx32ONU (single family)	SDTV:6Mbit/s	770Mbit/s
				HDTV:20Mbit/s	2.6Gbit/s
			e.g. 4chx16 users x32ONU (multiple families) =2048ch (but program limited e.g.200ch)	SDTV:6Mbit/s	1.2Gbit/s
				HDTV:20Mbit/s	4Gbit/s
3	Video-on-Demand (P-to-P)	Super-high grade video-server & Simple and end-to-end broadband network	e.g. 4chx32ONU (single family)	SDTV:6Mbit/s	770Mbit/s
				HDTV:20Mbit/s	2.6Gbit/s
			e.g. 4chx16 usersx32ONU (multiple families)	SDTV:6Mbit/s	13Gbit/s
				HDTV:20Mbit/s	41Gbit/s
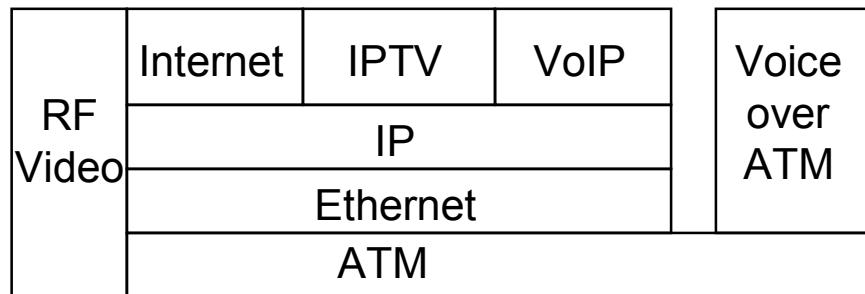
GPON Characteristics

- **Broadband**

- **Multi-service**

- **OAM**
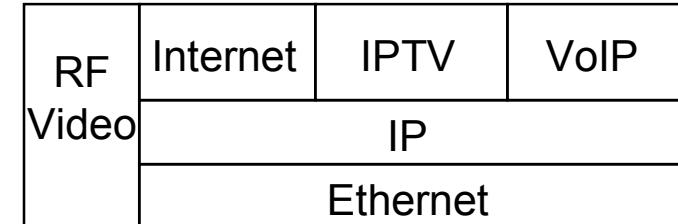
- **Interoperability**

PON Comparison(service viewpoint)

B-PON

RF Video	Internet	IPTV	VoIP	Voice over ATM
	IP			
	Ethernet			
	ATM			

IEEE E-PON

RF Video	Internet	IPTV	VoIP
	IP		
	Ethernet		

ITU-T G-PON

RF Video	Internet	IPTV	VoIP	POTS (64k)	T1	Voice over ATM
	IP					
	Ethernet			TDM		
	GEM					ATM
	GTC (125 μs frame)					
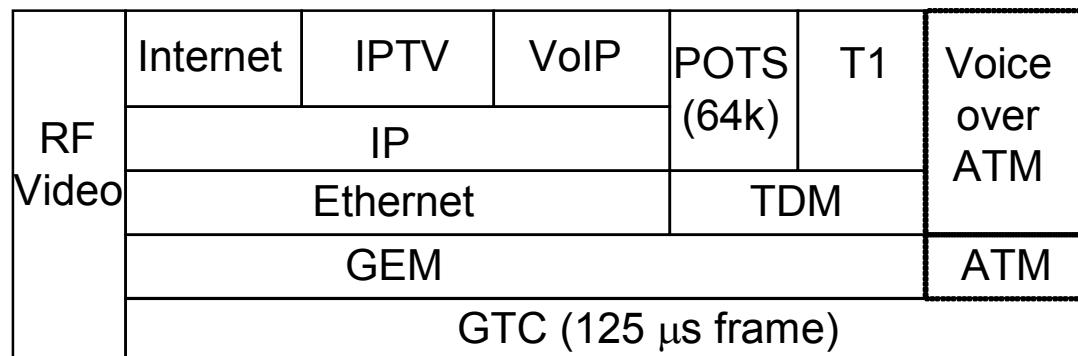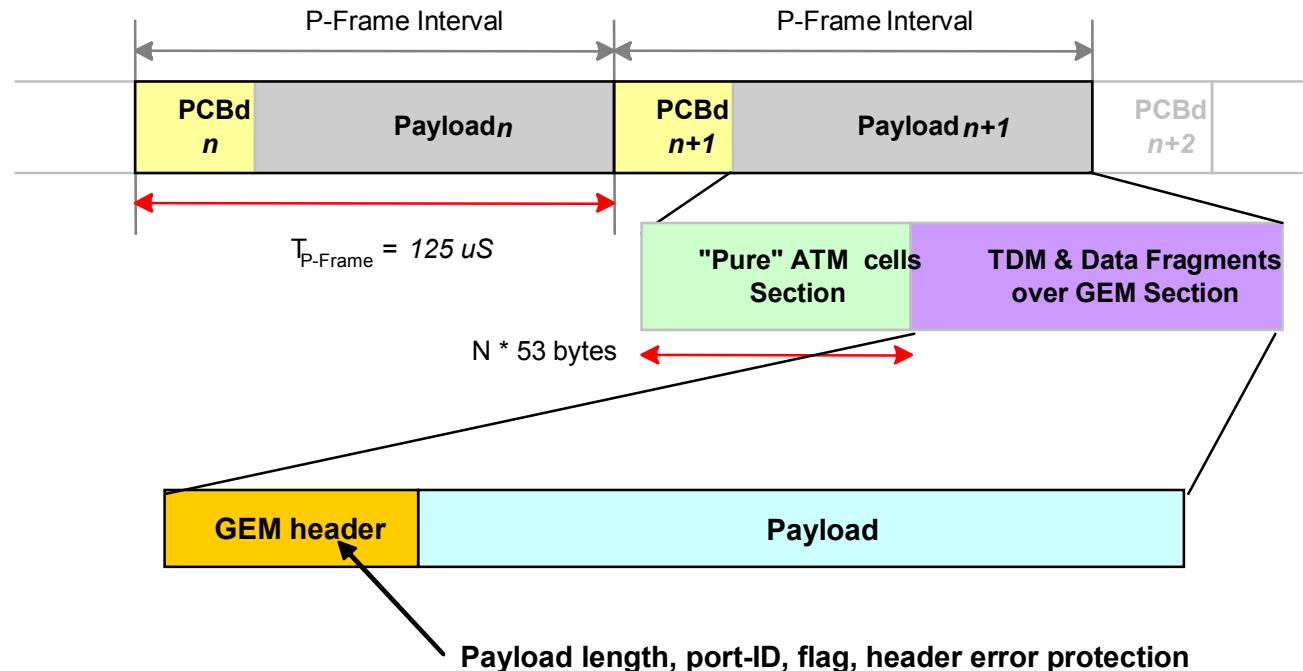
GEM: G-PON Encapsulation Method

G-PON Downstream(G.984.3)
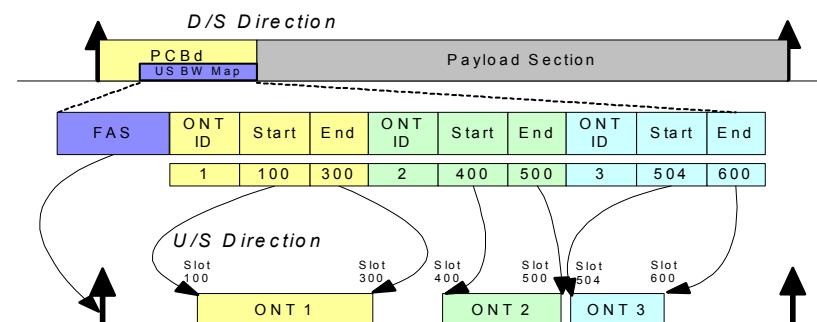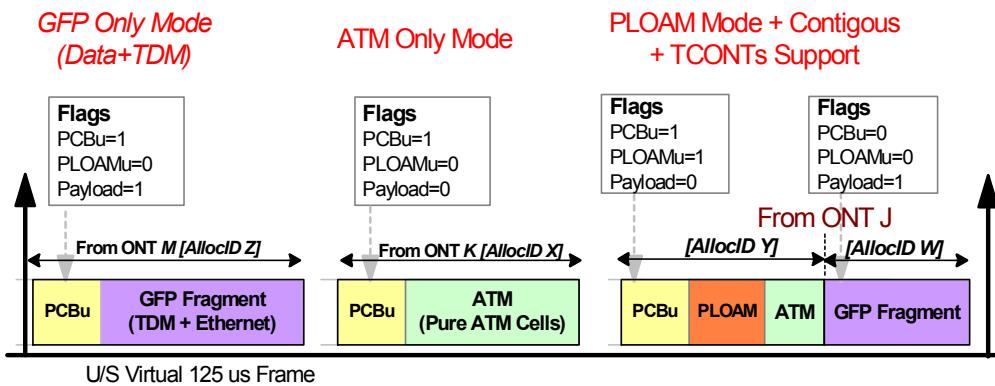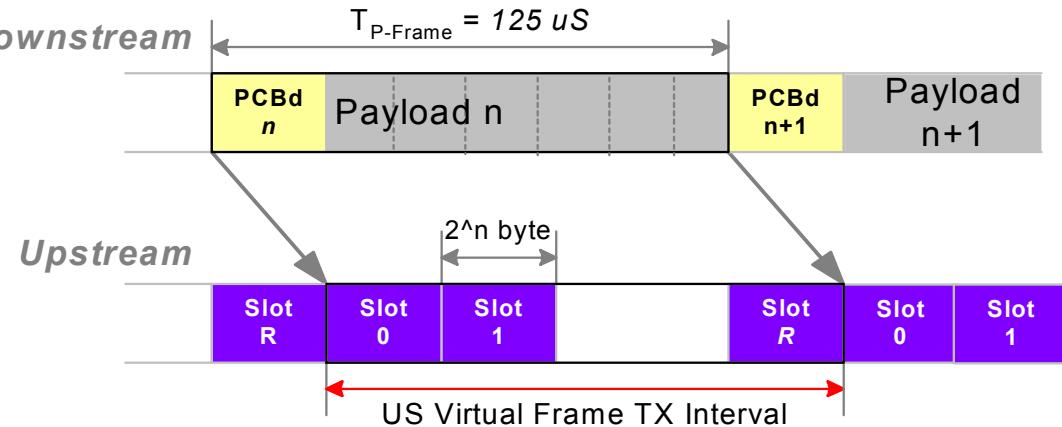
- 125 μ s-based framing

- Full-service(Voice, Data, video supported)

- Payload = ATM+GEM

- TDM and variable-length packet over GEM

P-Frame Interval		P-Frame Interval	
PCBd n	Payload n	PCBd n+1	Payload n+1

PCBd n+2

$T_{P\text{-}Frame} = 125\ uS$

"Pure" ATM cells Section	TDM & Data Fragments over GEM Section

N * 53 bytes

GEM header	Payload

Payload length, port-ID, flag, header error protection

GEM: G-PON Encapsulation Mechanism

G-PON Upstream(G.984.3)

- Upstream variable-length framing (byte-oriented)

- Payload = ATM+GEM

- Pointer of start & stop of burst frame from ONUs

Downstream

$T_{P\text{-}Frame} = 125\,uS$

| PCBd n | Payload n | PCBd n+1 | Payload n+1 |

2^n byte

Upstream

| Slot R | Slot 0 | Slot 1 | | Slot R | Slot 0 | Slot 1 |

US Virtual Frame TX Interval

GFP Only Mode (Data+TDM)

Flags
PCBu=1
PLOAMu=0
Payload=1

From ONT M [AllocID Z]

| PCBu | GFP Fragment (TDM + Ethernet) |

U/S Virtual 125 us Frame

ATM Only Mode

Flags
PCBu=1
PLOAMu=0
Payload=0

From ONT K [AllocID X]

| PCBu | ATM (Pure ATM Cells) |

PLOAM Mode + Contigous + TCONTs Support

Flags
PCBu=1
PLOAMu=1
Payload=0

Flags
PCBu=0
PLOAMu=0
Payload=1

From ONT J

[AllocID Y] [AllocID W]

| PCBu | PLOAM | ATM | GFP Fragment |

D/S Direction

| PCBd US BW Map | Payload Section |

FAS	ONT ID	Start	End	ONT ID	Start	End	ONT ID	Start	End
	1	100	300	2	400	500	3	504	600

U/S Direction

Slot 100   Slot 300   Slot 400   Slot 500   Slot 504   Slot 600

| ONT 1 | ONT 2 | ONT 3 |

GPON Characteristics

■ **Broadband**

■ **Multi-service**

■ **OAM**

■ **Interoperability**

OAM Function

2. PLOAM: Physical Layer Operation Administration & Maintenance
（ONU activation, encryption, state control etc.）

PLOAM

Downstream

P-Frame Interval   P-Frame Interval

| PCBd n | Payload$n$ | PCBd $n+1$ | Payload $n+1$ |

OLT

ONU

GEM header   OMCI

upstream

| GEM Fragment | | PCBu |

ONU

| OMCI | GEM header | PLOAM

1. Alarm: rich alarm for diagnosis

3. OMCI: ONT Management and Control Interface
（version management、UNI type,
connection/VLAN/QoS, etc.）

Alarm Function

Alarm detected by OLT (partial portion)

"i" indicates ONU-ID
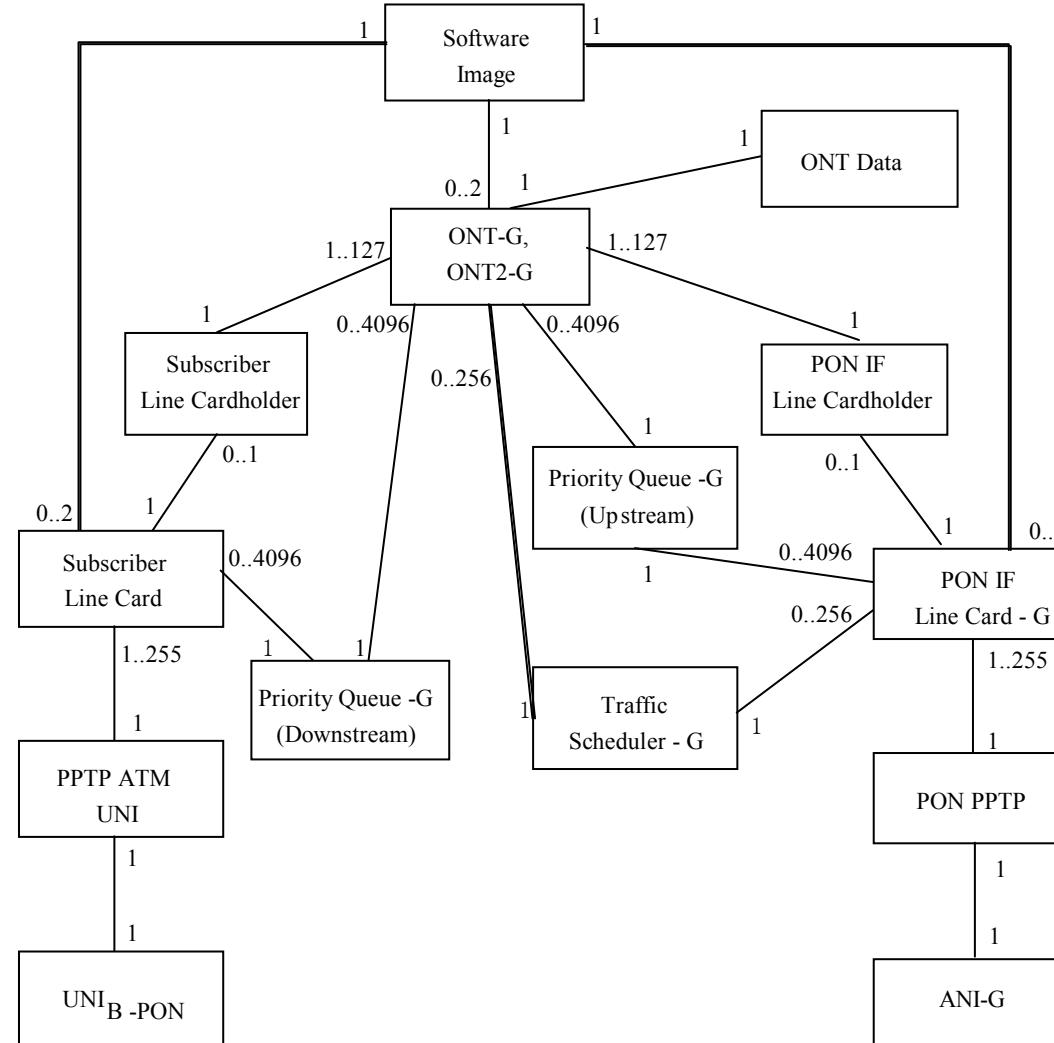
items	descriptions
TF	Transmitter failure
LOSi	Loss of signal of ONUi
LOFi	Loss of frame of ONUi
PEEi	Physical Equipment Error of ONUi
LCDGi	Loss of GEM channel delineation of ONUi
OAMLi	PLOAM cell loss for ONUi
DOWi	Drift of window for ONUi
SUFi	Startup failure of ONUi
LOAi	Loss of Acknowledge with ONUi
DFi	Deactivate Failure of ONUi
ERRi	Block error detection of ONUi
SDi	Signal Degraded of ONUi
REIi	Remote Error Indication of ONUi
MEMi	Message_Error Message from ONUi
DGi	Receive Dying Gasp of ONUi

PLOAM: Physical Layer Operation Administration & Maintenance

PLOAM messages (partial portion)

Messages	Description
Upstream_Overhead	OLT assigns burst overhead pattern and pre-assigned delay
Serial_number_mask	Only Indicated serial number ONU can be activated
Assign_ONU-ID	Assign ONU-ID(e.g. 0-31)
Ranging_Time	Equalized delay is set to ONU based on distance measurement
Deactivate_ONU-ID	De-activation of indicated ONU
Disable_serial_ number	Isolation of indicated ONU for system maintenance
Assign_Alloc-ID	Assign Alloc-ID(bandwidth control unit by DBA)
POPUP	Quick re-activation process
Configure Port-ID	Set of port-ID for OMCI communication
Password	Password notification for authentication
Dying_Gasp	Notification of ONU Power-down

OMCI Managed Entity (partial portion)

GPON Characteristics

- **Broadband**

- **Multi-service**

- **OAM**

- **Interoperability**

Interoperability activities in FSAN

- **06/01   Physical layer connection@Piscataway NJ**

- **06/05   Physical layer connection @Piscataway NJ**

- **06/09   OMCI @Santa Clara CA**

- **06/12   Telecom2006   @Hong Kong**
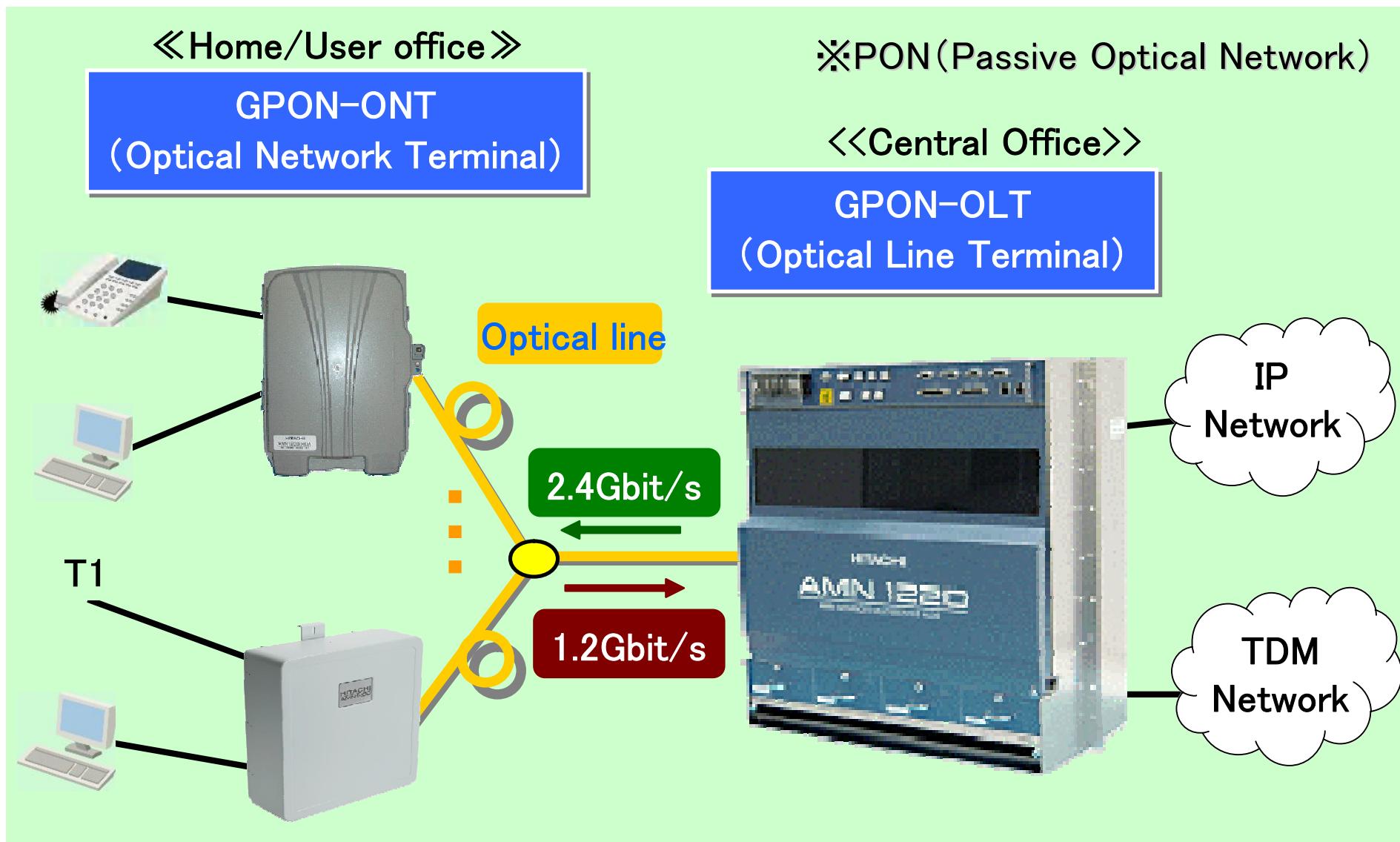
Contents

GPON System Implementation

≪Home/User office≫

※PON（Passive Optical Network）

GPON-ONT
（Optical Network Terminal）

≪Central Office≫

GPON-OLT
（Optical Line Terminal）

Optical line

2.4Gbit/s

T1

1.2Gbit/s

IP Network

TDM Network
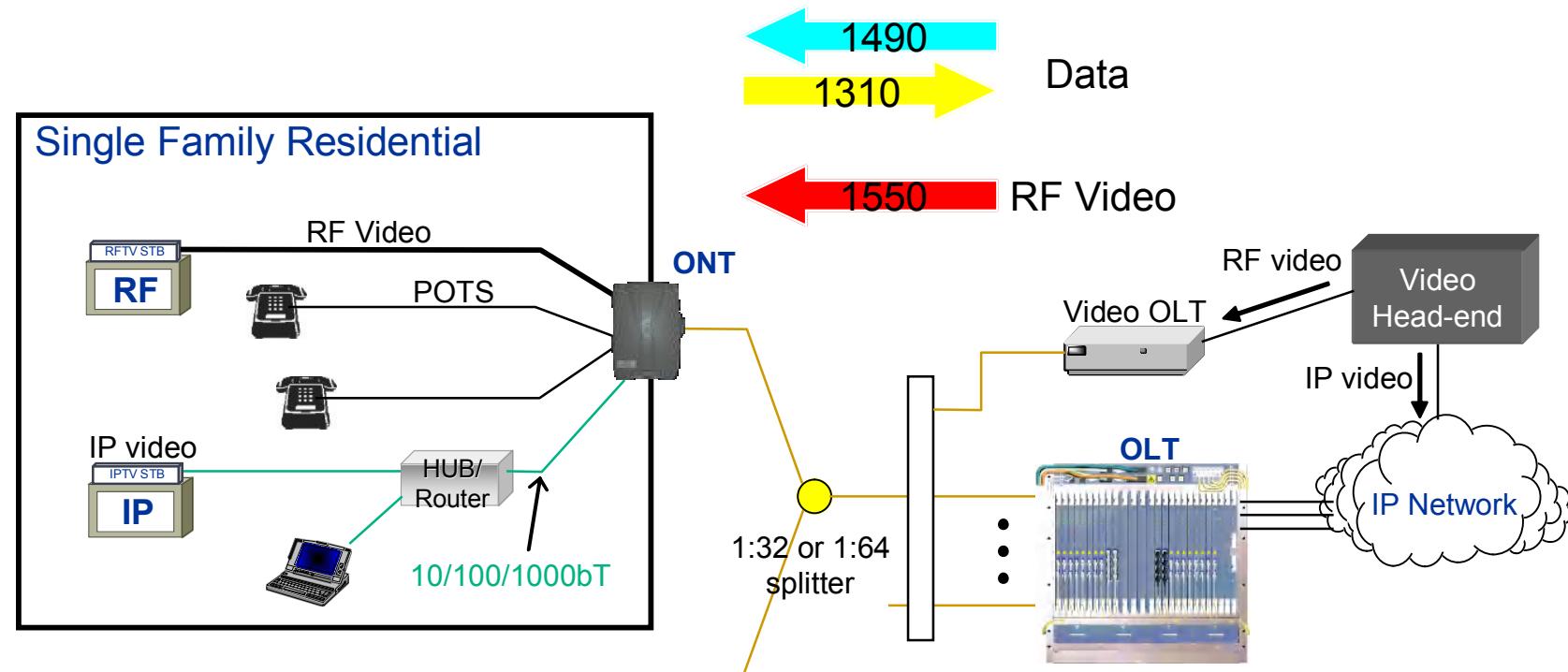
Video Service
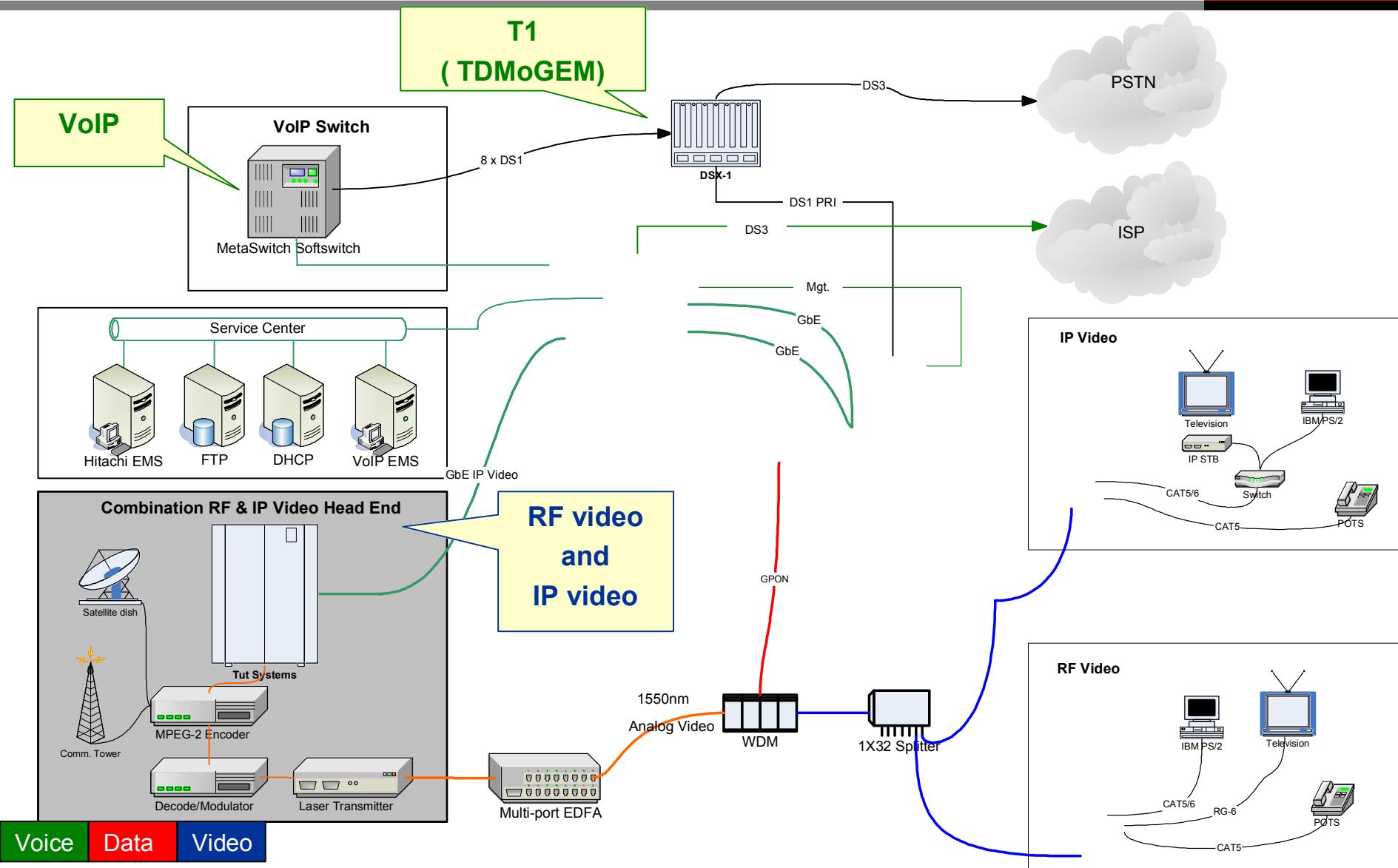
1. Analog video by WDM
2. IP multicast

Single Family Residential

1490 ← Data
1310 →

1550 ← RF Video

RFTV STB
RF

RF Video

POTS

IP video
IPTV STB
IP

HUB/ Router

10/100/1000bT

ONT

1:32 or 1:64 splitter

OLT

RF video

Video OLT

Video Head-end

IP video

IP Network

G-PON Network example

**T1
(TDMoGEM)**

VoIP

VoIP Switch

MetaSwitch Softswitch

8 x DS1

DSX-1

DS3 → PSTN

DS1 PRI

DS3 → ISP

Mgt.

GbE

GbE

Service Center

Hitachi EMS FTP DHCP VoIP EMS

GbE IP Video

Combination RF & IP Video Head End

Satellite dish

Tut Systems

Comm. Tower

MPEG-2 Encoder

Decode/Modulator Laser Transmitter

**RF video
and
IP video**

GPON

1550nm
Analog Video

WDM

1X32 Splitter

Multi-port EDFA

IP Video

Television IBM PS/2

IP STB

CAT5/6 Switch

CAT5 POTS

RF Video

IBM PS/2 Television

CAT5/6 RG-6 POTS

CAT5

Voice	Data	Video

32

G-PON technical study items

Burst multiplexing

Downstream encryption

Upstream BW control

Bi-directional transmission over single fiber

Optical burst transmitter

Higher speed   High-speed LD

Rich function   High sensitivity PD, Receiver

Variable length
Rich Management   High-speed ASIC

Optical burst receiver

Burst clock recovery

ONU 1

ONU 1

Burst mode signal

ONU 2

ONU 2

ONU 1

ONU 2

ONU n

ONU n

OLT

ONU n

Optical Splitter

ONU1   ONU2   ONU n

Continuous mode signal

How to use FP-LD and DFB-LD

1550nm FP-LD transmission (example)

1500 nm Band transmission

ONU Transmitter Design

LD

Optical Output

Data → Pulse current driver | I_{mod}

Bias Cnt. → Bias current driver | I_{bias}

Temperature control

Feed forward type APC

Optical burst transmitter (example)

Input Data   Bit rate: 155.52Mb/s

Optical output

first bit reserved

Off-light level (less than −45dBm)

25ns/div
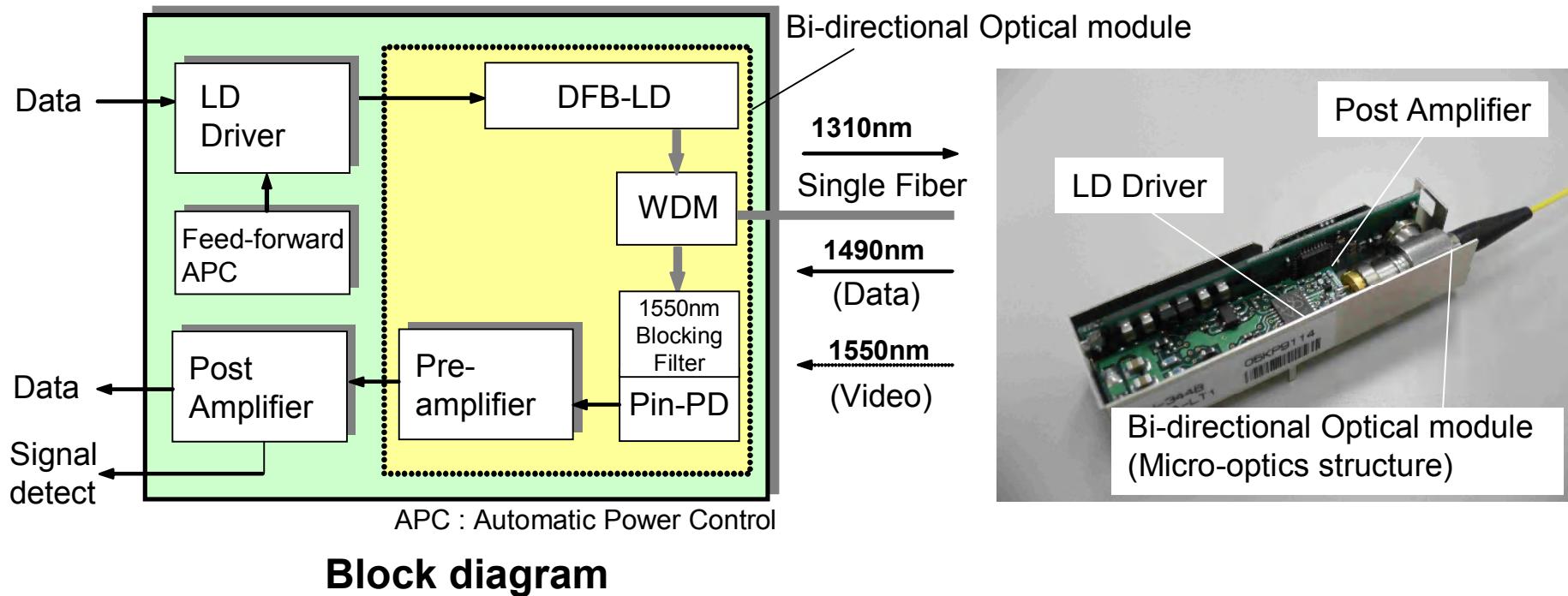
Optical burst waveform (example)

G-PON ONU Transceiver
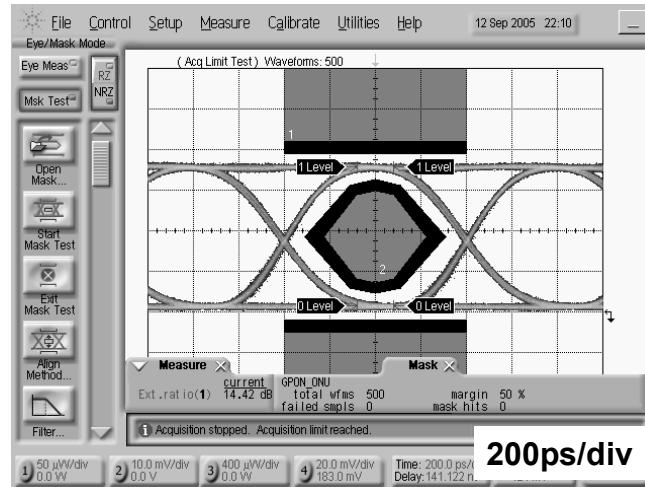
- Compact structure by Micro-optics
- 1.244Gbit/s burst-mode transmitter with feed-forward APC circuit
- 2.488Gbit/s continuous-mode receiver

Block diagram

APC : Automatic Power Control
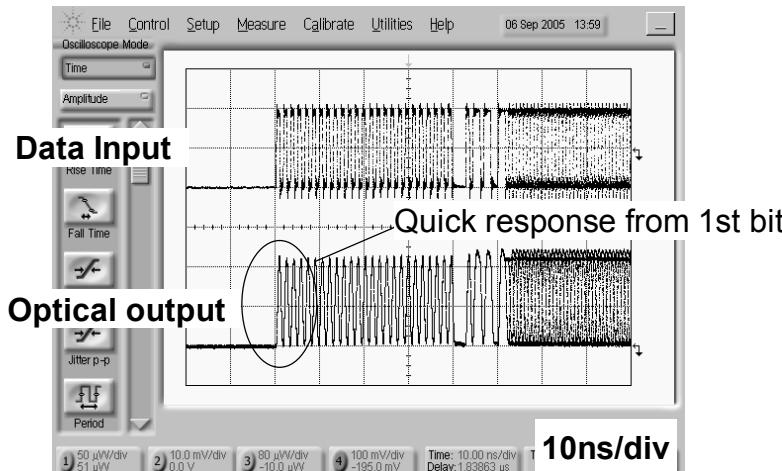
G-PON ONU Transceiver Operation
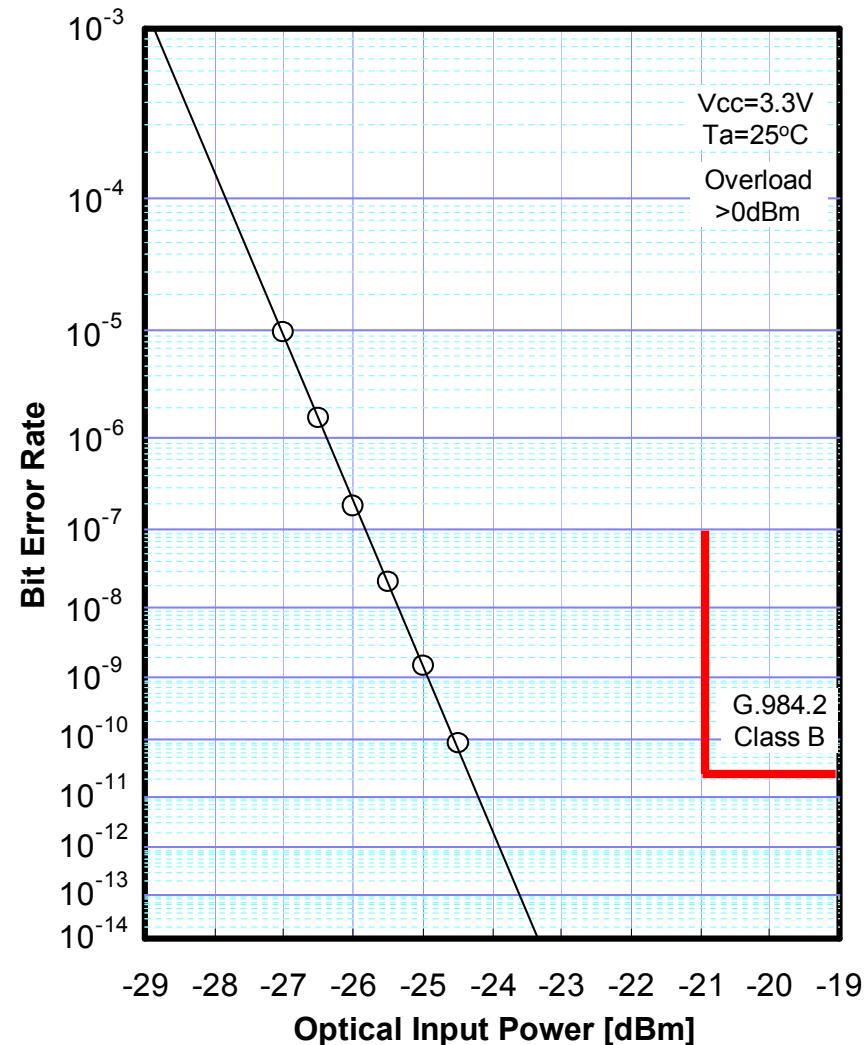
**Optical Eye Diagram (1.244Gbit/s)**
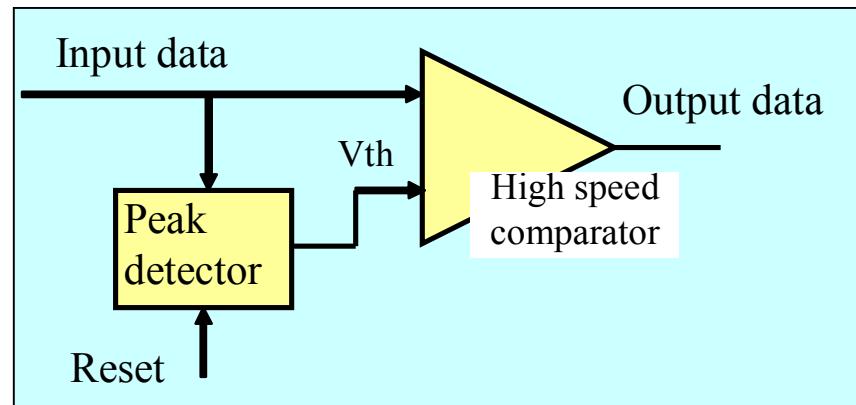
**Transmitter response of Burst-mode signal**
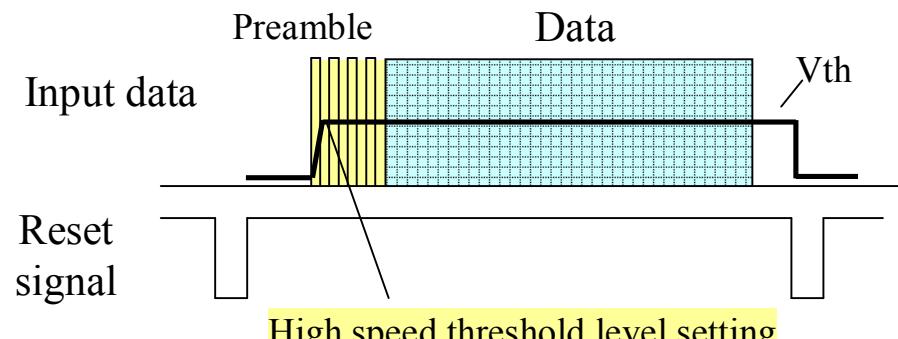

Receiver sensitivity

OLT Receiver ATC Design

Input data

Output data

Vth

High speed comparator

Peak detector

Reset

Block diagram of ATC

Preamble

Data

Input data

Vth

Reset signal

High speed threshold level setting

Response of ATC

ONT 1

ONT 2

ONT 3

Input data

Vth

1   2   3

Output data

ONT 1   ONT 2

Input data

Output data
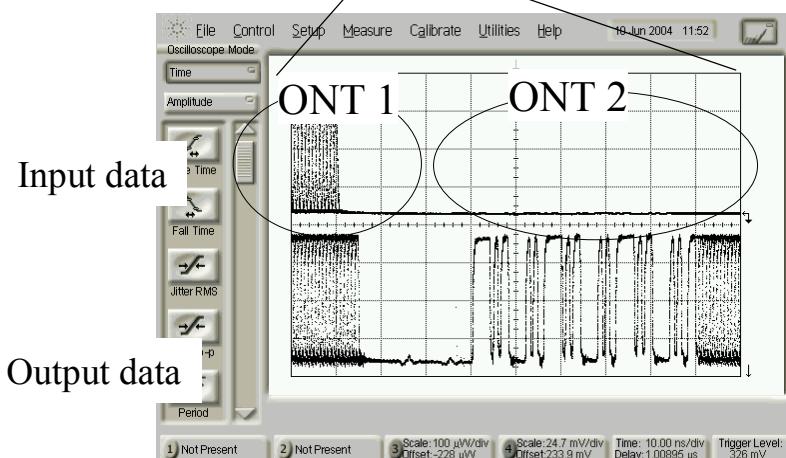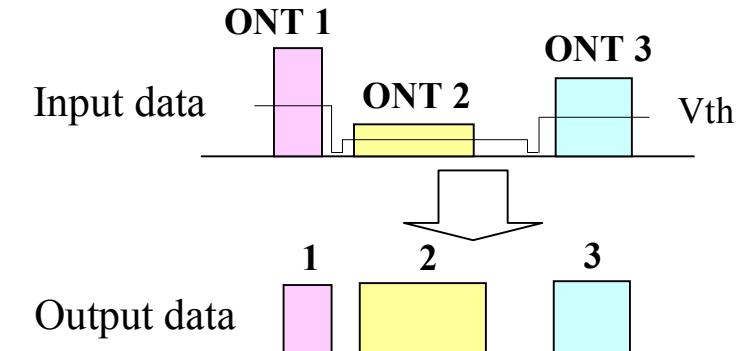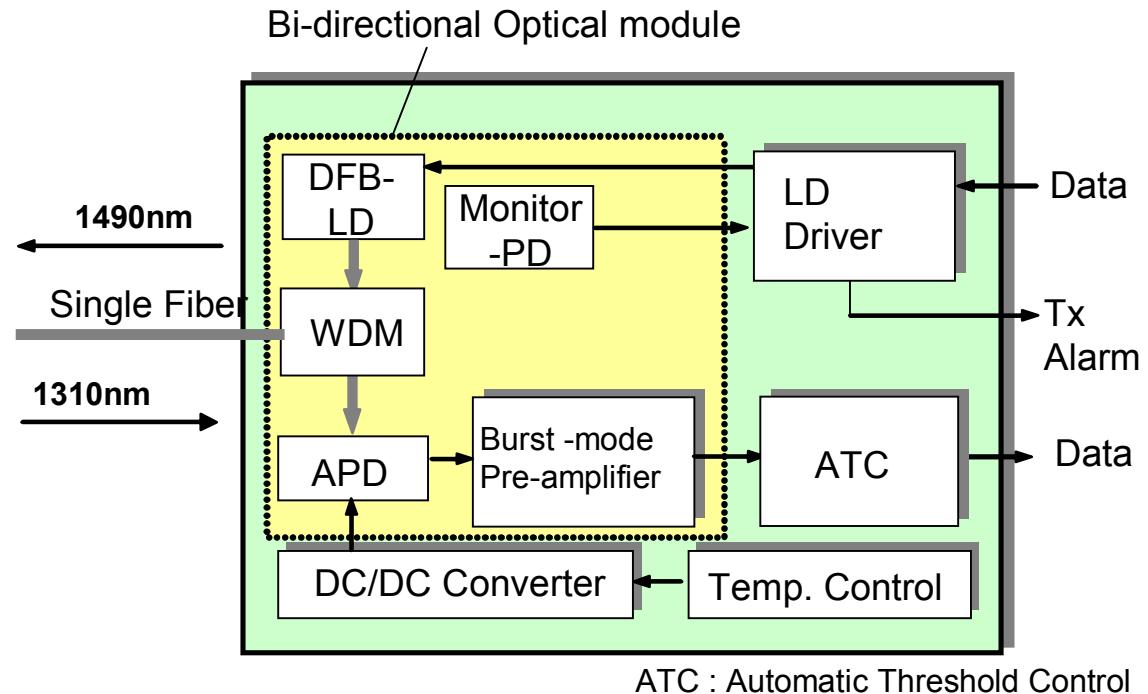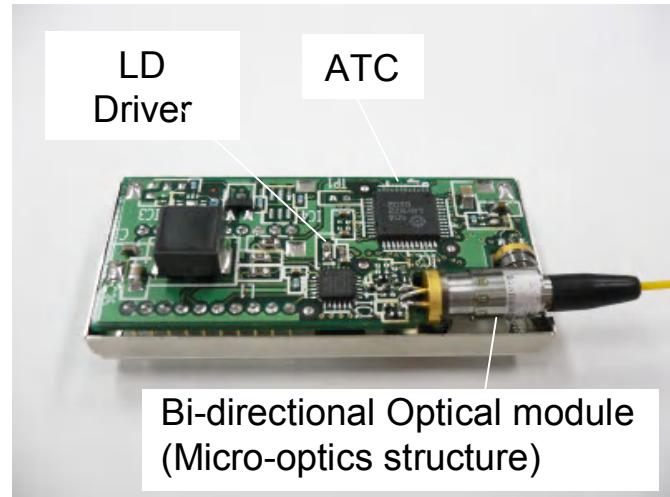
Example of Experimental response

G-PON OLT Transceiver
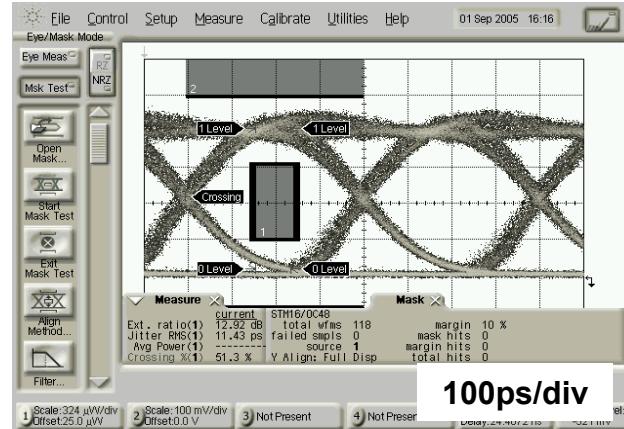
- Compact structure by Micro-optics
- 2.488Gbit/s continuous-mode transmitter using DFB-LD
- 1.244Gbit/s burst-mode receiver with high speed ATC circuit

LD Driver

ATC

Bi-directional Optical module
(Micro-optics structure)

Bi-directional Optical module

| DFB-LD | Monitor-PD | LD Driver | ← Data |

1490nm

Single Fiber

1310nm

WDM

APD → Burst-mode Pre-amplifier → ATC → Data

LD Driver → Tx Alarm

DC/DC Converter ← Temp. Control

ATC : Automatic Threshold Control
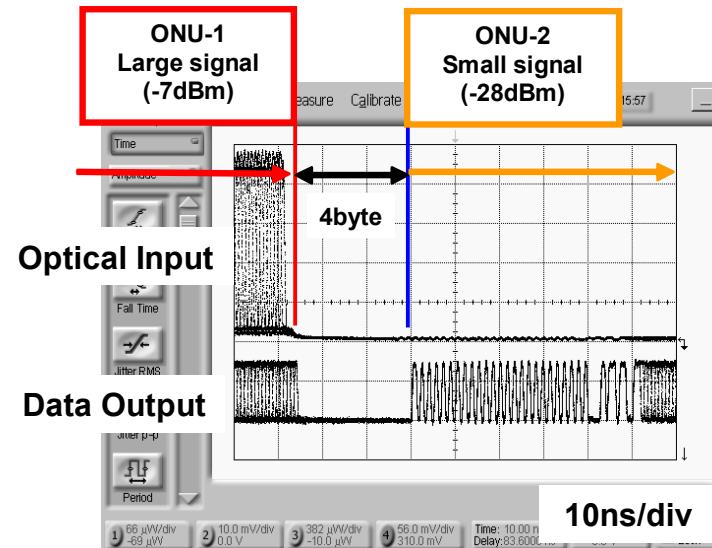
Block diagram

G-PON OLT Transceiver Operation
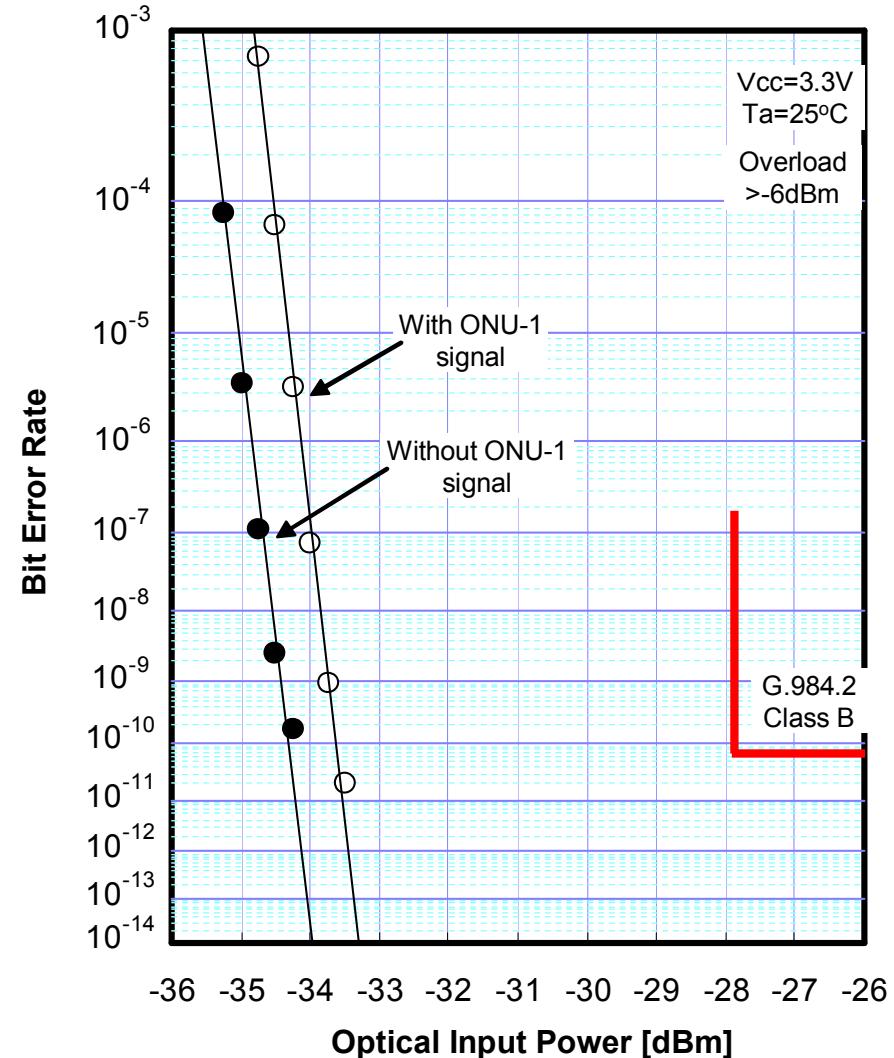

Optical Eye Diagram (2.488Gbit/s)
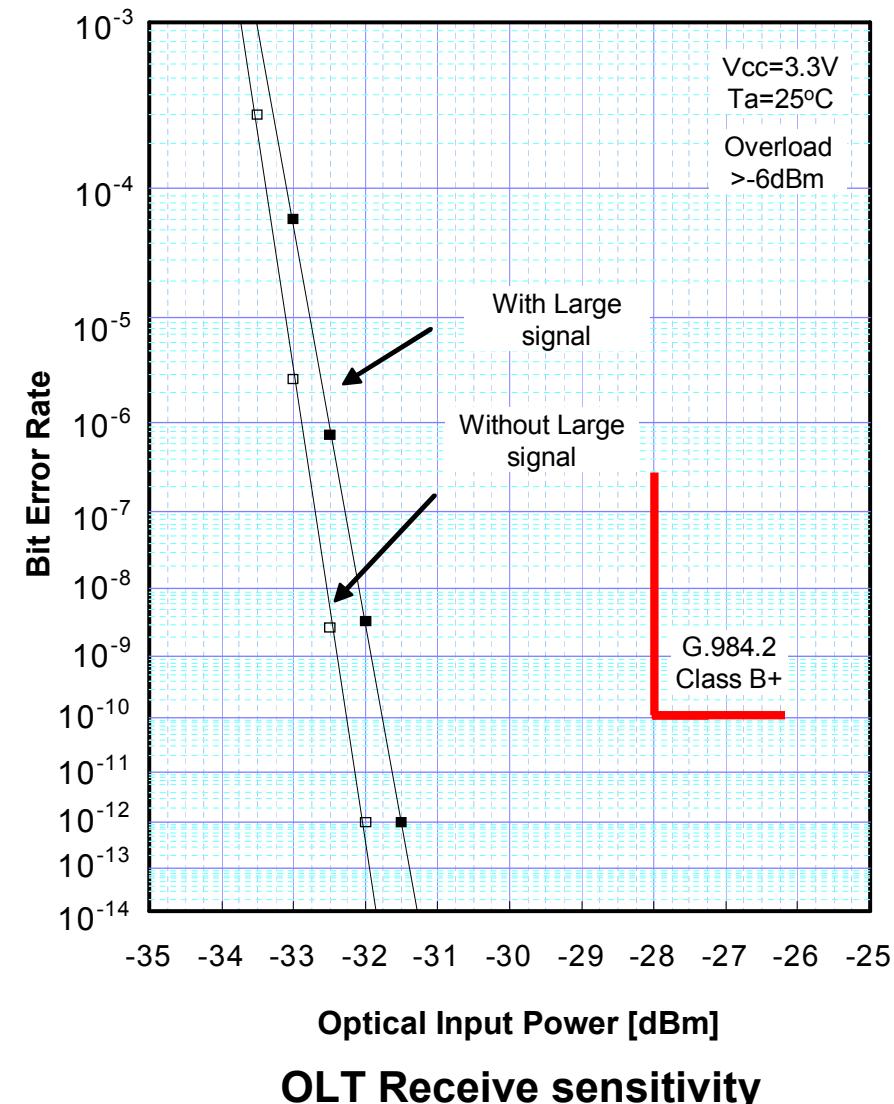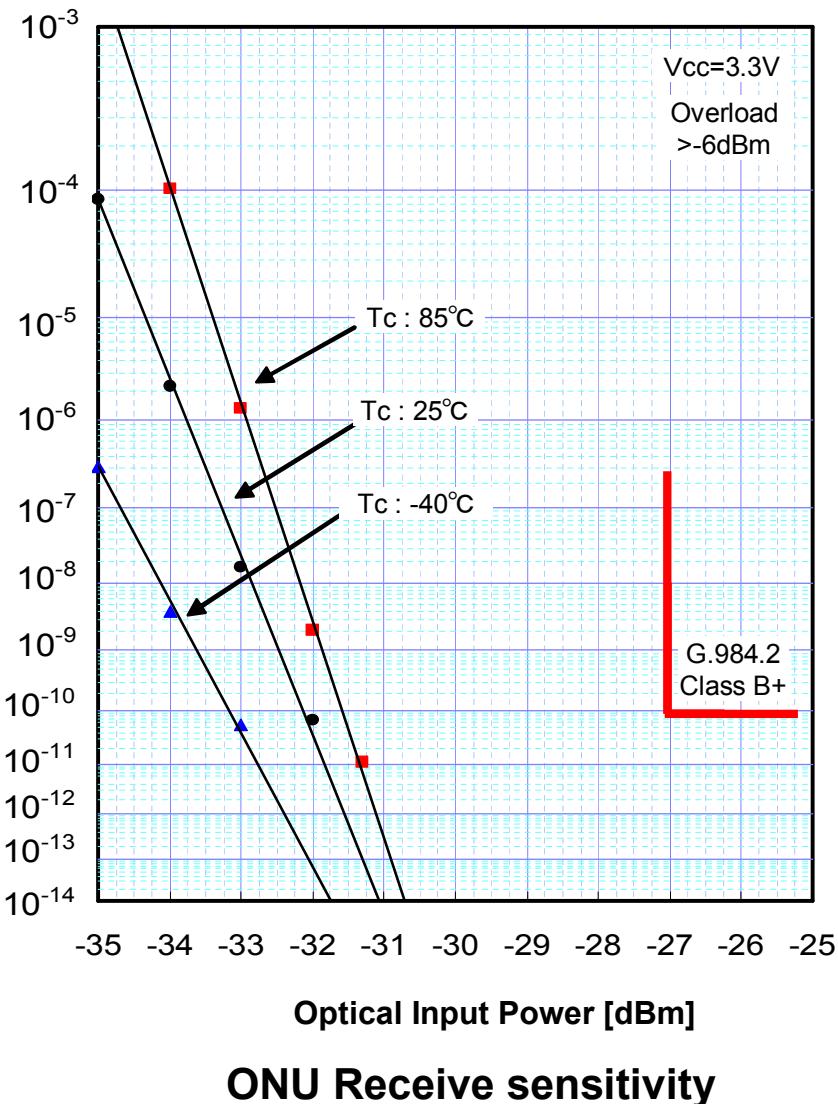

Burst-mode signal response

Receive sensitivity (@ONU-2 signal)
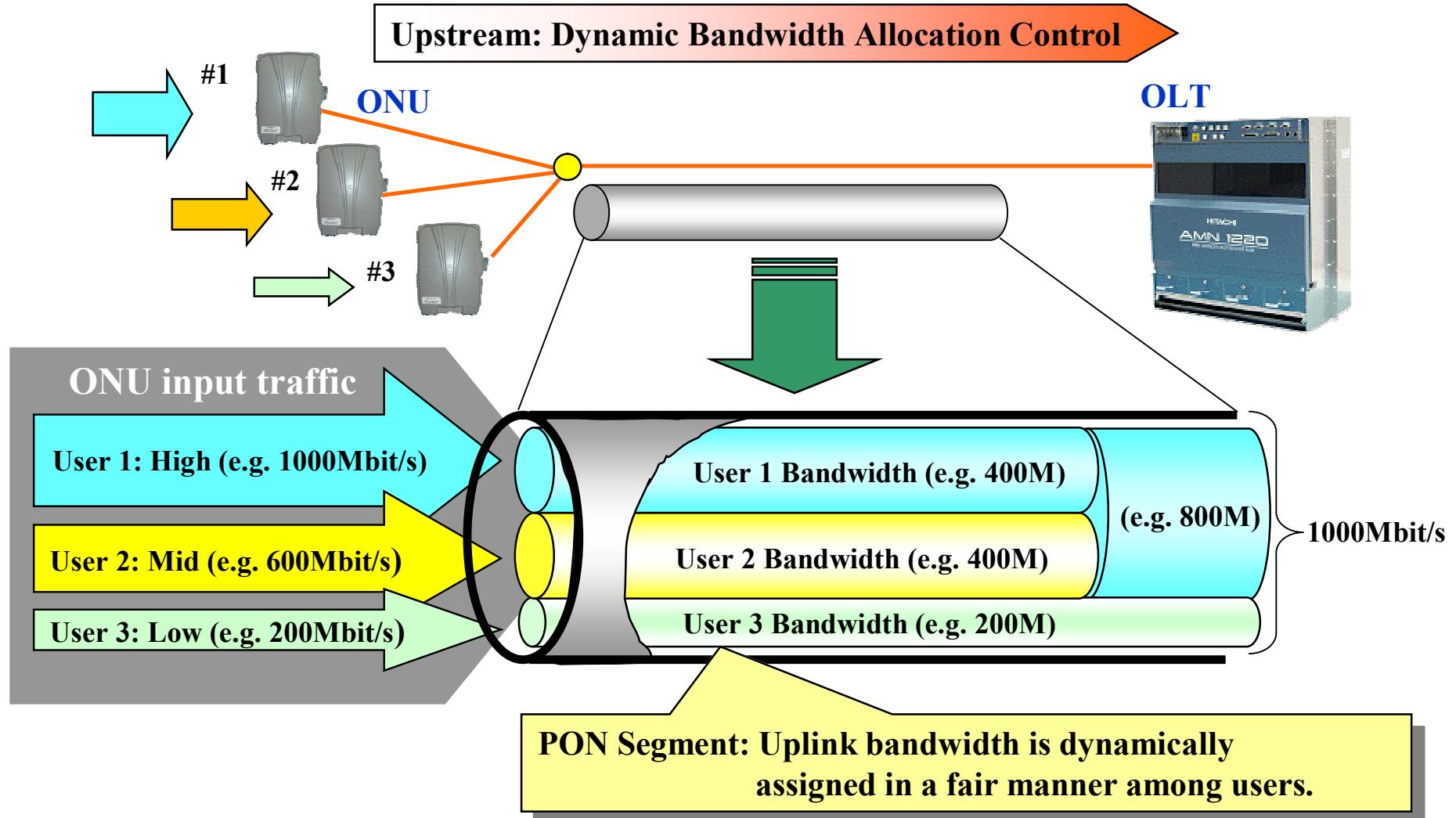
G-PON OLT/ONT Receiver (class B+)

ONU Receive sensitivity

OLT Receive sensitivity

DBA (Dynamic Bandwidth Assignment)

Upstream: Dynamic Bandwidth Allocation Control

#1

ONU

OLT

#2

#3

ONU input traffic

User 1: High (e.g. 1000Mbit/s)

User 2: Mid (e.g. 600Mbit/s)

User 3: Low (e.g. 200Mbit/s)

User 1 Bandwidth (e.g. 400M)

(e.g. 800M)

User 2 Bandwidth (e.g. 400M)

1000Mbit/s

User 3 Bandwidth (e.g. 200M)

PON Segment: Uplink bandwidth is dynamically assigned in a fair manner among users.
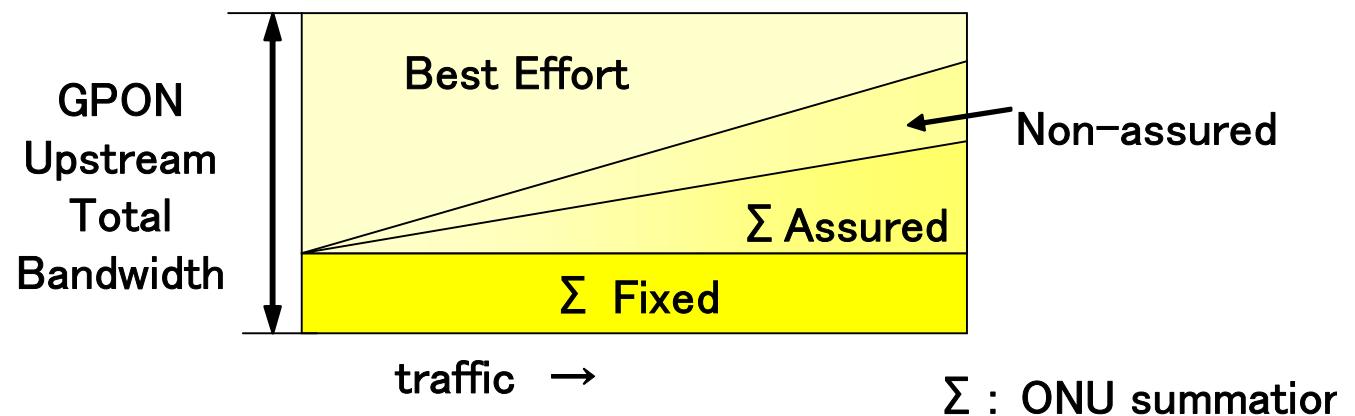
DBA Policy

| category	characteristics
Fixed Bandwidth	Always allocated to ONU independent of traffic request For delay/jitter sensitive services (e.g. TDM)
Assured Bandwidth	Allocated to ONU based on traffic request from ONU If not requested, allocated to other ONUs
Non Assured Bandwidth	Allacated after assured bandwidth Not guaranteed, and Proportion to assured BW
Best Effort Bandwidth	Allacated from surplus BW after non assured bandwidth Not guaranteed

BW configuration

Bandwidth parameters
(1)Fixed Bandwidth（FXB）
(2)Assured Bandwidth（ASB）
(3)Maximum Bandwidth（MAB）
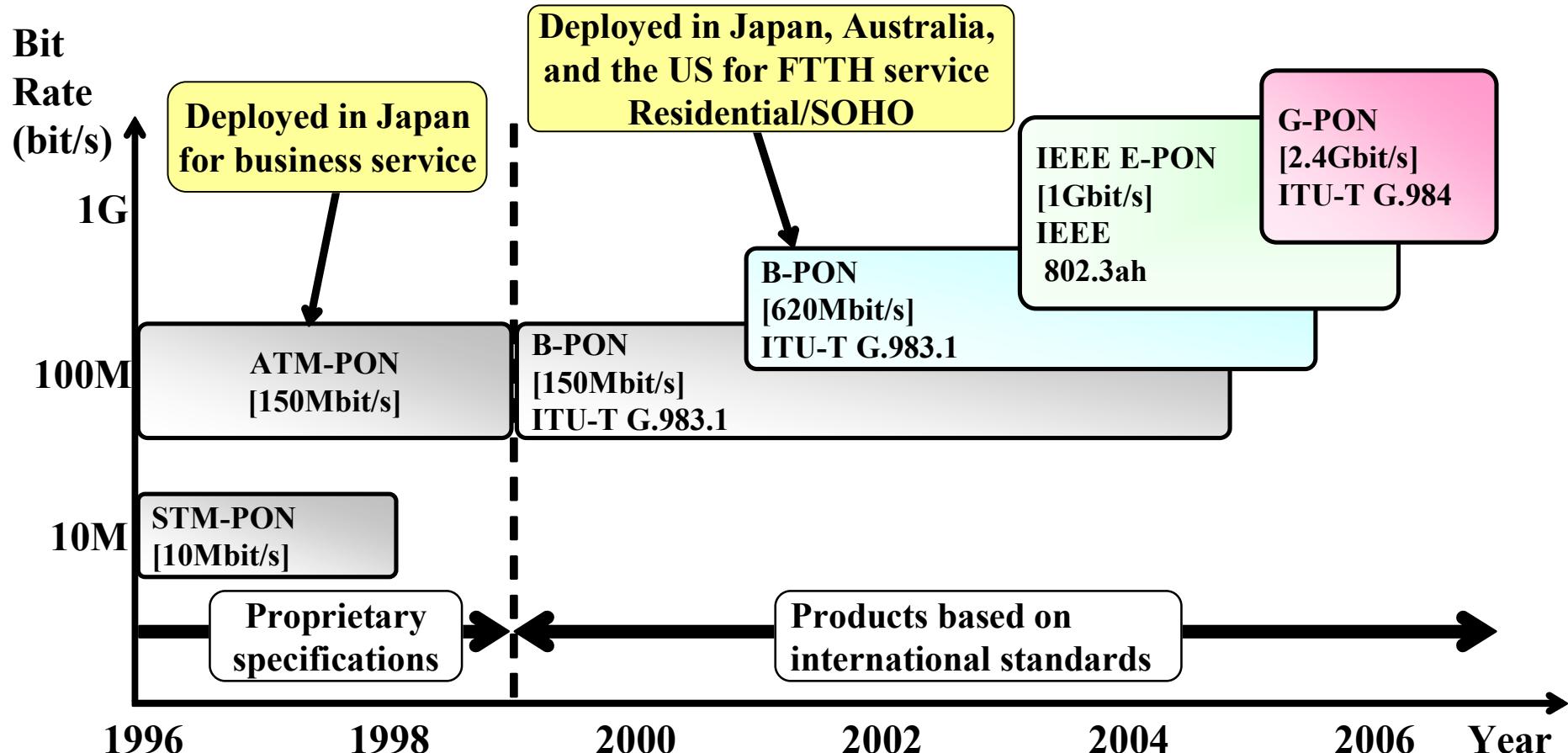
GPON
Upstream
Total
Bandwidth

Best Effort

Non-assured

Σ Assured

Σ Fixed

traffic →

Σ : ONU summatior

Contents
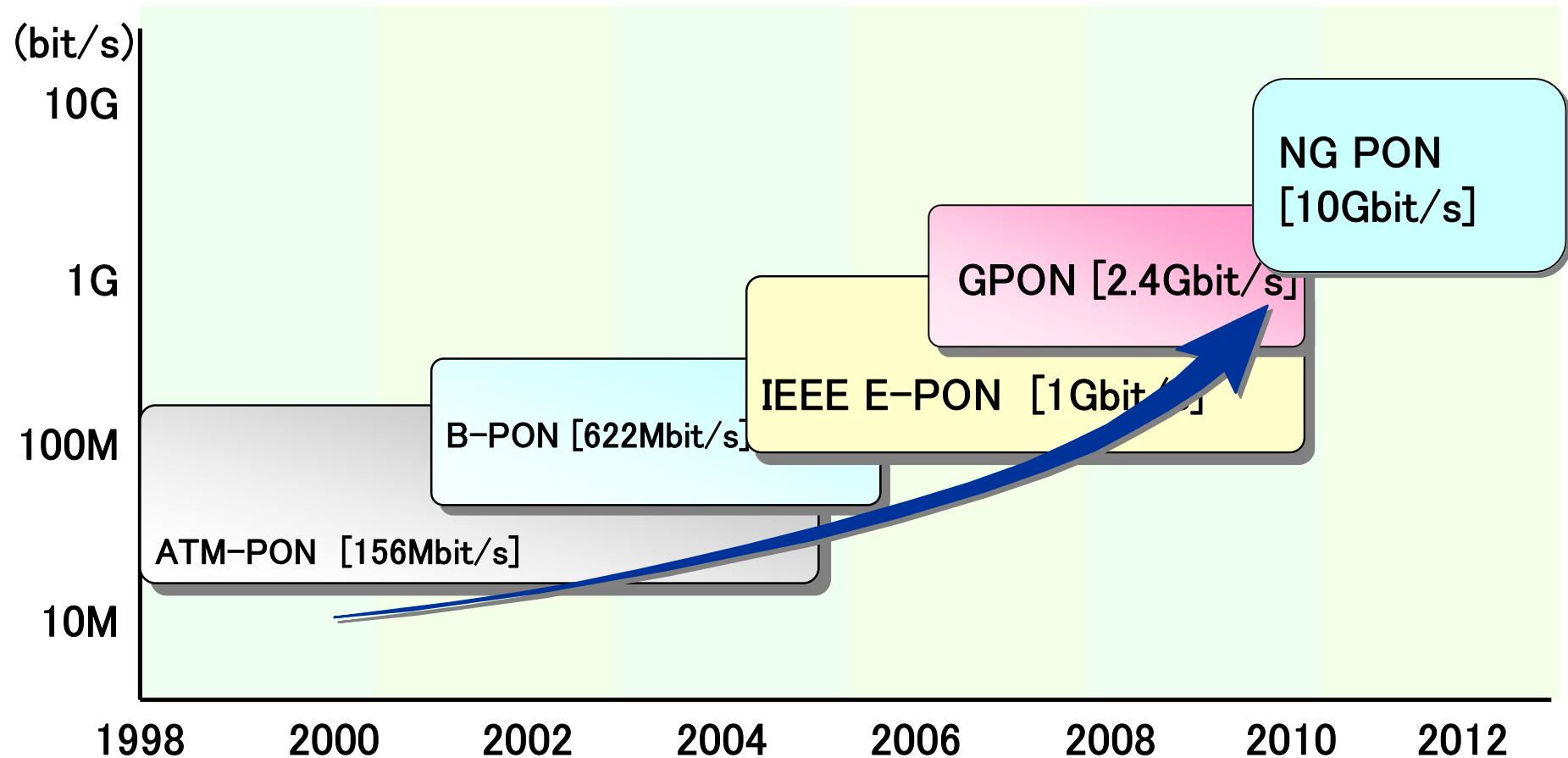
PON Roadmap

- From Business/specific use To FTTH.
- long (more than 8 years) development and continuous investment to PON

Bit Rate (bit/s)

Deployed in Japan for business service

Deployed in Japan, Australia, and the US for FTTH service Residential/SOHO

G-PON [2.4Gbit/s] ITU-T G.984

IEEE E-PON [1Gbit/s] IEEE 802.3ah

1G

B-PON [620Mbit/s] ITU-T G.983.1

ATM-PON [150Mbit/s]

B-PON [150Mbit/s] ITU-T G.983.1

100M

STM-PON [10Mbit/s]

10M

Proprietary specifications

Products based on international standards

1996   1998   2000   2002   2004   2006   Year

PON Roadmap 2

10G PON Requirements

- **Existing fiber plant** (Conventional SMF)
- Distance 20km
- **Loss budget** 29dB(class B+)

  e.g.
    - 20 km optical fiber (10dB loss at 0.5dB/km)
    - 1x32 optical split (more than 15dB)
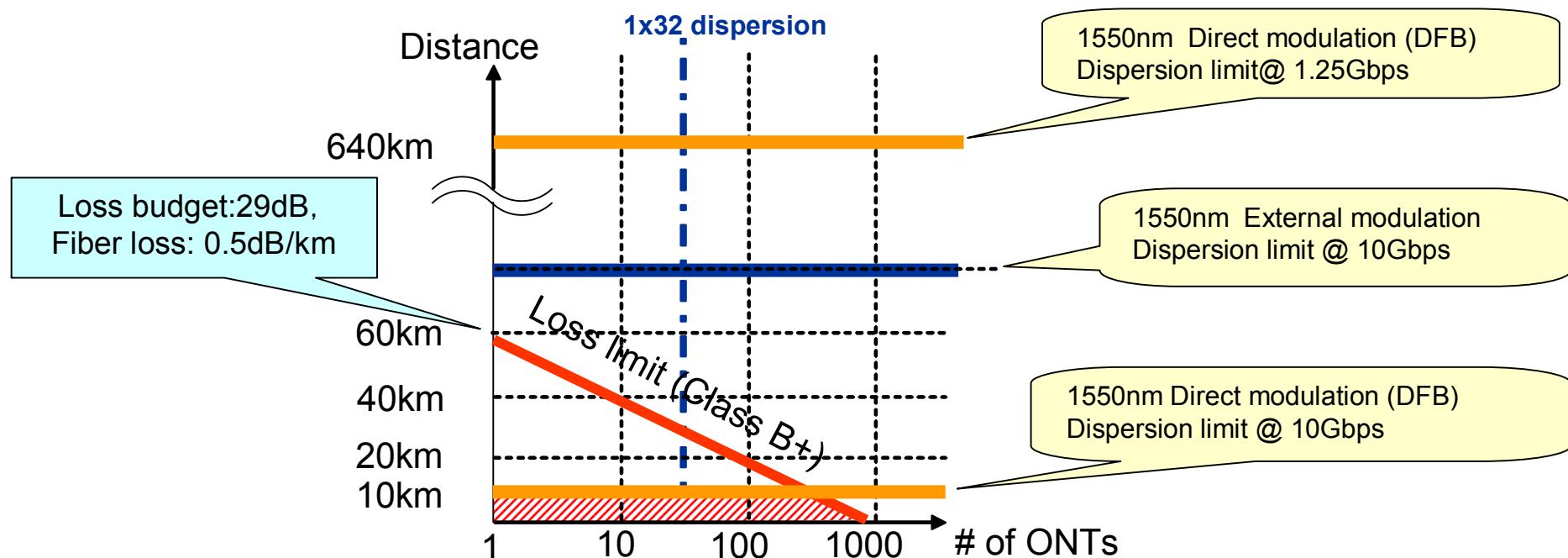
    →**study required on Optical power budget and dispersion**

Study item on 10G Optical Access

■ 64 x Impact of dispersion 10G vs 1.25G(Downstream)

■ Economical external modulator is required
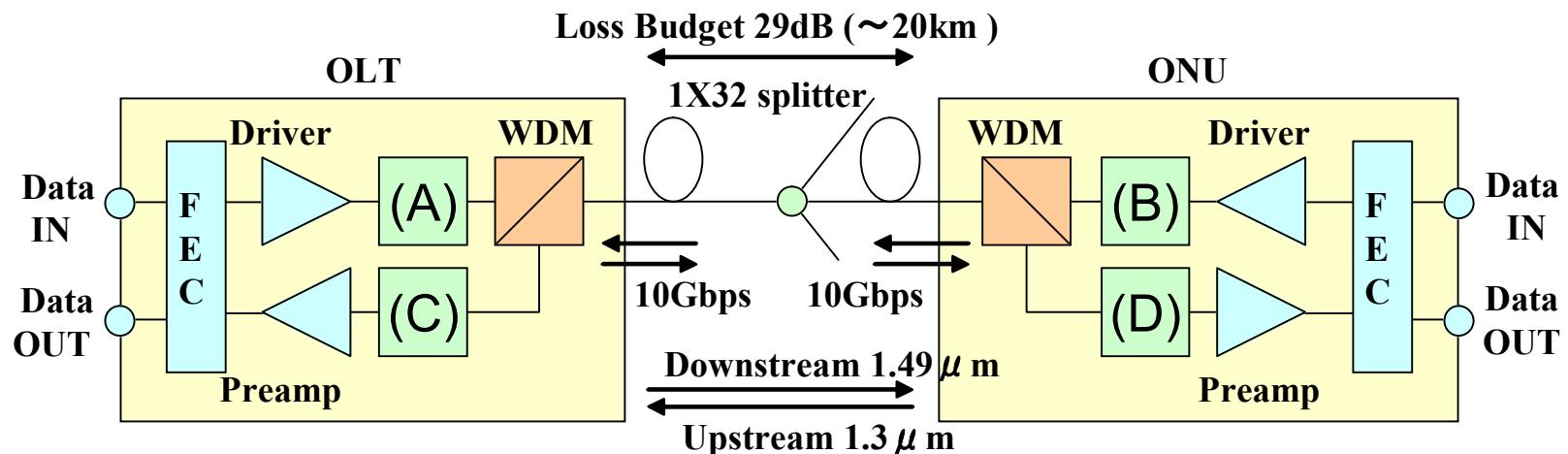
Correlation between dispersion in the ONT and transmission range (SMF)

Distance

1x32 dispersion

1550nm Direct modulation (DFB)
Dispersion limit@ 1.25Gbps

640km

Loss budget:29dB,
Fiber loss: 0.5dB/km

1550nm External modulation
Dispersion limit @ 10Gbps

60km

Loss limit (Class B+)

40km

1550nm Direct modulation (DFB)
Dispersion limit @ 10Gbps

20km

10km

1   10   100   1000   # of ONTs

10G TDM PON optical components

	Plan 1		Plan 2	
	OLT	ONU	OLT	ONU
Downstream: 1.49 μm	(A) EA-DFB →	(B) APD+FEC	EA-DFB +SOA →	PD+FEC
Upstream: 1.3 μm	(C) APD+FEC ←	(D) DFB	APD+FEC ←	DFB
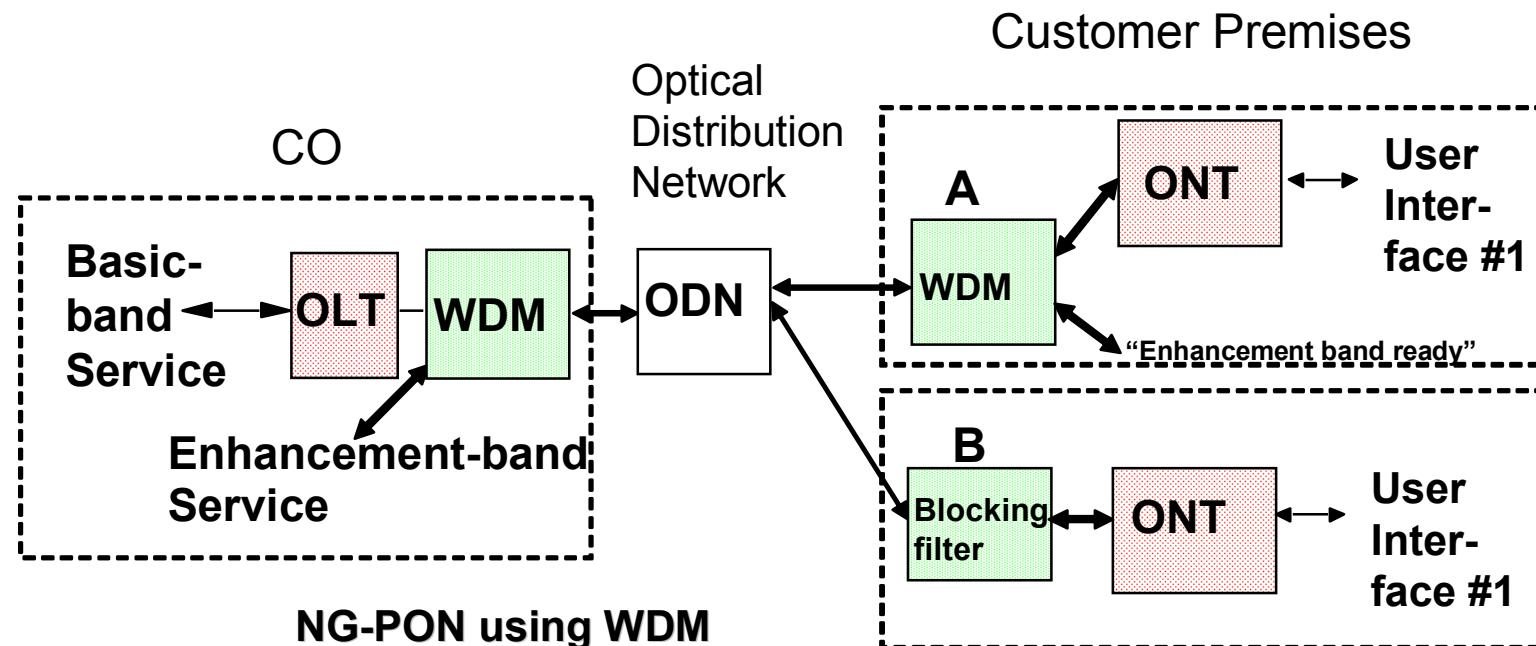
*1 QD-LD: quantum dot laser

Next Generation Access discussion in FSAN
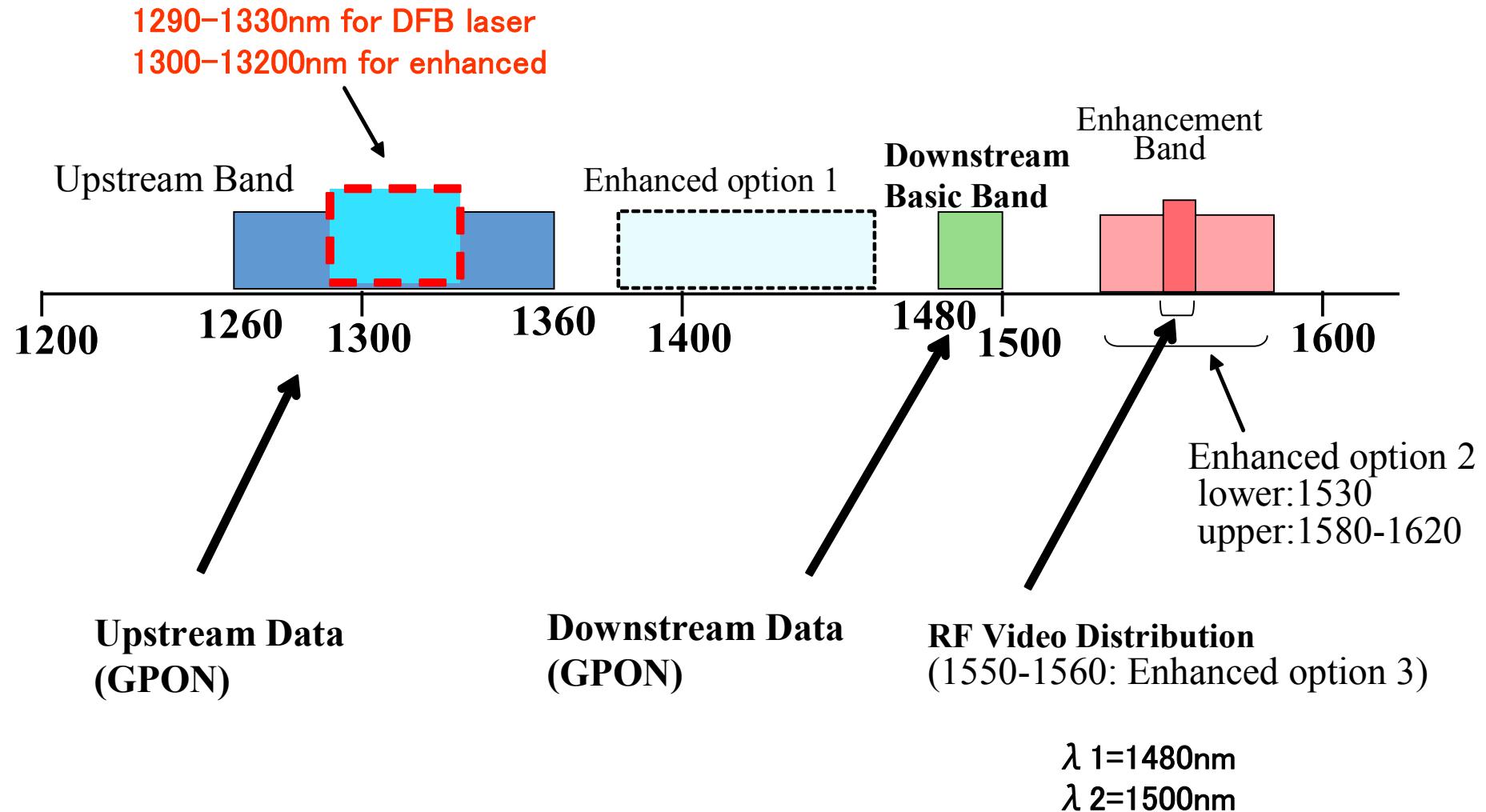
- **NGA(Next Generation Access) target**
  WDM-PON, 10G-PON, enhanced GPON
- **NGA should co-exist with existing PON by WDM**

Customer Premises

Optical Distribution Network

CO

Basic-band Service

OLT — WDM

Enhancement-band Service

ODN

A
WDM

ONT → User Inter-face #1

"Enhancement band ready"

B
Blocking filter — ONT → User Inter-face #1

NG-PON using WDM

PON Wavelength Plan Discussion

1290−1330nm for DFB laser
1300−13200nm for enhanced

Upstream Band

Enhanced option 1

Downstream Basic Band

Enhancement Band

1200   1260   1300   1360   1400   1480   1500   1600

Upstream Data (GPON)

Downstream Data (GPON)

RF Video Distribution (1550-1560: Enhanced option 3)

Enhanced option 2
lower:1530
upper:1580-1620

$\lambda 1 = 1480nm$
$\lambda 2 = 1500nm$

Based on ITU−T Recommendation G.984.enh discussion

Summary

- **G-PON for IP-TV deployment**

- **G-PON characteristics**

   Broadband, Multi-service, OAM, Interoperability

- **Next generation access(including 10G) will co-exist with G-PON**