Outline

- Introduction
- Telecom/datacom network concept
- Optical network concepts and architecture
  - Overview
  - Layers and protocol
  - (D)WDM network and wavelength routing
  - Optical switching
- Optical network deployment
  - Global
  - Fiber to the premise (home, business,...)
- Summary
WAN
Wide Area Network
Reti geografiche

MAN
Metropolitan Area Network
Reti metropolitane

LAN
Local Area Network
Reti locali
The first (last) mile: Fiber to the Home (FTTH) and FTTx
Recent news


The First Mile - Outline

- Introduction: the first/last mile bottleneck
- Evolution of FTTH considerations
- Network architecture and standards
- Enabling technologies
- The future: applications
Economies* with the Highest Penetration of Fibre-to-the-Home/Building + LAN

- **South Korea**
- **UAE**
- **Hong Kong**
- **Japan**
- **Taiwan**
- **Lithuania**
- **Norway**
- **Sweden**
- **Bulgaria**
- **Slovenia**
- **Latvia**
- **Russia**
- **USA**
- **Singapore**
- **Slovakia**
- **Denmark**
- **Estonia**
- **Portugal**
- **Hungary**
- **Netherlands**
- **China**
- **Malaysia**
- **Finland**
- **Ukraine**
- **Czech Republic**
- **France**
- **Turkey**
- **Italy**
- **Canada**
- **Romania**

**Household Penetration**

*Economies with at least 200,000 households

**Economies with greater than 1% household penetration**

- (blue) Fibre-to-the-Home subscribers
- (orange) Fibre-to-the-Building + LAN subscribers

December 2011 Ranking
Source: Fibre-to-the-Home Council
February 2012
The First Mile - Outline

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Access: Bottleneck & Brokers of Bandwidth

Optical Amplifiers (EDFAs)
DWDM (4, 8, 16, 40, 80, 96, 128, 256,…)
C + L band
100-50-25 GHz
S Band
Raman Amps
New Modulation Techniques
FTTH technical tutorial

Technical considerations - Speed

- Speed

- Required Data Rate

- Service

- VoIP

- Streaming audio

- Picture in 15 seconds

- SDTV

- HDTV

- DSL or cable modem

- FTTH

- VoIP

- Streaming audio

- Picture in 15 seconds

- SDTV

- HDTV

- DSL or cable modem
**FTTH technical tutorial**

**What is FTTH?**

**Old networks, optimized for voice**
24 kbps - 1.5 Mbps

- Copper
- Fiber

**Optical networks, optimized for voice, video and data**
19 Mbps - 1 Gbps +

Note: network may be aerial or underground
What use is all that bandwidth?
GREAT. SO NOW HOW DO WE ORDER A PIZZA?
Telecom market is redefining itself

Beyond voice – a fragmented market
The power of users

- **60 billion** online searches conducted worldwide in August 2007
- **45%** of US and European workers are away from their desk more than 20% of their time
- Over **8.6 million** articles and over **5.7 million** registered contributors on Wikipedia globally
- World of Warcraft, the subscription-based online game, has more than **10 million** players
- Global digital music sales reached **$3 billion** in 2007, half of the revenues came from mobile
- Over **3 billion** songs, 50 million TV episodes and 2 million Disney movies have been purchased and downloaded from iTunes
21st Century

Connected Home Entertainment Ecosystem

Source: Trends in Consumer Technology: Defining and Sizing the Market © 2006 Parks Associates

Source: Michael Lebby – US-OIDA
Han Le & Assoc
What do you Need Broadband for?

- Entertainment Center
- Monitor
- Wireless Pad
- Digital Picture Frame
- Internet Phone
- Smart Appliances
- Network Printer
- Internet Camera
- Telephone or Data Jacks
- Broadband Home Gateway

FTTH

E2E for under $1,000

- HD BUILT-IN
- DISCOVERY HD THEATER
LCD’s and FTTH...a parallel

Source: Paulo Dainese, Corning Optical Fiber
Larger Screens need Higher Definition

- 108 inch LCD 1080p HDTV now available - Larger screens under development
- Larger screens mean larger pixels and lower definition at the same distance
- Eventually Wall sized screens in multiple rooms of the home?
## Video Applications Consume Bandwidth...

<table>
<thead>
<tr>
<th>2D Video Format</th>
<th>Applications</th>
<th>Mb/s Native per stream</th>
<th>Mb/s (compressed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Definition (SD) 480p</td>
<td>DVD Digital Broadcast</td>
<td>249</td>
<td>4</td>
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<tr>
<td>High Definition (HD) 720p</td>
<td>HD Broadcast</td>
<td>1,493</td>
<td>16</td>
</tr>
<tr>
<td>Very High Definition (VHD) 1080p</td>
<td>HD-DVD Blue Ray Videoconferencing Camcorders</td>
<td>2,986</td>
<td>32</td>
</tr>
<tr>
<td>2160p</td>
<td>Super HD Large Screens</td>
<td>14,930</td>
<td>100</td>
</tr>
<tr>
<td>4320p</td>
<td>Ultra HD</td>
<td>59,720</td>
<td>400</td>
</tr>
</tbody>
</table>

Source: OFS Estimates from Industry Data

* Multiple streams/downloads/uploads will need 100 Mb/s – 1 Gb/s per unit symmetrical

3D Display Technology – Can drive > 1 Gb/s per video stream

One example

- 3D Volumetric Display with no moving parts
- 16” x 12” x 4” display with larger sizes (50”) possible
- 20 LCD screens stacked, each with 1024 x 768 resolution, higher resolution possible.
- This example enables viewer perception of 608 depth levels

Source: LightSpace Technologies Inc
Estimated minimum time to acquire Braveheart

<table>
<thead>
<tr>
<th>Technology</th>
<th>Minutes</th>
<th>Hours</th>
<th>Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modem 56 kb/s</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>ISDN 128 kb/s</td>
<td></td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>DSL 1 Mb/s</td>
<td></td>
<td>12</td>
<td>1.5</td>
</tr>
<tr>
<td>Cable 2.5 Mb/s</td>
<td>45</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>FTTH</td>
<td>0.4</td>
<td></td>
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</tbody>
</table>
The First Mile - Outline

- Introduction: the first/last mile bottleneck
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- The future: applications
## Service Requirements for Today & Tomorrow

<table>
<thead>
<tr>
<th>Application</th>
<th>Downstream</th>
<th>Upstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Streaming Audio</td>
<td>128K - 384K</td>
<td>64K</td>
</tr>
<tr>
<td>Internet Access</td>
<td>256K - 1.5M</td>
<td>64K - 640K</td>
</tr>
<tr>
<td>Telecommuting</td>
<td>1.5M - 3M</td>
<td>1.5M - 3M</td>
</tr>
<tr>
<td>Standard Video Conferencing</td>
<td>384K - 1.5M</td>
<td>384K - 1.5M</td>
</tr>
<tr>
<td>Distance Learning</td>
<td>384K - 1.5M</td>
<td>384K - 1.5M</td>
</tr>
<tr>
<td>Personal Telepresence – HD</td>
<td>1.5M - 10M</td>
<td>1.5M - 10M</td>
</tr>
<tr>
<td>Interactive Video</td>
<td>1.5M - 6M</td>
<td>128K - 6M</td>
</tr>
<tr>
<td>Video on Demand</td>
<td>1M - 18M</td>
<td>64K - 640K</td>
</tr>
<tr>
<td>Multiple Digital TV</td>
<td>2M - 8M</td>
<td>64K - 640K</td>
</tr>
<tr>
<td>HDTV/IPTV</td>
<td>6-18M</td>
<td>64K</td>
</tr>
<tr>
<td>Gaming</td>
<td>2-20M</td>
<td>64K – 20M</td>
</tr>
</tbody>
</table>
Technological evolution

<table>
<thead>
<tr>
<th>Dedicated Bandwidth</th>
<th>Active Optical</th>
<th>Passive Optical</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ethernet Point-to-Point</strong></td>
<td>Fast Ethernet Gigabit Ethernet</td>
<td>n* Fast Ethernet DWDM (n=32)</td>
</tr>
<tr>
<td>10 Gigabit Ethernet</td>
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<tr>
<td>(Active Ethernet) FTTB / FTTC</td>
<td>Gigabit Ethernet backhaul</td>
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**PON Standardization Roadmap**

**Capacity**

- **NG-PON1**
  - XG-PON1 10/2.5 G
  - XG-PON2 10/10 G (*)

- **NG-PON2**
  - TWDM, WDM
  - [TDM, OFDM (+)]

**Key Requirements**
- 40/10 G aggregate
- 1 Gbit/s per sub
- 40 km passive reach
- >64 subs (1000)
- Re-use of OSP
- Coexistence

---

**Ref.:**
- FSAN / ITU-T G.984
- IEEE 802.3ah
- G.987
- 802.3av

(*) Not a standard

(+ No longer considered

OSP: Outside Plant
FTTH technical tutorial

What is FTTH?

- “An OAN in which the ONU is on or within the customer’s premise. Although the first installed capacity of a FTTH network varies, the upgrade capacity of a FTTH network exceeds all other transmission media.”
  - OAN: Optical Access Network
  - ONU: Optical Network Unit
  - OLT: Optical Line Termination

Source: www.ftthcouncil.org
FTTH technical tutorial

Why FTTH?

- Enormous information carrying capacity
- Easily upgradeable
- Ease of installation
- Allows fully symmetric services
- Reduced operations and maintenance costs
- Benefits of optical fiber:
  - Very long distances
  - Strong, flexible, and reliable
  - Allows small diameter and light weight cables
  - Secure
  - Immune to electromagnetic interference (EMI)
FTTH technical tutorial

Why FTTH? - more capacity*

* Typical system capability for 100 m link

Source: Corning Incorporated
FTTH technical tutorial

Why FTTH? - longer distances*

* Typical distance for 1 Gbps system capability

Source: Corning Incorporated
FTTH technical tutorial

Why FTTH? - symmetric services

- Outbound Internet bursting to 80Mbps
- Inbound Internet (download) averaging about 35-40Mbps
- Upstream is consistently twice the download

Source: Grant County Public Utility District
Bitrate vs. Reach for Last Mile Technologies

[Graph showing bitrates vs. distance for various technologies, including GigabitEthernet, FastEthernet, GPON aggregate, GPON per user, ADSL, ADSL2+, VDSL, Cable aggregate, Cable per user, WiMax aggregate, WiMax per user, PLC aggregate, and PLC per user.]
Passive Optical Networks (PONs)
- Shares fiber optic strands for a portion of the networks distribution
- Uses optical splitters to separate and aggregate the signal
- Power required only at the ends

Active Node
- Subscribers have a dedicated fiber optic strand
- Many use active (powered) nodes to manage signal distribution

Hybrid PONs
- Literal combination of an Active and a PON architecture
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FTTH technical tutorial

Architectures – PON (A-, E- or G-)

Usually 10-20 km

OLT

Optical splitter
1x16 (1x2, 1x8)
1x32 (1x4, 1x8)

ONU
FTTH technical tutorial
Architectures – PON (2) (A-, E- or G-)

OLT

1550 nm broadcast (if used)

1490* nm data

1310 nm data

ONU

* Data may be transmitted at 1550 nm if not used for video
FTTH technical tutorial

Architectures – Active Node

OLT

Processing (powered)

Up to 70 km

Up to 10 km

ONU
FTTH technical tutorial

Architectures – Active Node (2)

OLT

1550 nm broadcast (if used)

Data, 1310 or 1550 nm (depending on distance) on separate fibers
FTTH technical tutorial

Architectures – Hybrid PON

OLT

Optical splitter

Processing (powered)

Optical splitter

Up to 70 km

Up to 10 km

ONU
Single fiber, 1550 broadcast, 1310 bidirectional data

Data, 1310 or 1550 nm (depending on distance) on separate fibers
FTTH provides greater bandwidth capacity and transmission speeds.

- **APON** – 622/155* Mbps (1:32 shared) - legacy
- **BPON** – 622/622* Mbps (1:32 shared) - legacy
- **GPON** – 2.5/1.2 Gbps to 2.5/2.5* Gbps (1:64 shared)
- **EPON** – 10/100* Mbps (1:32 shared)
- **GE-PON** - 1/1Gbps* (up to 1:128)
- **10G-EPON** – 10/10Gbps & 10/1Gbps*
- **P2P** – 100/1000 Mbps (non-shared)
- **WDM-PON** – 1.2-10Gbps/1.2-10Gbps
- **Hybrid** – varies by vendor
- **RFoG**- RF over Fiber (rates: Spectrum Avail- DOCSIS)

*The upstream data rates are shared*
Standards References

- FTTx employs clearly defined and widely used standards for both P2P and PON including:
  - Full Service Access Network (FSAN)
  - ITU-T G.983 (BPON), G.984 (GPON)
- Ethernet in the First Mile (EFM):
  - IEEE 802.3ah (Published Sept. 2004)
PON Architecture - FSAN Standard (ITU G.983)

OLT (Optical Line Terminal)
- Voice & Data
- Downstream 1490 nm
- Upstream 1310 nm

Optical Couplers (WDM)
- Voice/Data & Video
- 1490nm/1310nm, 1550nm

ONT (Optical Network Terminal)
- Video
- Data
- POTS
- (AAL5)(AAL2)

Bandwidths & Services
- Upstream 1310 nm
  - Voice and Data @ 155 to 622 Mbps
- Downstream 1490 nm
  - Voice and Data at 622 Mbps
- Downstream 1550 nm
  - Video

Frequency Ranges:
- 42 MHz: Analog TV
- 550 MHz: Digital TV
- 860 MHz: HD/VID
EPON Architecture - IEEE Standard (802.3ah)

OLT (Optical Line Terminal)
- Voice & Data Downstream 1490 nm
- Upstream 1310 nm

Optical Couplers (WDM)
- Voice/Data & Video 1490nm/1310nm, 1550nm
- Optical Splitter
- 1x32 Or Cascade

ONT (Optical Network Terminal)
- Video (λ)
- Data (IP)
- POTS (VOIP)

Bandwidths & Services
- Upstream 1310 nm: Voice and Data @ 1Gbps
- Downstream 1490 nm: Voice and Data at 1Gbps
- Downstream 1550 nm: Video
- Frequency Bands: 42 MHz Analog TV, 550 MHz Digital TV, 860 MHz HD/VID

Video
IEEE 802.3ah – Ethernet in the First Mile
PON Standards

BPON – ITU G.983.3 – Published (FSAN group)
- 622 Mb/s or 155 Mb/s downstream. 155 Mb/s upstream.
- 20 KM reach ATM Protocol
- Up to 32 users share one fiber

GPON – ITU G.984.2 - Published
- 2.4 or 1.2 Gb/s downstream, 155 Mb/s, 622 Mb/s, 1.2 Gb/s, or 2.4 Gb/s upstream.
- 20 KM reach
- Can use ATM or Ethernet Protocol Up to 64 users share one fiber
PON Standards

Ethernet - PON and Point to Point – IEEE 802.3ah, 2004
- EPON – 10/100/1000 Mb/s upstream and downstream, 16 – 32 users per PON
- Point to Point – 100 Mb/s and 1 Gb/s up to 20 KM distances

RFoG
- SCTE RFoG Specification is currently in development
- FTTH solution for traditional cable operators
- Method to deploy HFC services over fiber optics
  - DOCSIS VoIP and DOCSIS data
  - RF video (analog and digital QAMs)
  - Billing and operations support remain the same
  - Service provisioning is just like HFC
  - Supports switched digital video and existing VOD
  - Keep narrowcast service groups
Technological evolution

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<tr>
<td></td>
<td>n * 10 Gigabit Ethernet DWDM (n=32)</td>
</tr>
</tbody>
</table>

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<th>Shared Bandwidth</th>
<th>(Active Ethernet) FTTB / FTTC</th>
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</tr>
</tbody>
</table>

RFOG
Example excerpted from

Rob Bond
Telcordia
rbond@telcordia.com
### TDM PON Example

- **Downstream** – TDM transmission with multiple “listeners” (encryption to insure privacy)
- **Upstream** – TDMA transmission with upstream transmissions (bursts) scheduled to prevent overlap

**Downstream** (single-fiber systems):
- 1490 nm

**Upstream**:
- 1310 nm
- 1555 nm

- **E1/DS1**
- **GigE**
- **STMn/OCn**

**Access Node**
- **CC**
- **NB**
- **BB**

**OLT**
- **TDM**

**ONT1**
- **Data**
- **VOIP**

**ONT2**
- **E1/T1/Telephony**
- **Video**

**ONT32**
- **POTS**
- **Data**

**1:32 Optical splitter**
- (or 1:64 for shorter reaches or with Reach Extender)

- **Up to 60 km* physical reach**
  - (* with G.984.6 Reach Extender)

**PONs are (in some sense) like HFC systems – shared medium**
**Downstream Format:**

Tframe @ 155.52 Mbps = 56 cells of 53 bytes = 152.67 us

Capacity Downstream = 155.52 Mbps x 54/56 = 149.97 Mbps
PLOAM cells contain 53 Grants, 12 Message fields, Sync, CRC

**Upstream Format:**

Tframe @ 155.52Mb/s = 53 cells of 56 bytes = 152.67us

Capacity Upstream = 155.52 Mbps x 53/56 = 149.19 Mbps

= 3 Overhead bytes per Cell, 4 bit Guard, 20 bits Preamble and Delimiter
Example of WDM-PON

**Hybrid WDM-PON example**

*“Fixed” optics might be a cost reduced version of convention DWDM long-haul optics*

**NOTE:** Most believe adaptable optics will be required for a practical WDM-PON system

**Colorless ONTs:** Transmitter and Receiver front-end filter characteristics are wavelength adaptable
Today’s PON Systems

- **TDM-PONs Rule:** The vast majority of PON systems deployed today are TDM-based PON systems (i.e., B-PON, E-PON, and G-PON)
  - They almost exclusively operate on a single fiber, with WDM used to provide bi-directional transmission
  - A third wavelength in the downstream is sometimes used for broadcast video services (e.g., Verizon FiOS)
- **WDM-PON:** Very limited deploys, mainly in Korea
  - Costs of WDM-PON in delivering mass market dedicated wavelength services are still higher high relative to TDM-PON
  - WDM and hybrid WDM-PONs are expected to play a greater role in Next Generation (NG) PON systems (e.g., 5+ years) than today
- Shared fiber from OLT to the remote node splitter
- Lower duct space requirements/ cost of lease
Single feeder fiber from CO to remote node – duct space needs similar to GPON
• RFoG is architecturally **agnostic**
  - PON version – all electronics in HE or Hub (similar to B/GE/GPON)
  - Hybrid PON version – actives in the field (short PONs)
• Three main splitting strategies
  - Home run
  - Centralized
  - Distributed
• 28dB required to match existing and future xPONs
RFOG Migration Path?

- Achieving a 28dB link budget and using 1610nm for the return wavelength ensures RFOG has a migration path to another type of xPON solution.
FTTH Technologies E-FTTH

Future proof, with no bandwidth limit, higher security, flexibility & resiliency

However, needs one fiber per subscriber
Level 2: MAC Layer Connectivity

Central Office Active
Outside Fiber Plant
Street Cabinet
Household

WDM-PON
Ethernet P2P
EPON/GPON

Building Fiber-to-the-Home Communities Together
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A single copper pair is capable of carrying 6 phone calls.

A single fiber pair is capable of carrying over 2.5 million simultaneous phone calls (64 channels at 2.5 Gb/s).

A fiber optic cable with the same information-carrying capacity (bandwidth) as a comparable copper cable is less than 1% of both the size and weight.

Source: Corning Incorporated
There are two laser technologies that are used for nearly all single mode communications applications:

- **Fabry-Perot (F-P) lasers**
  - Lower in cost, lower in power
  - Poorer wavelength stability

- **Distributed Feedback (DFB) lasers**
  - Higher cost, higher power
  - Excellent wavelength stability
  - Excellent temperature stability
    - Internally modulated
      - Good for moderate powers and distances
    - Externally modulated
      - Ultimate today for quality in broadcast applications

- **Vertical Cavity Surface Emitting Lasers (VCSELs)**
  - Coming technology, promises lowest costs
FTTH technical tutorial

Types of lasers used

- Wavelengths used for Single Mode Fiber (long distances) communications
  - 1310 nm
    - Usually lowest cost lasers
    - Used for shorter broadcast runs and short to moderate data runs
  - 1550 nm
    - Can be amplified with relatively low-cost erbium doped fiber amplifiers (EDFAs)
    - Lasers are fabricated on a number of different wavelengths (about 1535 – 1600 nm) for wave division multiplexing (WDM) applications
      - Slightly lower fiber loss at 1550 nm
  - 1490 nm
    - Increasingly popular for downstream data in 3λ systems.
      - Cannot be amplified as easily
      - Somewhat higher device cost
Figure 2  Block diagram of transceiver module for ONU.

Figure 3  Photo of SFF transceiver module for ONU.

Figure 4  Block diagram of transceiver module for OLT.

Figure 5  Photo of transceiver module for OLT.
Figure 6  Structure of OSA for ONU transceiver.

Figure 7  Photo of OSA for ONU transceiver.

Figure 8  Cross-sections of OSA.

Figure 9  Cross-sections of V-groove alignment on silicon substrate (left) and omega groove of plastic mold (right).
Figure 10  WDM filter vapor-deposited on the facet of angle-polished fiber.

Figure 11  Characteristic of the short wavelength pass filter (SWPF) on a 30° polished fiber facet.

Figure 12  Structure of SSP-PLC.

Figure 13  Calculated result of coupling loss between fiber and LD and SSC-PLC.
Figure 16 Schematic diagram of OSA for OLT transceiver.

Figure 17 OSA for OLT transceiver.

Figure 19 Eye diagram of ONU transceiver in burst mode operation.
Figure 20  Bit error rate of ONU transceiver.

Figure 23  Bit error rate of OLT transceiver.
Fused or Fused Biconical Taper (FBT)
A fused coupler is a structure formed by the joining of two independent optical fibers (Figure 2). The claddings of the fibers are fused in a small region. FBT devices work as a result of an energy transfer by coupling proximity between optical fiber cores.

![Diagram of Fused coupler technology](image)

*Figure 2: Fused coupler technology*
Figures 3 and 4: FBT couplers
- Single window: 1310 or 1550 nm operating wavelength window (Figure 5)
- Single window, wavelength flattened coupler:
  1310 ± 40 or 1550 ± 40 nm wavelength window (Figure 6)
- Dual window or wideband: 1310 ± 40 and 1550 ± 40 nm (Figure 7)
Planar Splitter or Planar Lightwave Circuit (PLC)
The second type of splitter is made up of a bulk integrated optical circuit assembled with an input and an output fiber array device. (Figure 10).

![Figure 10: Planar splitter sub-assembling parts](image)

The power split is achieved by a Y-junction (see Figure 11) fabricated inside the bulk material using photolithography techniques similar to the procedures used in the semiconductor industry.

![Figure 11: Planar splitter general design](image)
Figure 12: Photolithography mask
Figure 16: REM picture of waveguide after mask lift off

Figure 17: REM picture of waveguide after upper cladding deposition
Figure 20: Fiber arrays

Figure 21: Packaged planar splitters
New Technology
Bend Insensitive Fiber – Enables fiber to reach inside homes and apartments

- Bend Capable Optical Cable - No Conduit or bend radius management required
- Can be stapled using traditional fast, low skill copper cable practice
- Up to 500 times lower bending loss than conventional fiber: 0.1 dB maximum loss at 5 mm radius single turn (1550 nm)
- Splicing/Connector mounting with Conventional Process

35 quarter turns, 25 staples
Key Cost Considerations for FTTH Splitter Management

Centralized in Cabinets
- Typically Lowest cost for up to 50% take rate
- Enables efficient pay as grow CO electronics provisioning
- Some can provide modular and simplified upgrade path

Distributed in closures
- Lowest cost for > 50% take rate, can save up to $100/HP
- Enables efficient pay as grow CO electronics provisioning

In the CO/Head End
- Typically lowest cost for < ~1 KM distances from CO/HE
- Enables efficient pay as grow CO electronics provisioning
Key Cost Considerations for FTTH

Pieces of the OSP Puzzle – Must work together for 40 years

- CO/Head End
- Feeder
- Fiber Distribution Point
- Distribution
- Drop

Bend Optimized, Low Loss Connectivity, indoor cable, video and splitter modules

Buried/Aerial/ADSS/Micro Cables
Dry Technology

Splitter Cabinets and Modules, Splitters in Closures Bend Optimized and Low Loss

Buried/Aerial/ADSS/Micro Cables
Dry Technology

Buried/Aerial/ADSS/Micro Cables
Dry Technology

Drop Cables MDU Plug and Play Systems

Full Spectrum, Low loss, Bend Optimized Optical Path

Building Fiber-to-the-Home Communities Together

Choosing the Right FTTH Technology 12_10_08 JEG
Cost comparison 40/10G NG-PON2 (year 2015)

Effective cost per subscriber (16 ONU connected per OLT)

Ref.: E. Harstead et al., Alcatel-Lucent

Larger uncertainties for higher risk technologies

(*) Self-seeded PON used as example case
(+) Asymmetrical OFDM PON used as example case

Volumes:
• OLT = 10k
• ONU = 100k

Peter Vetter — Bell Labs, Alcatel-Lucent
ECOC, Amsterdam, September 18th, 2012
The First Mile - Outline

- Introduction: the first/last mile bottleneck
- Evolution of FTTH considerations
- Network architecture and standards
- Enabling technologies
- The future: applications
Services Transformable Through FTTH

Few are new – all could be vastly improved with FTTH

- Teleworking
- Telemedicine
- Entertainment
- Social Video
- Distance Learning
- Videophones
- Gaming
Services Transformable Through FTTH

Video Telephony and Video Mail

Video Teleconferencing

- non-FTTH
  - 0.3 – 1 Mb/s upstream limits resolution and motion

- FTTH
  - 2 – 10 Mb/s upstream enables full HD resolution and motion
  - 100 – 1000 Mb/s for future higher definition and 3D video

Video mail becomes feasible

- 2 minute VHD 1080p video clip
  - non-FTTH: 10 / 1
    - Download: 3 min
    - Upload: 30 min
  - FTTH: 50 / 10
    - Download: 40 sec
    - Upload: 3 min

Disney Oct 07
메가TV 은행업무 서비스

TV 리모콘 사용으로 인터넷뱅킹

메가TV 셋톱박스의 USB단자에 연결하여 사용하실 수 있습니다.
Services Transformable Through FTTH Teleworking

- Face time?
  - Videophone face time
    - Big Screen and in VHD

- Productivity solution
  - Videophone face time
  - Video conferencing
  - File sharing and e-mail at in-Office LAN Speeds

<table>
<thead>
<tr>
<th>Data Rate (Mb/s typical)</th>
<th>Office Worker on LAN</th>
<th>Teleworker at home (HFC / DSL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downstream</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>Upstream</td>
<td>100</td>
<td>1</td>
</tr>
</tbody>
</table>

Source: VSGI
### Teleworking - Transformable Through FTTH

<table>
<thead>
<tr>
<th>Teleworking Benefits Projection</th>
<th>2006 Baseline</th>
<th>Fiber Enabled Projection</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>USA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teleworkers (%)</td>
<td>11.0%</td>
<td>35.0%</td>
</tr>
<tr>
<td>Teleworkers (M)</td>
<td>16.0</td>
<td>50.8</td>
</tr>
<tr>
<td>Avg days/week</td>
<td>1.6</td>
<td>2.6</td>
</tr>
</tbody>
</table>

| Incremental over 2006 baseline  |               |                          |
| Productivity Improvement/yr ($M)| $ 156,097     |                          |
| Fuel Savings/yr ($M)            | $ 14,647      |                          |
| Business Travel savings/yr ($M)| $ 34,000      |                          |

**TOTAL ANNUAL BENEFIT ($M)**

- $204,744

- **$4000 per teleworker annual benefit**
- **2% increase in GDP**

*Estimated and Projected
Additional Teleworking Benefits

- Greenhouse gas output reduced by about 56M tons/year
- Lower dependency on foreign oil imports by about 5%
- Fuel efficiency increases though reduced traffic
- Less road maintenance and construction
- Reduced office space requirements
- More flexibility and less stress
Health Care - Transformable Through FTTH

US Health Care Costs
- $2 Trillion annually
- Growing 4%/yr above inflation

<table>
<thead>
<tr>
<th>Videotelemedicine</th>
<th>$B hypothetical savings</th>
<th>2005 Expenditure</th>
<th>10% Savings</th>
<th>Savings opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physician and Clinical</td>
<td>$420</td>
<td>$42</td>
<td></td>
<td>Virtual Dr appts at home</td>
</tr>
<tr>
<td>Nursing Home Care</td>
<td>$120</td>
<td>$12</td>
<td></td>
<td>At home monitoring vs institution</td>
</tr>
<tr>
<td>Home Health Care</td>
<td>$40</td>
<td>$4</td>
<td></td>
<td>Fewer visits from health practitioner</td>
</tr>
<tr>
<td>Total</td>
<td>$580</td>
<td>$58</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FTTH Bandwidth Enabled Telemedicine Tools
- VDH (1080p) videophone links, super fast file downloads/uploads
  - Health care practitioner to Patients
  - Remote diagnostics of large files (XRay, MRI, etc)
Services Transformable Through FTTH

Total Annual Revenues:
Internet Video Services (Ad-supported and User-paid)
(Millions of Dollars, U.S. Households)

Source: Internet Video: Direct-to-Consumer Services
© 2006 Parks Associates
Online Movies: $35B market possible at FTTH Speeds?

- In 2011 total of $1.3B for online movies
  - Only 4% share of $35B combined US and W. European Home Movie Markets
- FTTH bandwidths could dramatically grow online movie share.
Online Movie Distribution

Inhibitors and Enablers for growth

- Lack of connectivity from PC to Large Monitors in the Home
  - Solutions: multi-room set-tops, in-home connectivity over existing cables, etc

- Online movie downloads currently bandwidth inhibited

<table>
<thead>
<tr>
<th>2 hour HD-DVD download time</th>
<th>Data Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>480 minutes (8 hrs)</td>
<td>4 Mb/s</td>
</tr>
<tr>
<td>100 minutes (&lt; 2 Hrs)</td>
<td>20 Mb/s</td>
</tr>
<tr>
<td>20 minutes</td>
<td>100 Mb/s</td>
</tr>
<tr>
<td>2 minutes</td>
<td>1,000 Mb/s</td>
</tr>
</tbody>
</table>

Choosing the Right FTTH Technology 12_10_08 JEG
Building Fiber-to-the-Home Communities Together
Improved Economy, Quality of Life, and Business Case

- Home Values increased $4,500 (RVA data)
  - Homebuyers already value FTTH with only 7% of homes passed
- Attract and retain businesses
  - Improved business efficiencies, sales, and marketing.
- Productivity and Quality of Life
  - The true “virtual office” and teleworking enabled by HD and later 3D video meetings and collaboration. Improved and lower cost education and health care
  - Distance learning
  - Distance medicine
  - Entertainment and video networking
- Greater revenue potential for the same cost as other options