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HUT Communications Laboratory

S-72.3340 Optical Networks Course

Lecture 10: Deployment Considerations

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Lecture Outline

- Introduction
- Network hierarchies
  - Global, backbone, metro, local access networks
- Rights-of-way
- Fiber deployment options
- Miscellaneous networks
- Conclusion

1. Introduction

- Optical networks are now widely deployed in different environments
- Special considerations have to be taken when deploying network infrastructure
  - Environmental conditions
  - Security
  - Support facilities
  - Cost
  - Demand
  - Legal considerations

2. Network Hierarchies

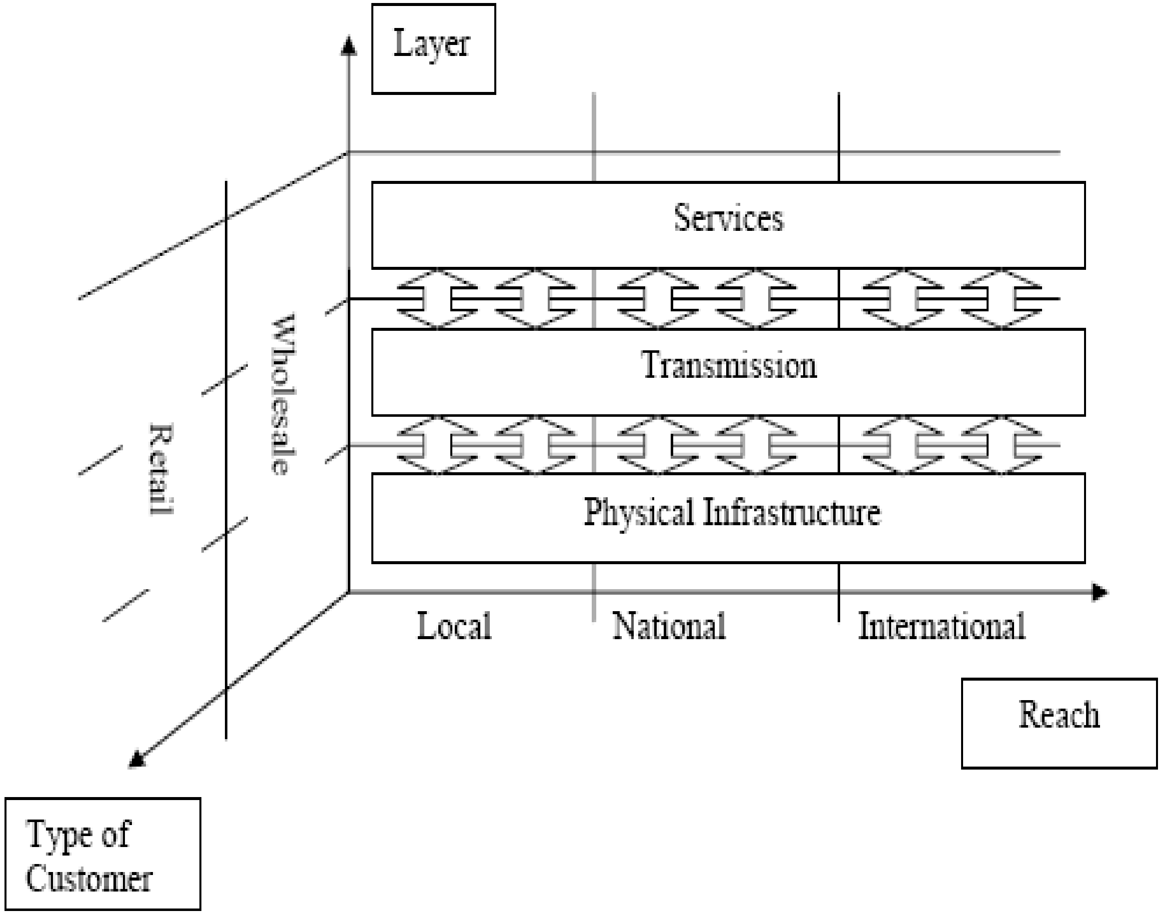


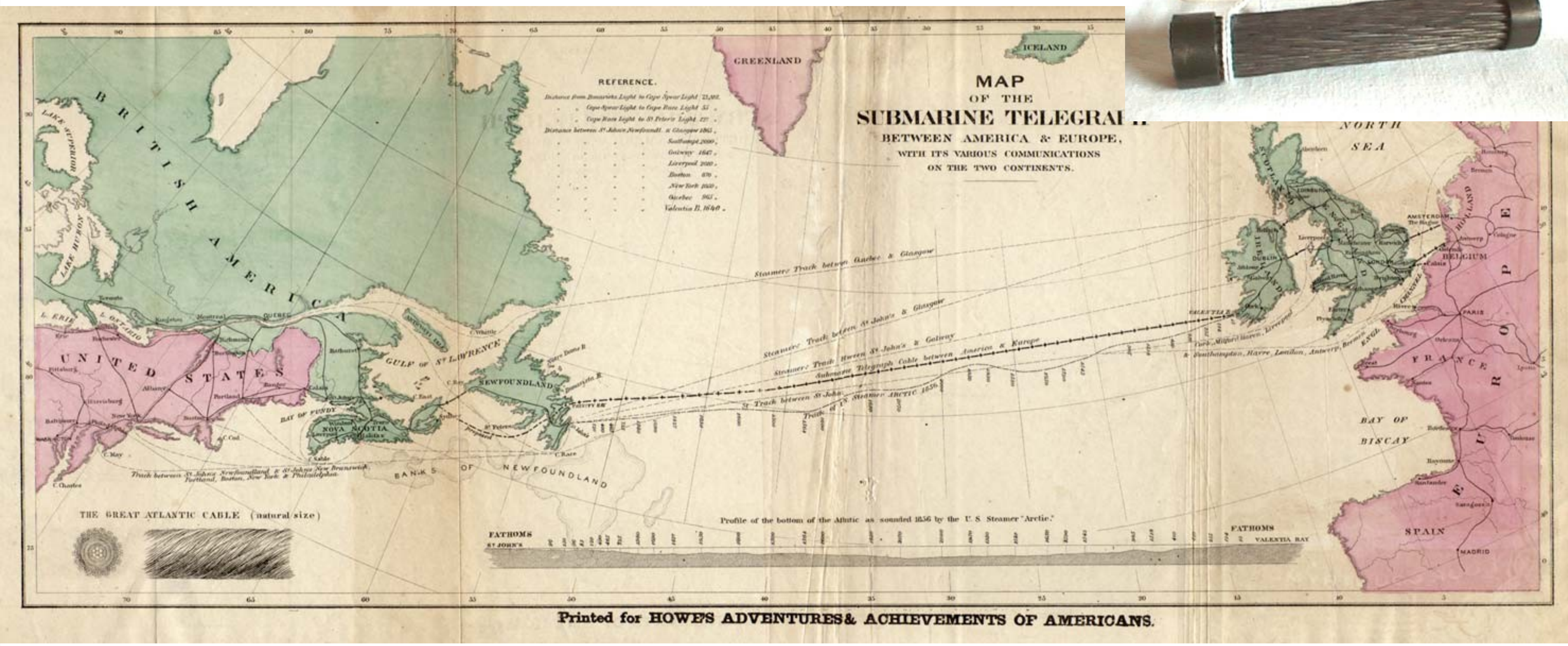
Figure: 3-D representation of the Layered Networks model.

2.1 Intercontinental Optical Networks

- About 70% of earth's surface covered by water bodies
- For intercontinental (global) connectivity communication links must traverse water bodies
  - Overhead in the sky via orbiting satellites
  - Underwater using "submarine cables"

2.1 Intercontinental Optical Networks

- First submarine (copper) cable (1856-1920)
  - Between Newfoundland and Ireland
  - Telegraph connectivity



2.1 Intercontinental Optical Networks

- First transatlantic (TAT-1) coaxial cable (1956-1978)
  - Between Canada and UK
  - Carried up to 48 voice circuits
- Last (TAT-7) coaxial cable [1978-1994]
  - Between USA and UK
  - Carried up to 10500 voice circuits

Figure: Cross-sectional view of the TAT-1 cable 1956
(Source: National Museum of American History)

2.1 Intercontinental Optical Networks

- First transatlantic (TAT-8) fiber cable (1988-2002)
  - Between USA and France
  - Standard singlemode fibers
  - 1300 nm wavelength window
  - Electrical regenerators
  - Carried up to 40000 voice circuits (550 Mb/s aggregate capacity)
  - Expected to be filled by 2000, instead got filled up by 1990!

Figure: TAT-8 cable 1988 (Source: National Museum of American History)

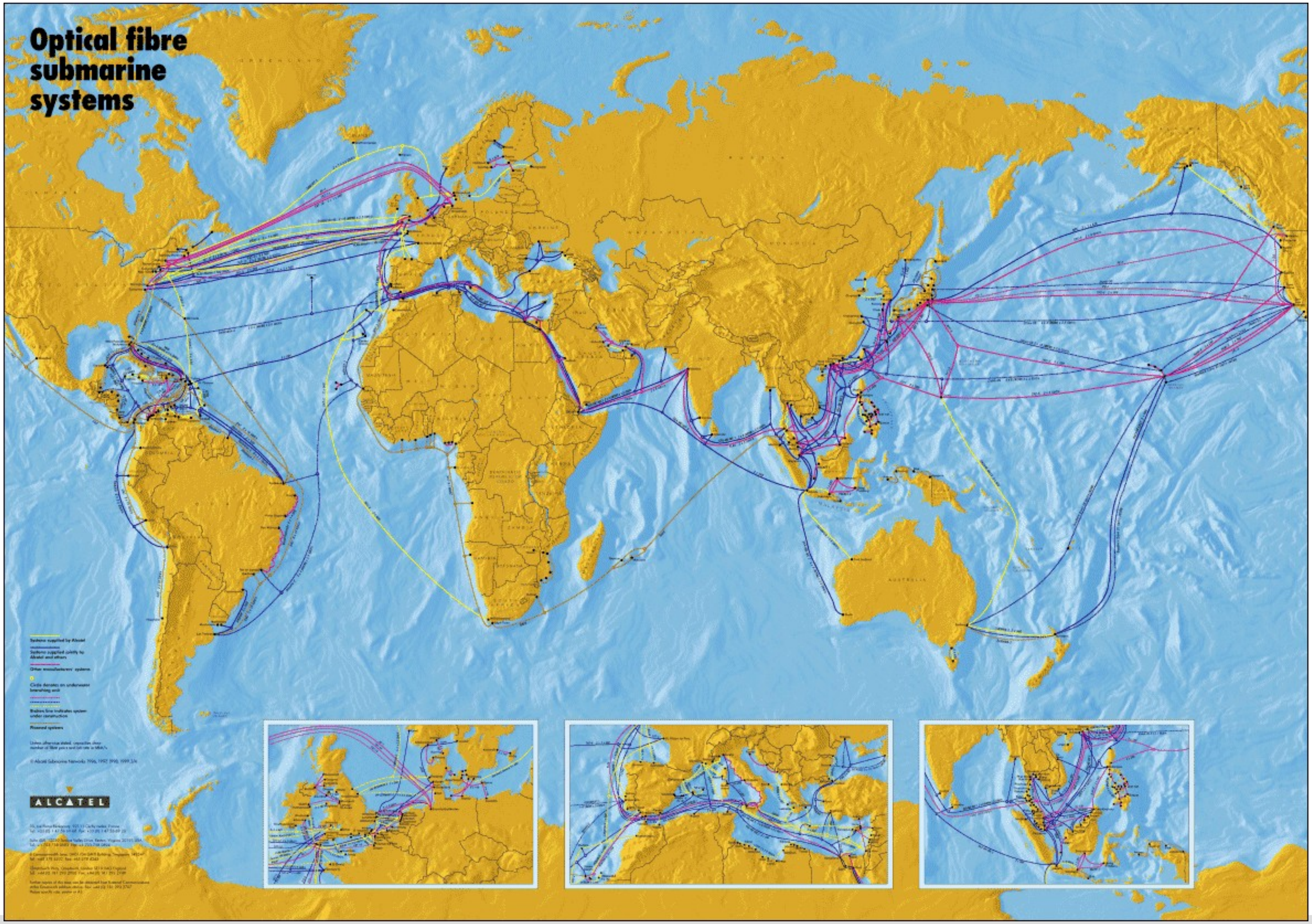
2.1 Intercontinental Optical Networks

- Most recent fiber (TAT-14) fiber cable (2001-present)
  - Between USA, UK, France, Netherlands, Germany and Denmark
  - Configured as a 4 fiber shared protection ring
  - 16 protected WDM channels @ 10 Gbit/s (640 Gbit/s capacity)
  - 1550 nm wavelength window operation
  - EDFAs and non-zero dispersion shifted fibers used

Figure: TAT-14 landing points (Source: www.tat-14.com).

2.1 Intercontinental Optical Networks

- Majority (>75%) of intercontinental traffic now carried on fiber rather than satellite



2.2 Backbone Optical Networks

- Continental backbone network providing connectivity between different countries

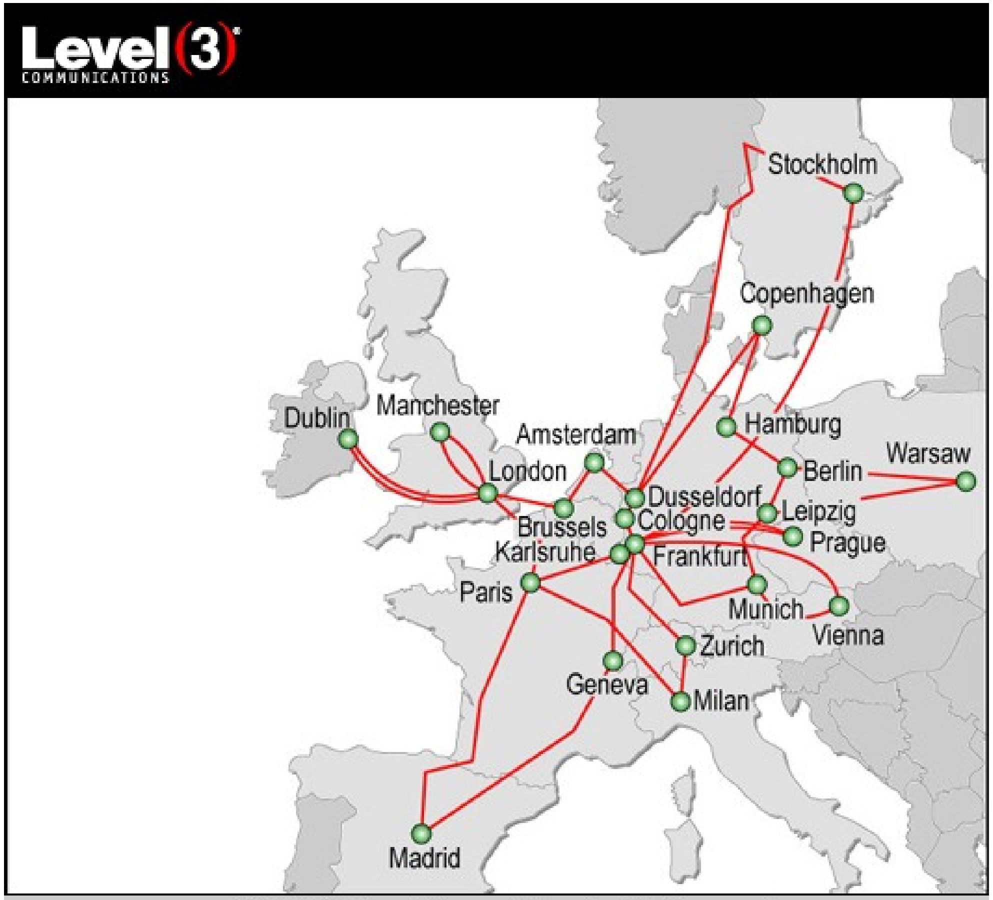
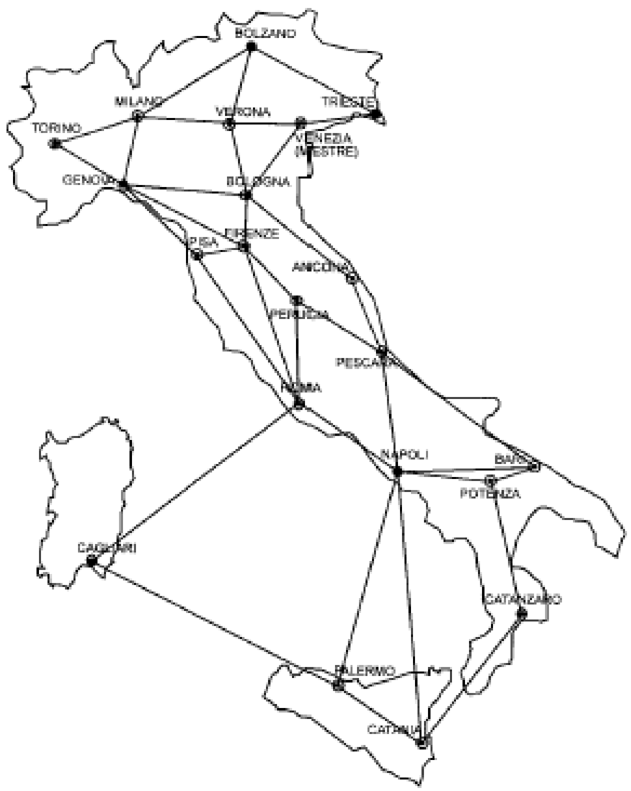
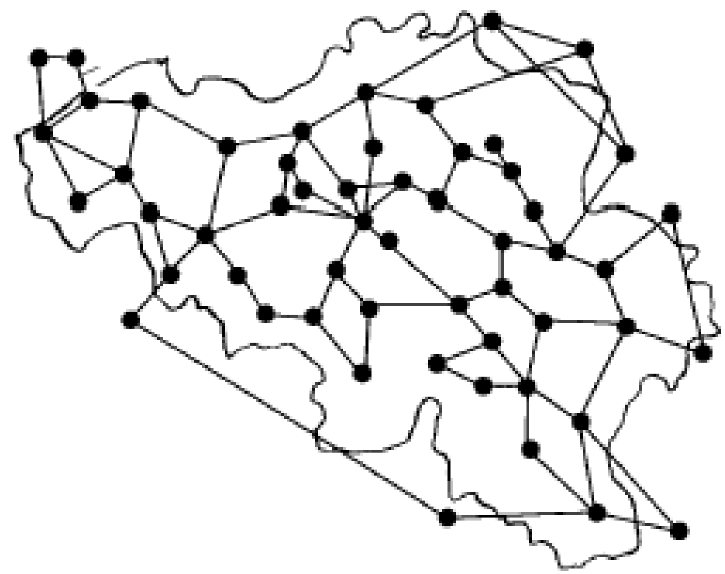


Figure: Level 3's European backbone

2.2 Backbone Optical Networks

- National backbone network interconnecting cities and main towns of a country





*Ref: R. Sabella et al, Journal of lightwave Technology, Vol. 16, No. 11, Nov. 1998

Figure: Conceptual backbone networks for Italy (left) and Belgium (right)

2.3 Optical Metro Networks

- Provide connectivity within a city/metro or region

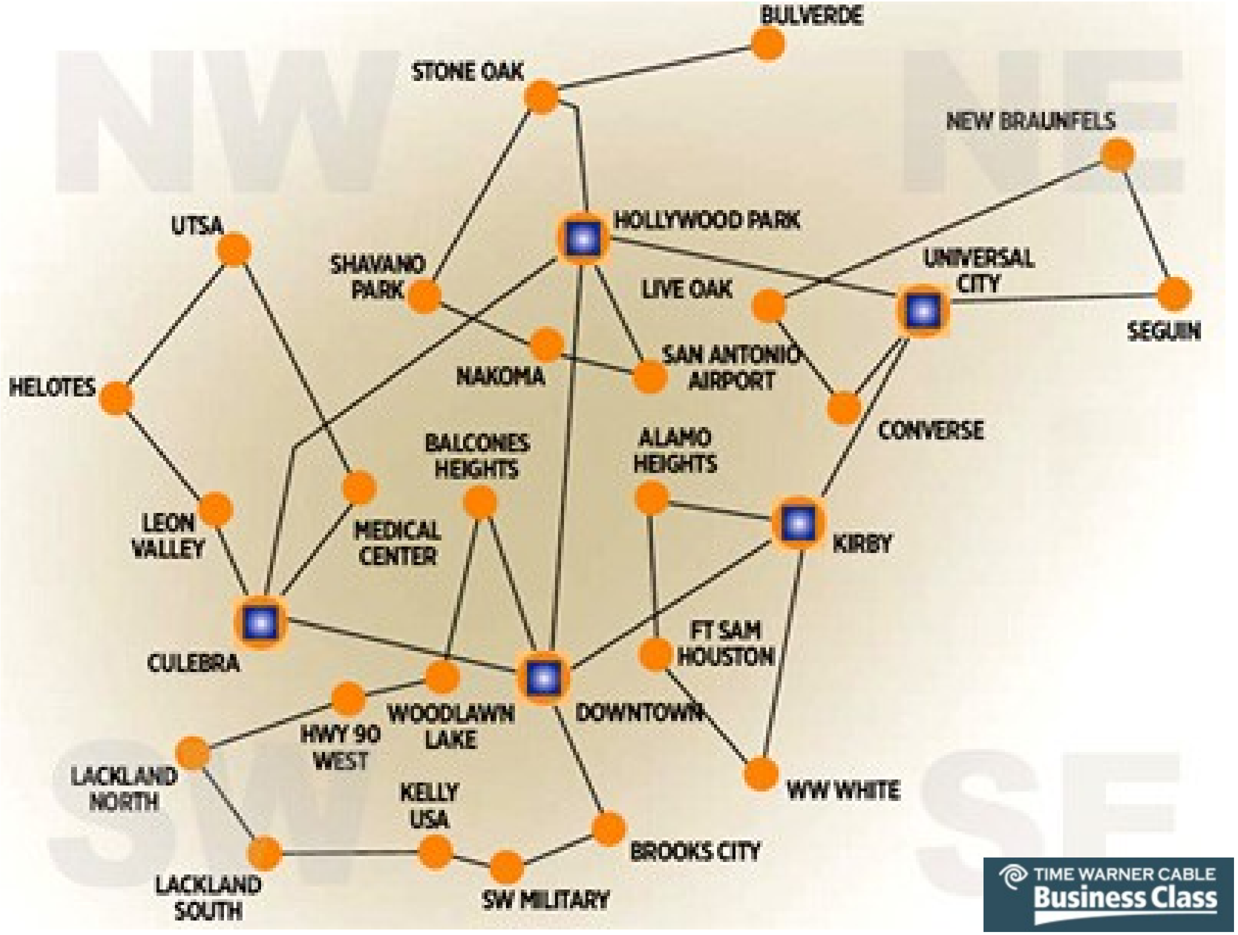
•San Antonio Metropolitan Fiber Network

•Time Warner Cables

•2400 km of fiber

•Ethernet, IP/MPLS

•Connectivity for corporate customers



2.4 Access Networks

- Access network are "last leg" of telecommunications network
  - Between service provider distribution facility and user's home or business
  - Other names:
    - last mile
    - local loop
    - first mile
    - etc.

2.4 Access Networks

- Access network now deregulated or unbundled
  - Great competition to deliver voice, video and internet services
  - Service delivery possible via digital subscriber lines (DSL), cable modems, broadband wireless, optical fibers etc.

Table 1 Hungry for information: The bandwidth requirements for different multimedia applications. Data courtesy of Ovum.

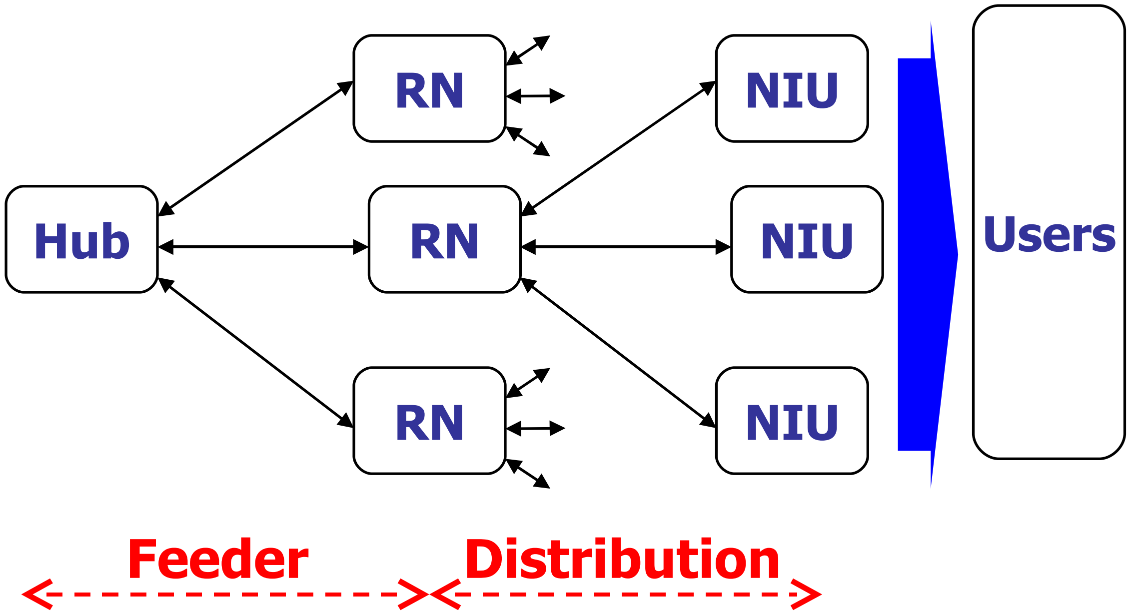
Application	Downstream
VoIP	80 kbps
Video telephone services	124–2,000 kbps
Online gaming	256 kbps
TV channel (MPEG2)	3–5 Mbps
TV channel (MPEG4)	2–4 Mbps
HDTV (MPEG2)	18–20 Mbps
HDTV (MPEG4)	8–15 Mbps

VoIP: voice over Internet protocol.

Source: Nature Photonics, Mar 2007

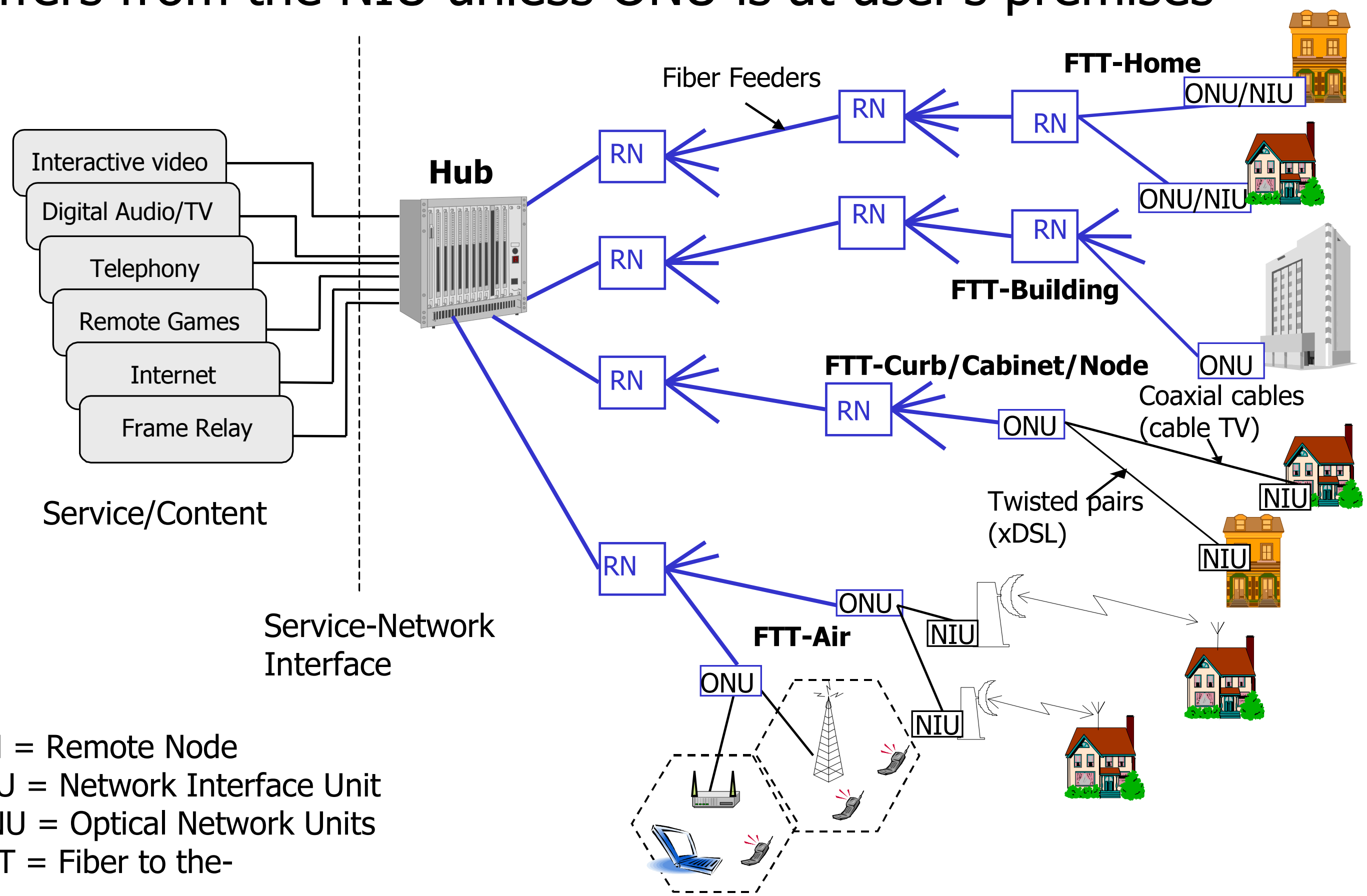
2.4.1 Access Network Architecture

- Generally access networks consists of:
  - Hub ⇒ Central office, local exchange, headend etc.
  - Remote nodes (RN) ⇒ Receives traffic from hubs and distributes to NIUs
  - Network interface units (NIU) ⇒ Located at user premises



2.4.1 Access Network Architecture

- The optical terminating node in the access network is the optical network unit (ONU)
  - Differs from the NIU unless ONU is at user's premises



RN = Remote Node
NIU = Network Interface Unit
ONU = Optical Network Units
FTT = Fiber to the-

2.4.1 Access Network Architecture

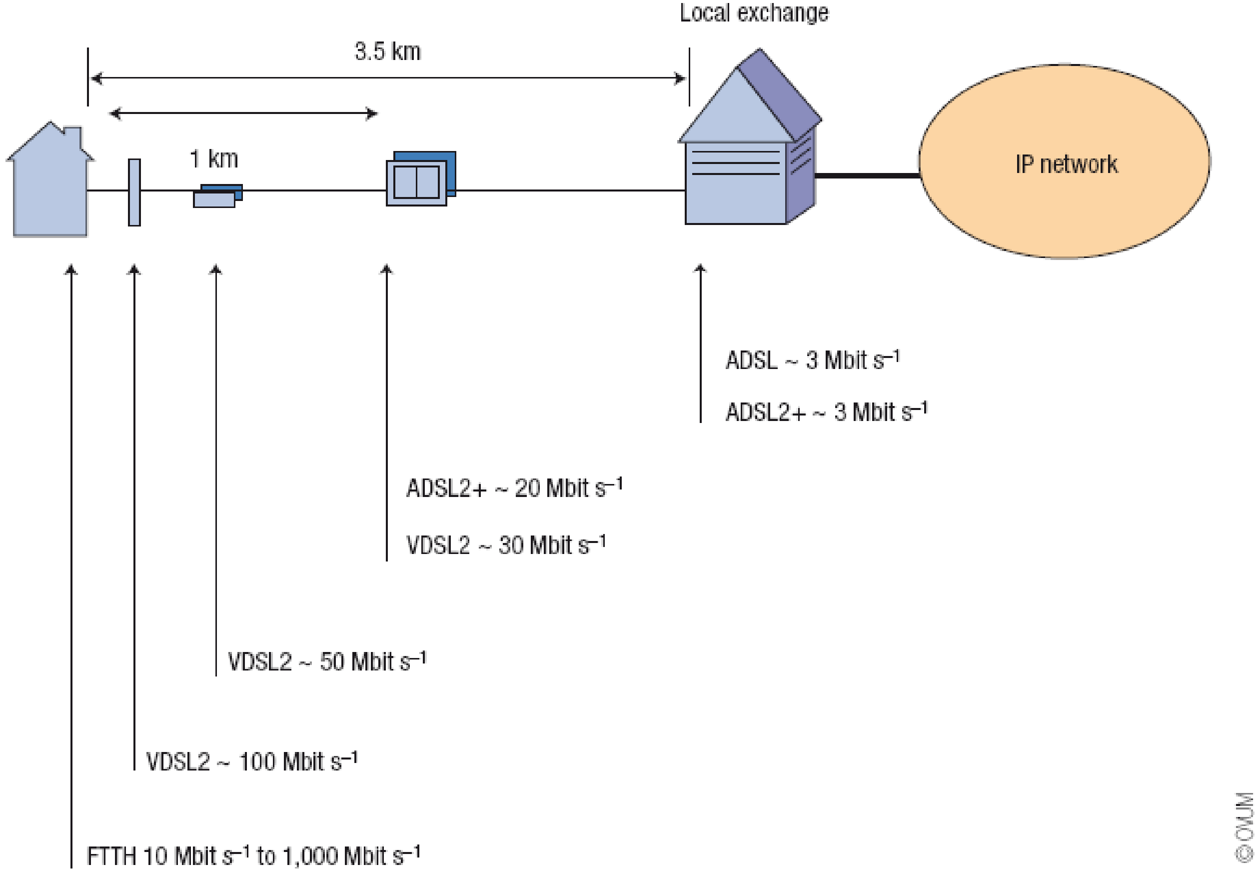


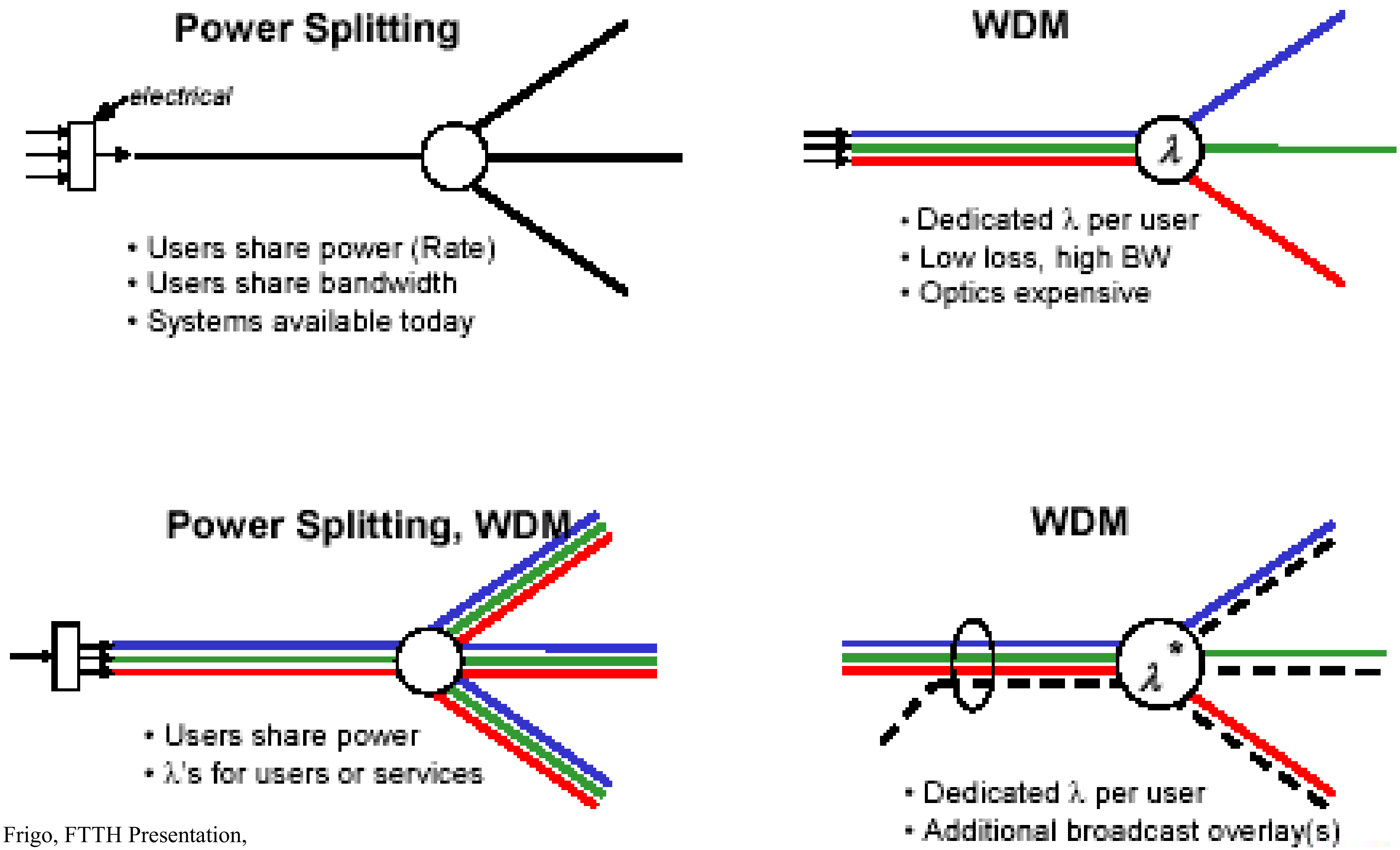
Figure 1 Decreasing copper-loop lengths, increasing bandwidth. Fibre-to-the-home (FTTH) provides a bandwidth pipe that is capable of providing data-transfer speeds of 10 to 1,000 Mbit s^{-1} direct to the user. In contrast, VDSL and ADSL technologies that use existing telephone wiring are limited both in terms of their transmission distance and data speeds. IP stands for Internet protocol.

Source: Nature Photonics, Mar 2007

2.4.2 Passive Optical Networks (PON)

- The optical portion of the access network
  - Must be simple
  - Must easy/cheap to service
- Optical networks preferred for access networks are called passive optical networks (PONs)
  - Remote nodes ⇒ passive components (e.g. star couplers)
  - Reliable, easy to maintain and no need for powering
  - Easy to upgrade without need to change the infrastructure

2.4.2 Passive Optical Networks (PON)



*Ref: N. Frigo, FTTH Presentation, AT&T Labs. Feb. 2004.

Figure: Different PON types

2.4.2 Passive Optical Networks (PON)

- WDM PONs at present mostly proprietary solutions
- Currently 3 main standards for power splitting PONs
  - IEEE EPON (gigabit Ethernet PON [GE-PON] in Japan) mostly deployed in Asia
  - North America and Europe operators opting for ITU-T PONs

Table 2 PON summary. The three main types of PON commonly deployed to support FTTP. Data courtesy of Broadlight and Ovum.

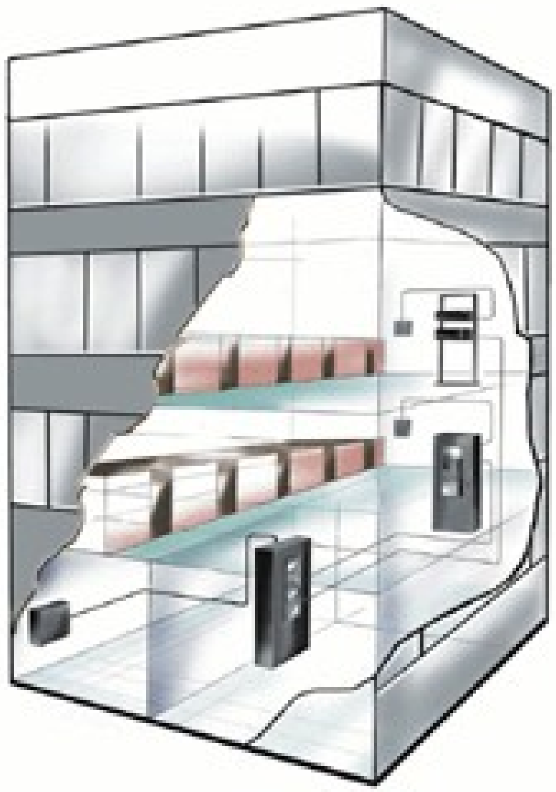
	IEEE 802.3ah EPON (GE-PON)	ITU-T G.983 BPON	ITU-T G.984 GPON
Format	Ethernet	ATM	GEM
Downstream	1.25 Gbit s^{-1}	622 Mbit s^{-1}	2,488 Mbit s^{-1}
Upstream	1.25 Gbit s^{-1}	155 Mbit s^{-1}	1,244 Mbit s^{-1}
Efficiency	~ 50–72%	~ 80%	~ 95%
Fibre split	Up to 32	Up to 64	Up to 128

BPON: Broadband PON, ATM: asynchronous-transfer mode, GEM: GPON-encapsulation method, VoATM: voice over ATM.

Source: Nature Photonics, Mar 2007

3. Rights-of-Way

- Deployment of fiber and equipment in LANs
  - Simple, straightforward
  - Building or premises usually owned by the LAN operator
  - No special permissions required



3. Rights-of-Way

- More complicated to deploy network infrastructure beyond operator's own premises
  - Equipment need to be suitably housed at different sites
  - Wireless links occupy some frequency band that either requires a license or is license free
  - But linear facilities (transmission cables) need to be physically laid continuously between different sites

Figure: Example Helsinki-Tampere-Vaasa fiber link

3. Rights-of-Way

- Network operators require rights-of-way
  - Legal right to access the locations that are owned or controlled by others
- With rights-of-way an operator has following rights:
  - Option to place facilities in the area covered by the rights-of-way
  - Construction and maintenance rights for installed facilities
  - Occupation or ongoing use of rights-of-way to do business

3.1 Difficulties with Rights-of-Way

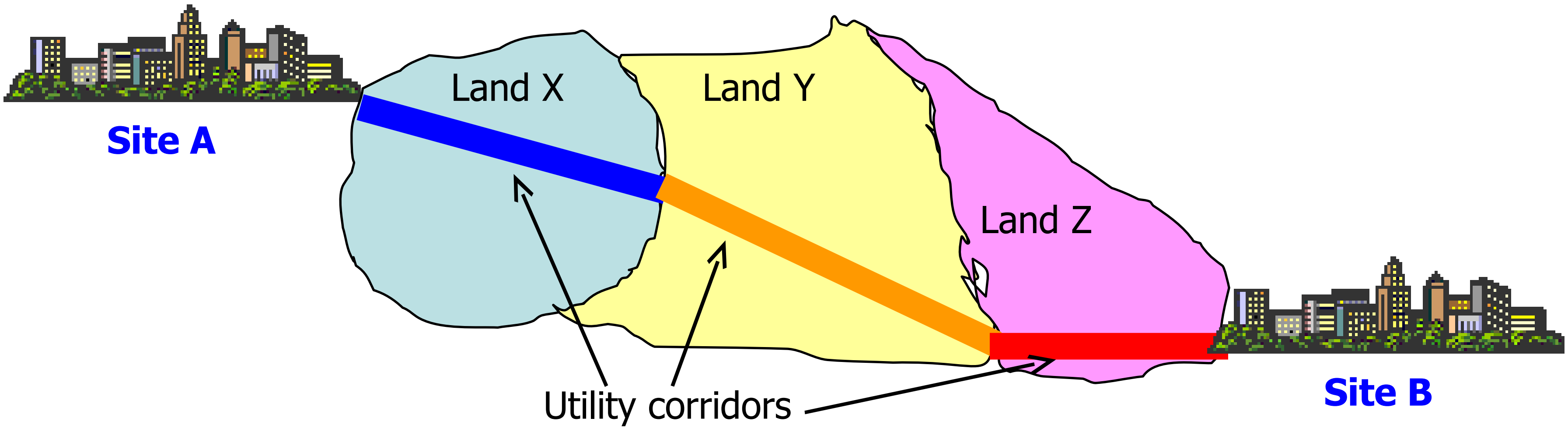
- Similar challenges faced by other utility companies
  - Power/gas suppliers, water, sewage etc.
- Utility companies require access to various locations to deploy equipment or linear facilities
  - Underground routes
  - Tower sites
  - Undersea routes
  - Roads, highways etc.
  - Buildings
- These locations owned by local governments, private individuals, businesses, or even competitors

3.1 Difficulties with Rights-of-Way

- Obtaining rights-of-way can be a very tedious, costly and time-consuming process
  - Environmental or archeological concerns
  - Inconsistent regulations and bureaucracy in different municipal or local authorities
  - Complications with private landowners
    - Deceased landowners
    - Family disputed land
    - Changing ownership
    - NIMBYs (Not-In-My-BackYard) etc.
    - Example: The German Network Development project had to negotiate with 11,500 individual landowners when building a backbone network!

3.2 Utility Corridors

- Rights-of-way acquisition simplified by having utility corridors
  - Linear strips of land designated for use by utility companies
- Utility corridors may provide rights-of-way for more than one purpose (telecom cables, pipelines etc.)
- Corridor assembler/resellers provide a one-stop-shop for operator deploying networks over wide spans



3.2 Utility Corridors

- Corridor owners may increase value of their assets by going higher up the telecommunications value curve
  - Revenues higher
  - Increased exposures to investment risks
  - Dark fiber is fiber which is currently not in use (lit)

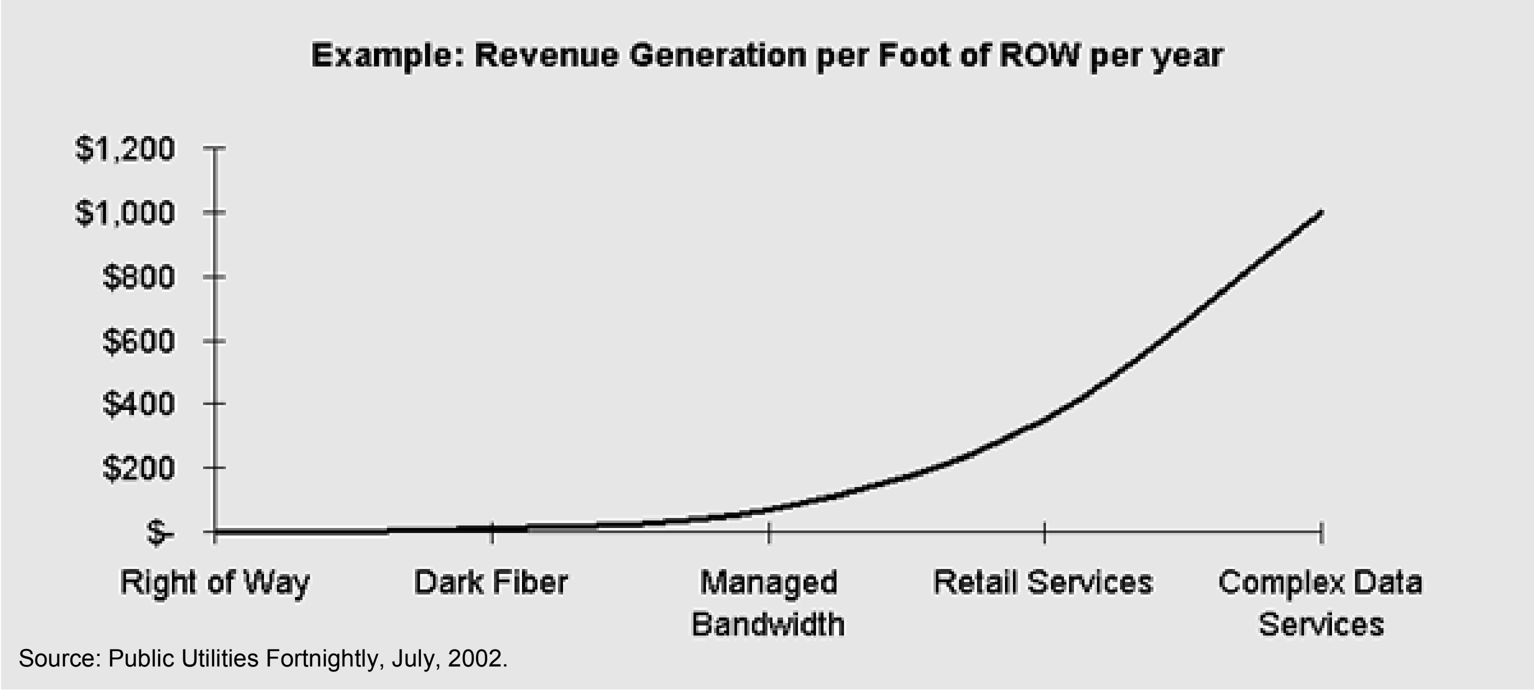


Figure: The fiber optic telecommunications value curve

3.2 Utility Corridors

- Non-telecomm companies able to become service providers
  - Railway operator VR offering services via its subsidiary Corenet Ltd.
  - Corenet and TeliaSonera provide capacity (STM-1 to STM-16, GbE) to Finnish University Network (FUNET)

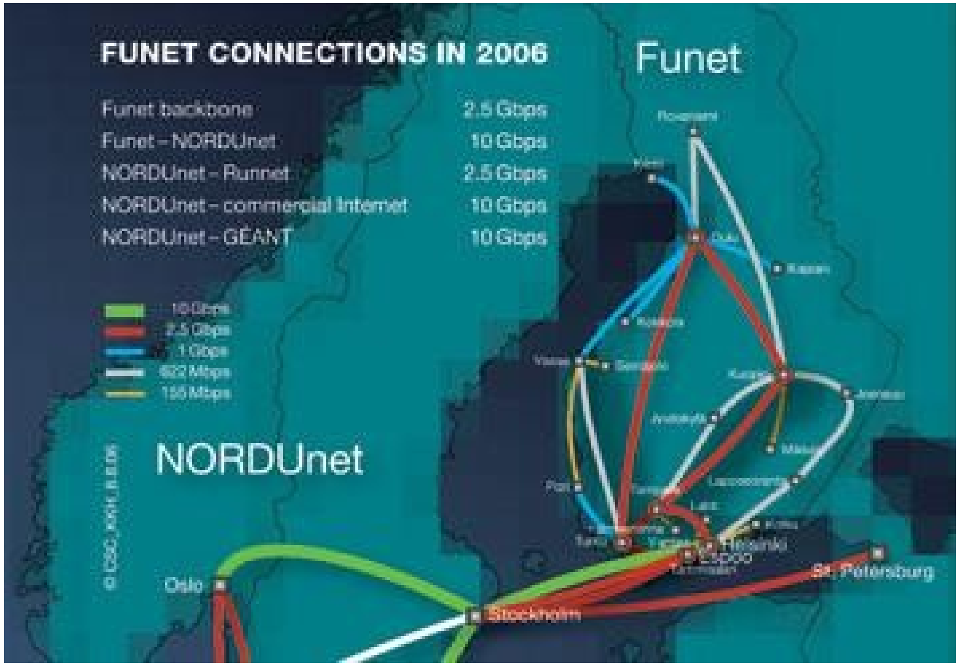


Figure: Corenet's 5800 km mostly fiber backbone network laid along VR railway lines

Figure: FUNET backbone network (http://www.csc.fi/suomi/funet/verkko.html.en)

3.3 Equipment Location

- Equipment location
  - Operator's sites
  - Facilities collocation service providers
- Telehousing facilities requirements
  - Sufficient floor space
  - Protection from rodents, fire, leaks etc.
  - No-break power system
  - Proximity to fiber plant
  - Security against theft and vandalism

4. Fiber Cable Deployment

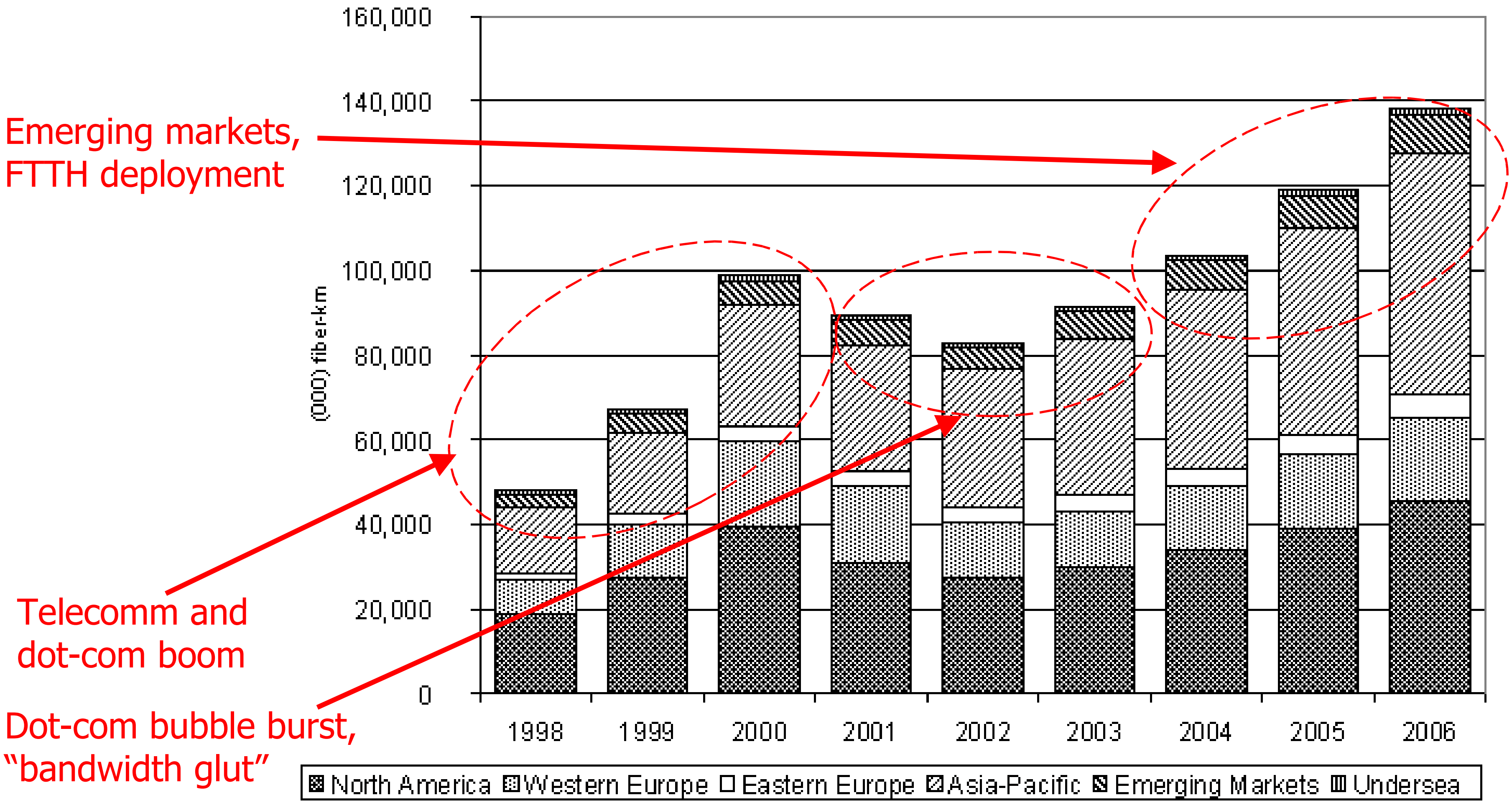


Figure: Worldwide fiber cable deployment by region expressed in thousands of fiber-km (Source: KMI Research).

4. Fiber Cable Deployment

- Various methods exist for deployment of fiber cables
- Selected cable deployment method depends on various factors
  - Geographical topography of an area
  - Availability of rights-of-way
  - Time constraints
  - Operator's business strategy

4.1 Fiber Deployment Options

- Digging trenches specifically for burying fiber Cables
  - Well established technique also used for laying other infrastructure (gas pipeline, water pipes etc.)
  - Trenches usually 0.5 to 3.0 m deep
  - Trenches made using trenchers, ditchers, plows etc.

Figure: Heavy duty ride-on trencher (Source: Vermeer).

Figure: Compact walk-behind trencher (Source: Ditch Witch).

4.1 Fiber Deployment Options

- Digging trenches has many disadvantages
  - Digging or excavation permits difficult to get and more costly
  - Slow cable laying speed e.g. due to boulders encountered in digging
  - Unsettling of humans and wildlife in their current habitat
  - Possible accidents to passersby due to open trenches
  - Damage to existing roads or buried infrastructure (cables, pipes etc.)

Figure: Damage to roads due to trenching

4.1 Fiber Deployment Options

- Resistance to traditional trenching methods is now widespread
  - Magazines (e.g. Trenchless Technology Magazine, Tunneling & Trenchless Construction)
  - Conferences e.g. 24th International NO-DIG Conference and Exhibition http://www.nodig06.im.com.au/welcome.html
  - Societies e.g. International Society of Trenchless Technology (ISTT)
- Methods such as horizontal directional drilling getting popular
  - Horizontal holes in the ground drilled using a jet of high pressure fluids

Figure: Non-intrusive deployment of cables under pavements using horizontal directional drilling (Source: Vermeer).

4.1 Fiber Deployment Options

- Collocating cables with other utility infrastructure
  - Extensive networks of infrastructure such as:
    - Power transmission and distribution lines
    - Potable water lines and irrigation pipelines
    - Natural gas, petroleum pipelines
    - Industrial waste lines, sewage and drainage systems
  - Well planned, maintained, almost similar routes to fiber cable routes
  - Rights-of-way straightforward using existing utility corridor

4.1 Fiber Deployment Options

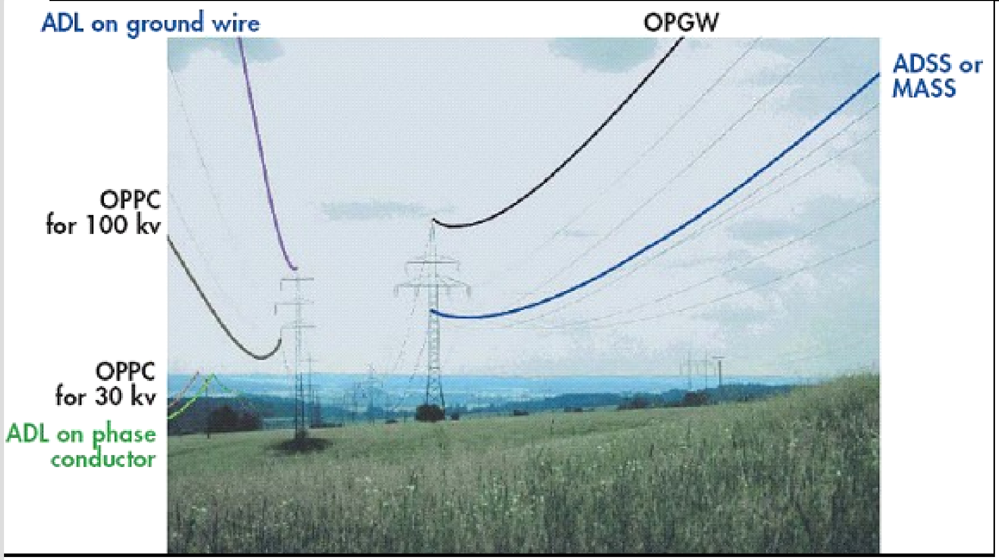


Figure: Fiber cables deployed on power transmission lines (source: Alcatel)

Figure: Fiber cables in sewage systems (source: CityNet, CableRunner)

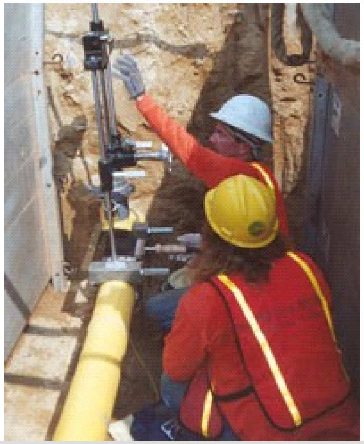
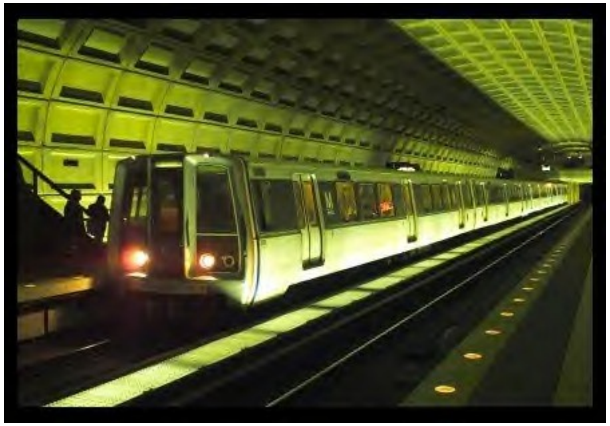


Figure: Installation of fiber cables in natural gas pipes (Source Sempra Fiber Links).

4.1 Fiber Deployment Options

- Placing fiber on transport networks
  - Networks for various transport modes for people and freight
    - Railway lines (e.g. VR/Corenet)
    - Alongside motorways/freeways
    - Underground rail or road tunnels
  - Simplified rights-of-way and ready made routes



4.1 Fiber Deployment Options

- Fiber cabling using blown fiber techniques
  - Cables containing microducts only laid once
  - Extra fibers when needed blown into microducts using compressed air $\Rightarrow$ reuse investment, pay-as-you-grow, no re-digging
  - Up to 12 fibers could be blown into microducts simultaneously
  - Used at Pentagon, Las Vegas (McCarren) International Airport, University of Utah etc.

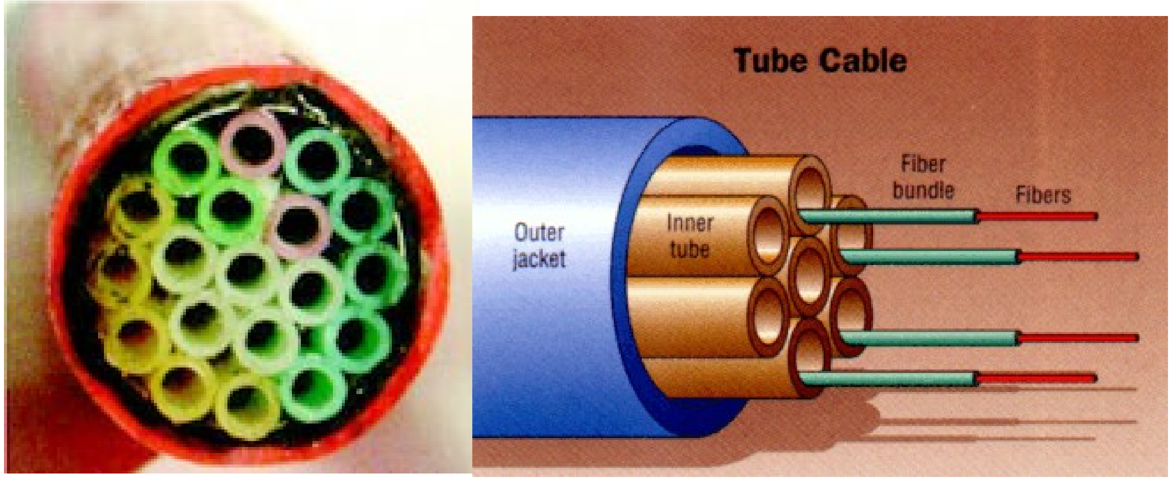


Figure: A conduit containing several microducts (left) and fibers blown into separate microducts (right). (Source: FiberDyne)

4.1 Fiber Deployment Options

- Underwater or submarine fiber cabling
  - For cable deployments in oceans, seas and inland waterways
  - Avoid over digging in developed urban areas
  - Provide nationwide connectivity for countries made of many Islands

Figure: Neuf Cegetel has 200 km of underwater fiber in the River Seine waterway that runs through Paris.

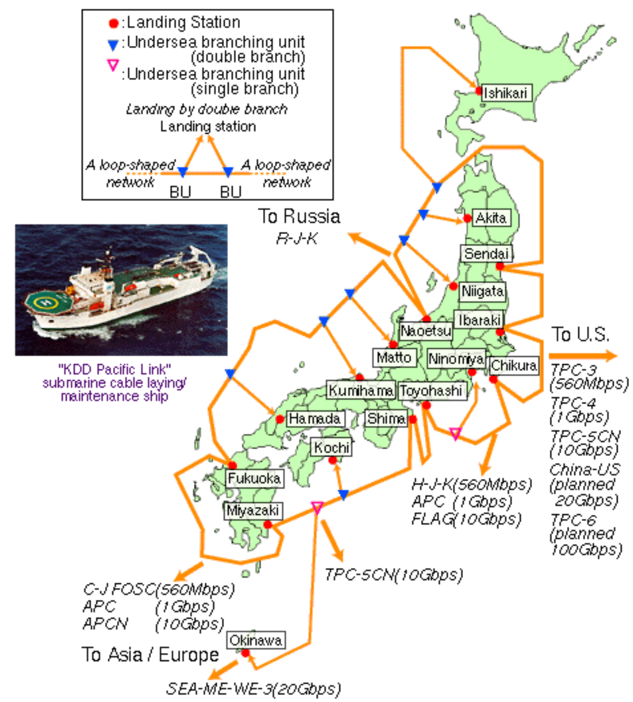
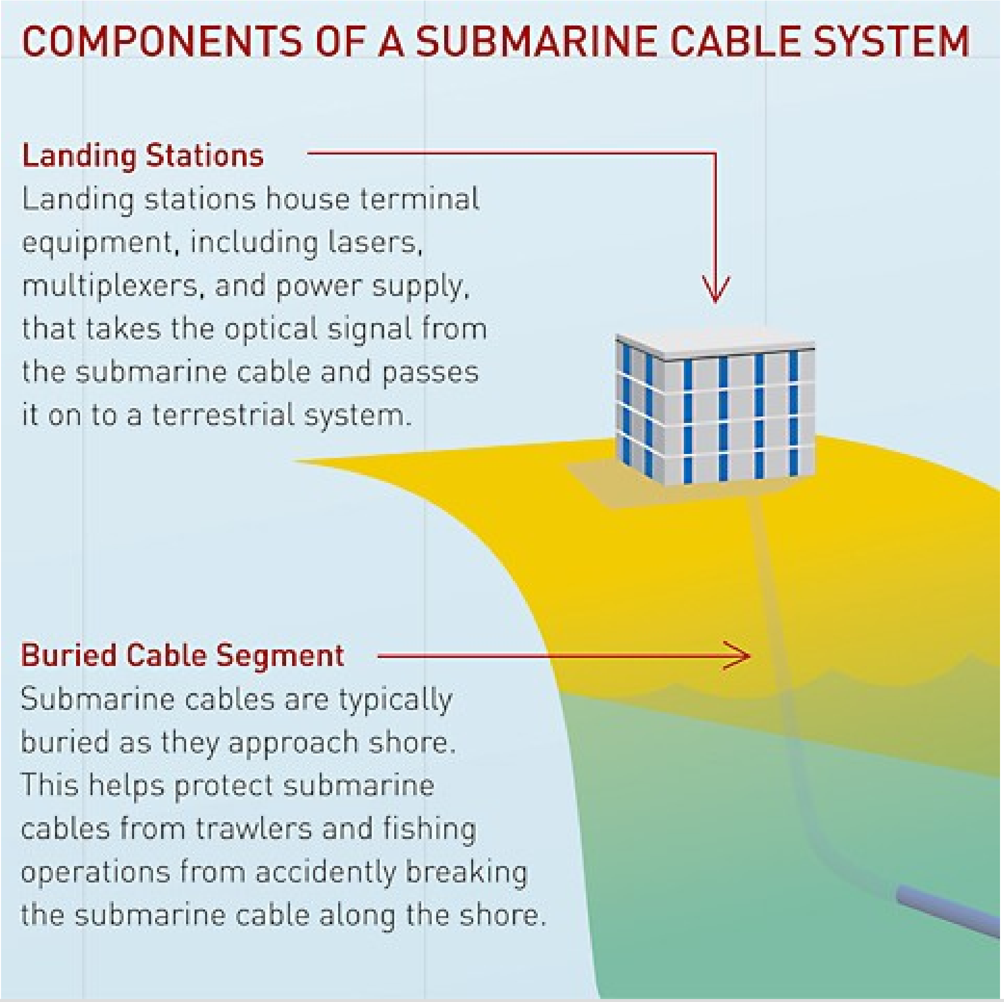


Figure: Japan Information Highway (JIH) cable.

4.1 Fiber Deployment Options

- Underwater or submarine fiber cabling



4.1 Fiber Deployment Options

- Underwater or submarine fiber cabling
  - Cable loaded onto ship and placed or buried in seabed

Figure: Feeding of cable onto ship storage (Canada, 2000)

Figure: Cable installation and maintenance ship (KDD, Japan)

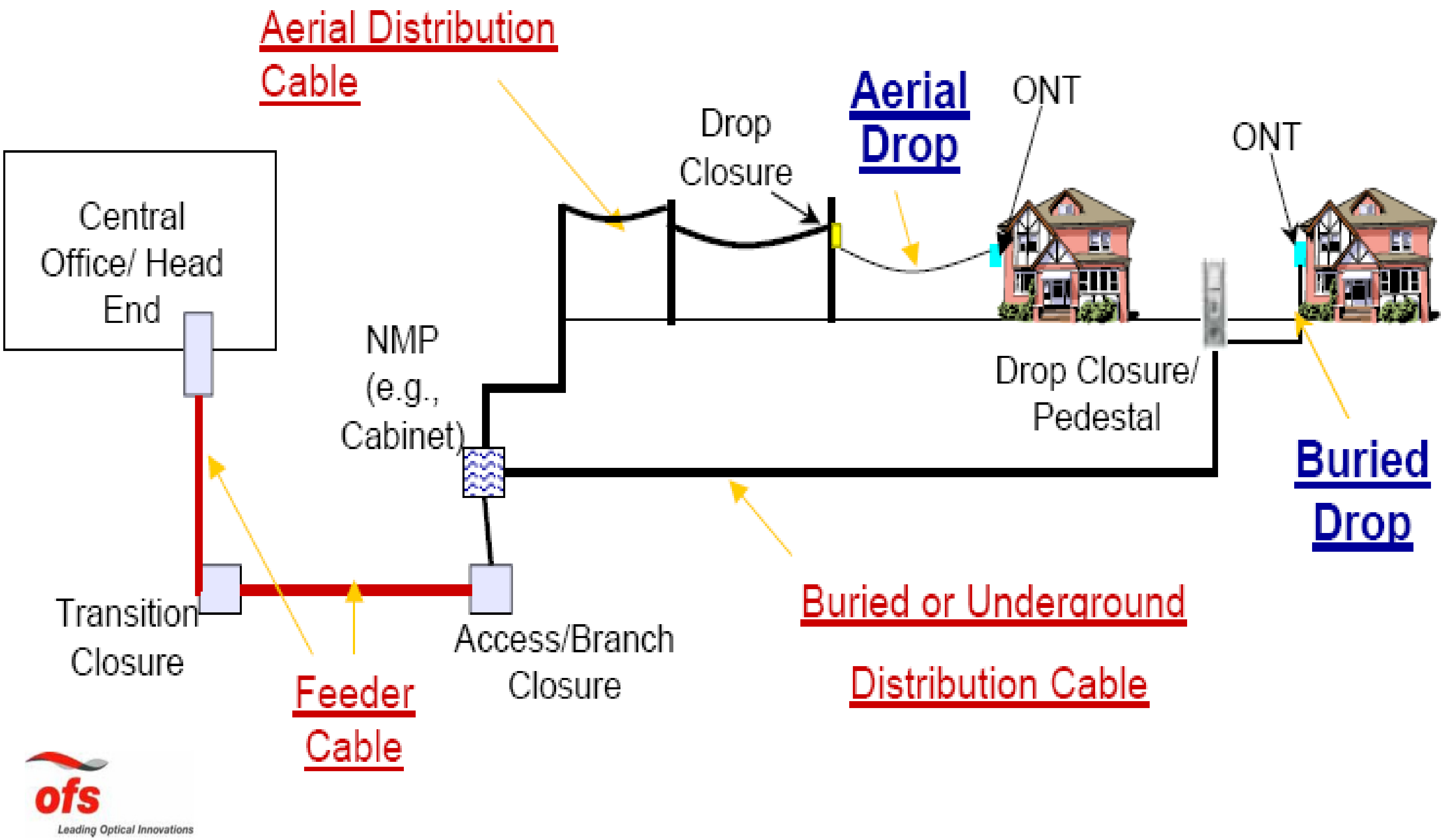
4.2 Deployment in Metro Networks

- Metro areas are usually heavily built already
  - Trenchless/no-dig methods are extremely attractive
  - Different local or municipal authorities institute measures to reduce digging by multiple operators
    - Example: City of Milwaukee rents out space in city-owned network of conduits
    - Example: City of Stockholm owns an optical network and rents out capacities to various operators www.stokab.se

4.3 Deployment in Access Networks

- Deployment of fiber in access network in fiber-to-the-home (FTTH) configuration
- Plenty of bandwidth for end users but some disadvantages
  - Competing technologies are already installed (e.g. twisted pairs, coaxial cables) or tetherless (e.g. WLAN)
  - Expensive because of reduced sharing of investment costs
  - Damage to infrastructure and environment if fiber is to be buried

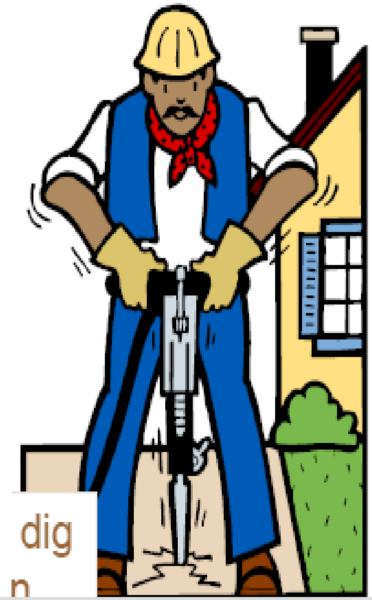
4.3 Deployment in Access Networks



4.3 Deployment in Access Networks

- Greenfield deployment allows cable pre-installation
  - Example: construction companies (e.g. YIT, Sato) ensure fiber deployed to basement of new multiple tenant buildings

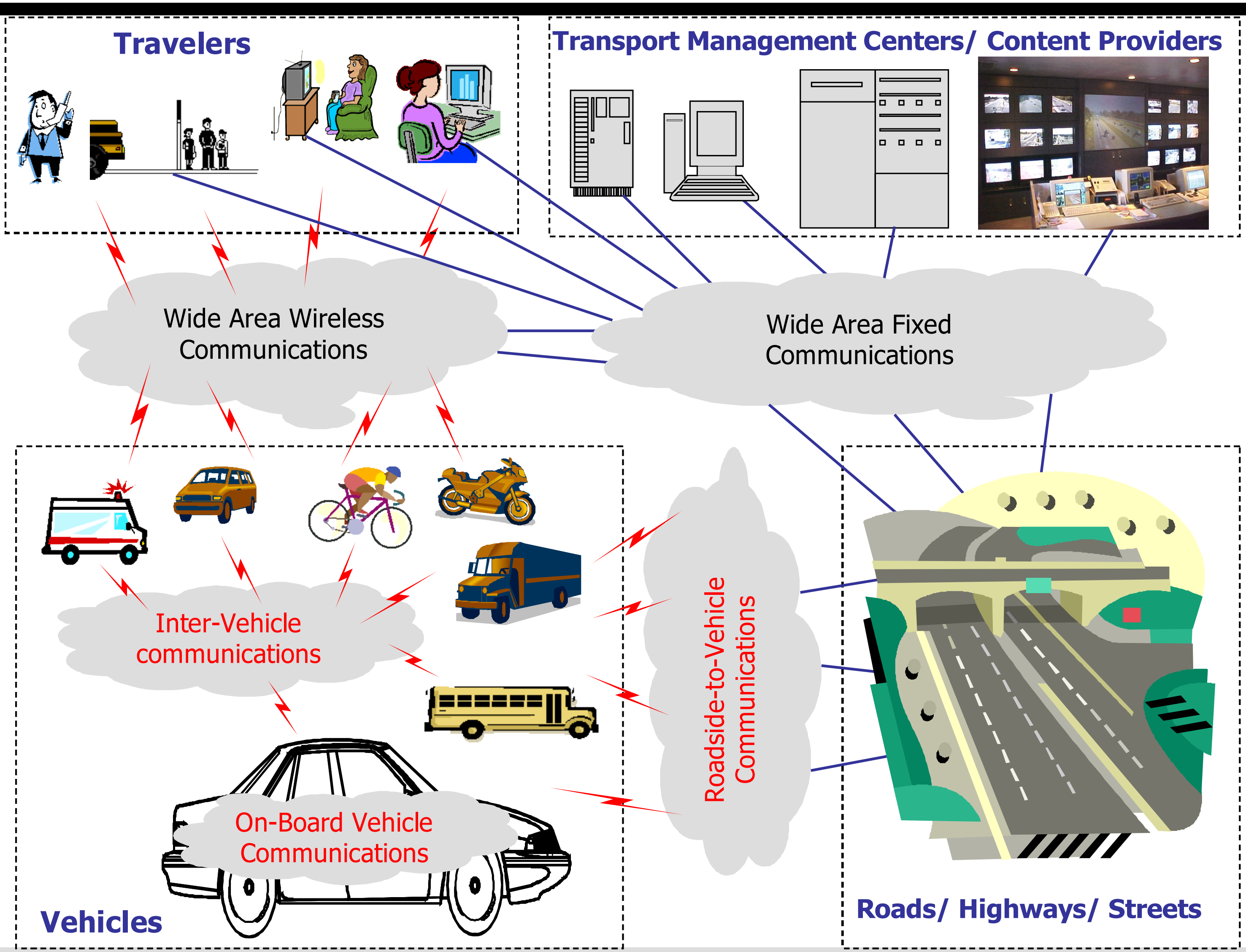
- Brownfield deployment digging or aerial (cheaper)
  - Bring fiber 1.5 km from home and finish with copper links
  - Many deployments in Japan, S. Korea and USA
  - Sonera HOASnet (FTT-Building)



5. Miscellaneous Networks

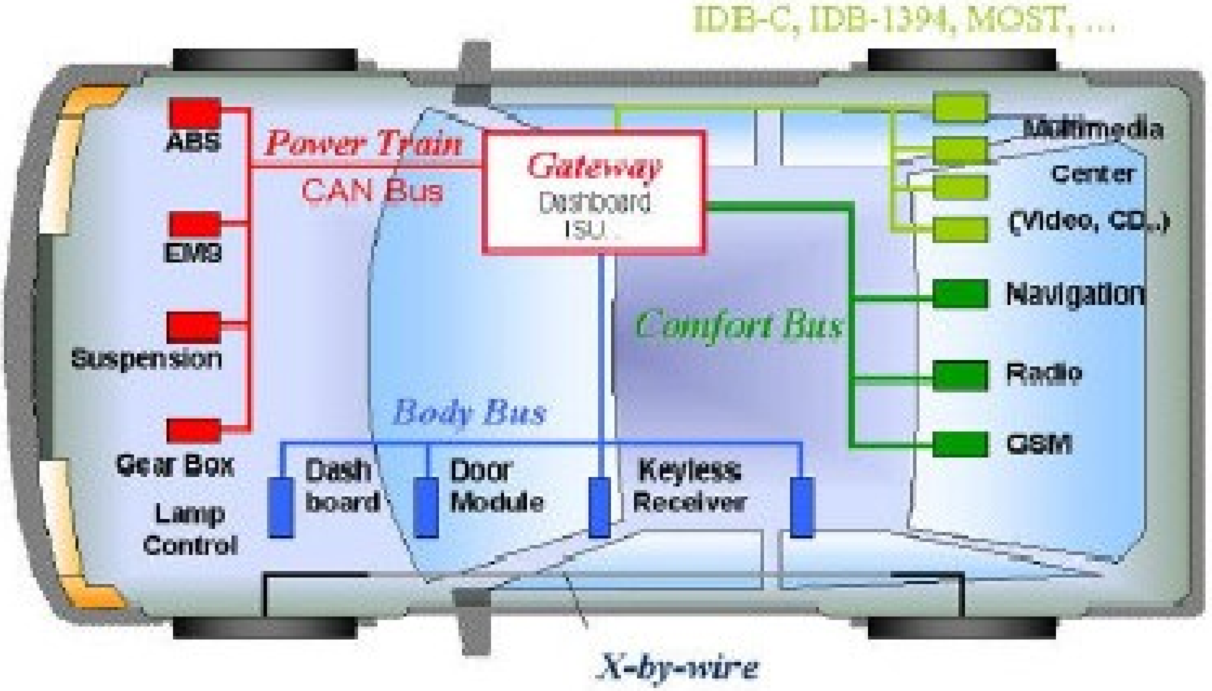
- Optical networking technologies now used for various non-conventional applications
- Introduce high-capacity and low signal loss advantages to new application environments
- Need for some device modifications from traditional optical networks
  - Different operating environment
  - Unfamiliar traffic types

5.1 Intelligent Transportation Systems



5.1 Intelligent Transportation Systems

- Optical technologies now used for on-board vehicles networks
  - Assisted driving, increased safety, entertainment and navigation purposes
- Networking cables and devices adapted for vehicular environment
  - Rugged (vibrations, dirt, moisture, chemicals etc.)
  - Unpredictable (e.g. large temperature variation)



5.1 Intelligent Transportation Systems

- Various standards for optical on-board vehicle communications
  - FlexRay, MOST (Media Oriented Systems Transport), IDB-1394 (automotive version of IEEE-1394 or FireWire)
  - Mostly use plastic optical fibers
  - Peak rates: Flexray (10 Mb/s), MOST (24.8 Mb/s), IDB-1394 (400 Mb/s)
  - Flexray for vehicle control, MOST and IDB-1394 for multimedia applications

2006 BMW X5

Mercedes E-Class

Saab 9-3

Audi A8

Flexray

MOST

5.2 Avionics Fiber-Optics

- Fiber networks on planes
  - High capacity ⇒ in-flight entertainment, internet, control etc.
  - Long reach to various parts all plane sizes
  - Low weight ⇒ less fuel
  - Small size
- Challenges
  - ”New technology” for flight critical systems
  - Vulnerability of fiber connectors in extreme environments (temperature, vibrations etc.)

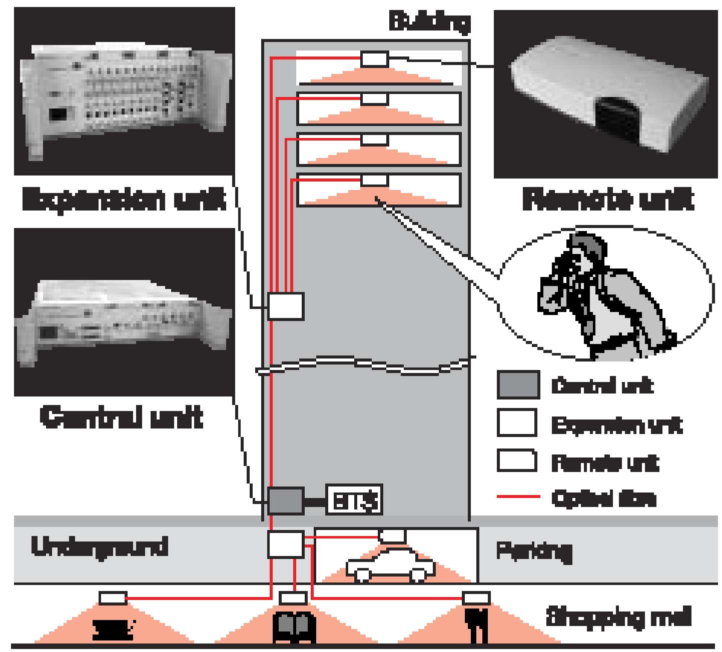
- Example: Avionics Full-Duplex Ethernet/ARINC 664 standard
  - 10 Mb/s (Copper), 100 Mb/s (Copper or Fiber), GbE (future)
  - Planned for A380s, 787s

Airbus A380

Boeing 787

5.3 Fiber Transmission for RF Networks

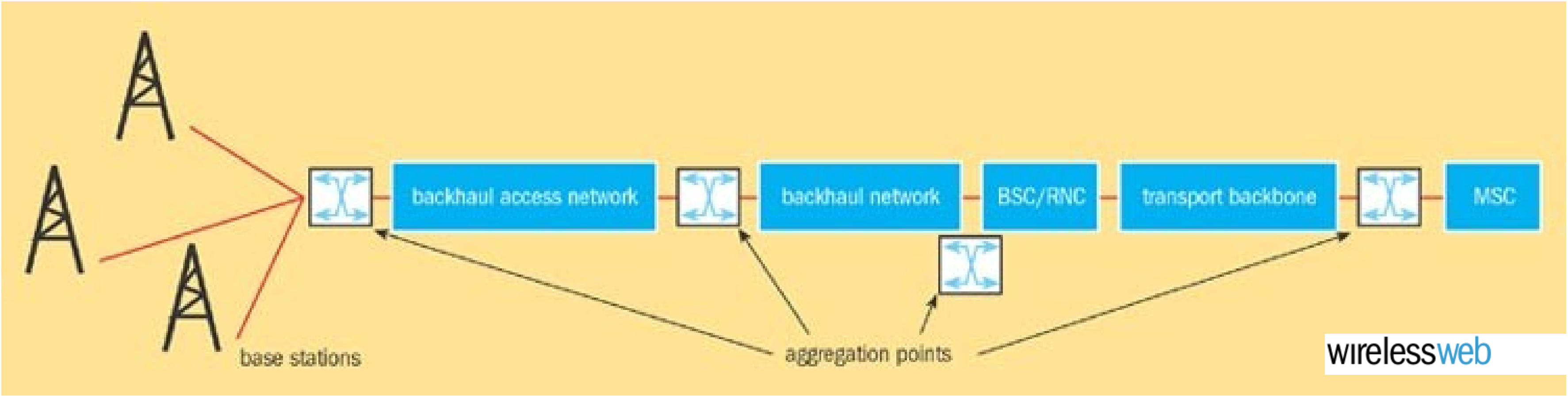
- Fiber connecting distributed antenna systems
  - Improved indoor coverage in malls, underground parking, high-rise buildings etc.
  - Centralization of baseband processing functions ⇒ less complex remote RF processing in antenna units
- Example products for cellular networks
  - Toshiba's RF Optical Distribution System
  - Ericsson's Fiber Radio Solutions for 2G/3G networks



*Ref: http://www3.toshiba.co.jp/snis/ovs/rof_english/catalog/ROF_Leaflet001.pdf

5.3 Fiber Transmission for RF Networks

- Backhaul links for signal transfer between base stations and switching centers
  - Leased lines or self-owned point-to-point digital microwave links
  - About 25% of operator's OPEX and expensive to scale
  - 3.5G networks could require up to 15 times more backhaul capacity compared to 2G/2.5G networks
  - 4G networks will increase requirements even further
- Now use of fiber backhaul links increasingly attractive



5.3 Fiber Transmission for RF Networks

- Fibers for collecting radio astronomy signals from radio telescopes and transporting them to observation point
  - The wider the radio signal bandwidth the clearer the images
  - Example e-MERLIN (UK): 6 telescopes spanning 217 km work as a single giant telescope after being linked by fibers
    - 4 GHz bandwidth radio astronomy signal digitized and sent to Jodrell Bank observation point over 30 Gb/s WDM fiber link (3×10 Gb/s)

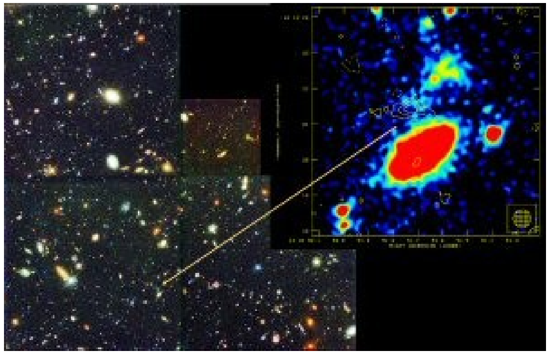


Figure: Observed radio image

Figure: A 76 m radio telescope used in MERLIN

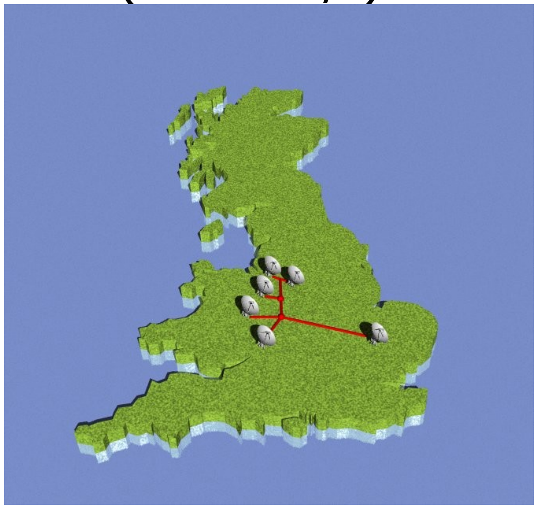


Figure: Fiber-linked e-MERLIN network.

*Ref: http://www.jb.man.ac.uk/news/connected/

5.4 Optical Wireless

- Transmission of infrared beams (optical signals) in free space (fiberless)
  - Also known as free space optics (FSO)
  - Utilize conventional optical 1300/1550 nm transmitters and receivers with some slight modifications

5.4 Optical Wireless

- Advantages of FSO over fiber communications
  - Tetherless flexibility
  - Cost-effectiveness
- Advantages of FSO over RF wireless communications
  - Availability of large unregulated unlicensed bandwidth
  - Data rates up to a several Gbit/s possible
  - Links usually not affected by multipath fading

5.4 Optical Wireless

- Disadvantages of optical wireless
  - Obstructed by opaque objects ⇒ stringent line-of-sight requirement
  - Maximum transmitter power limited by eye safety regulations
  - Ambient noise due to sun-light, light-bulbs etc.
  - Variable signal loss due adverse weather conditions e.g. fog, snow

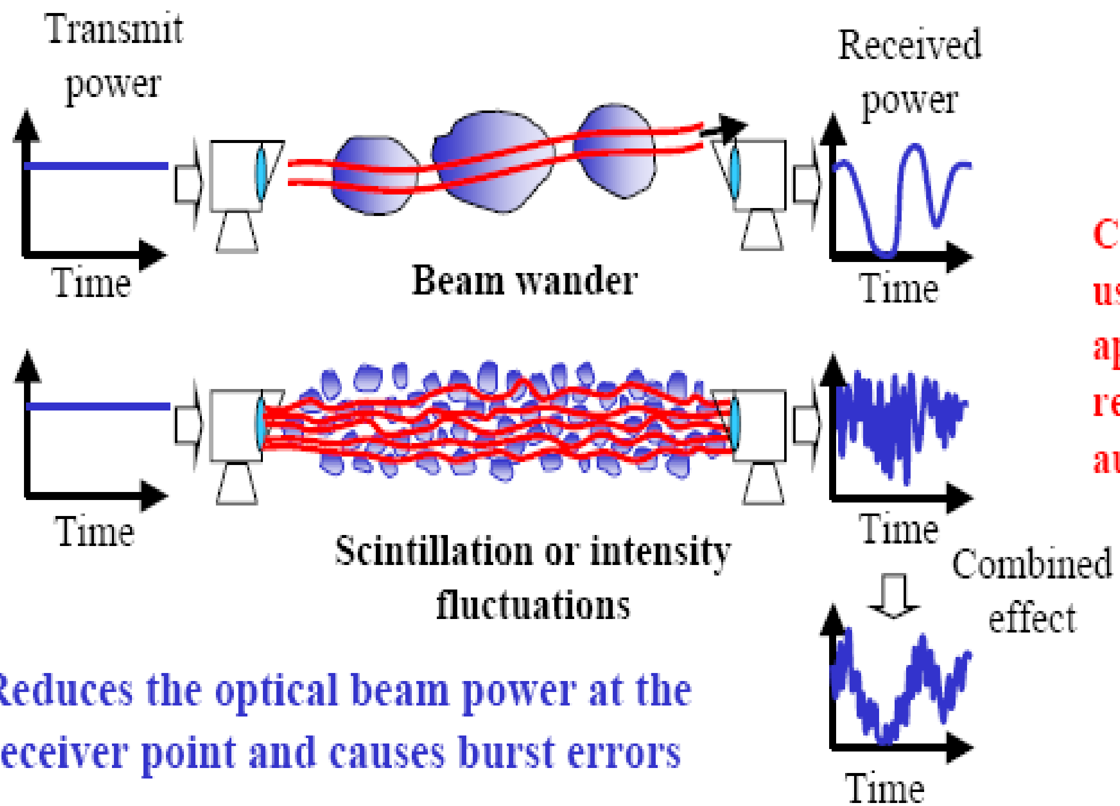
Attenuation 0.19 dB/km — Attenuation 2.58 dB/km — Attenuation 12.65 dB/km

Figure: Example path attenuation for various weather conditions (visibility levels)

Sources: K. Kazaura (Waseda University)

5.4 Optical Wireless

- Disadvantages of optical wireless
  - Need for transmitter-receiver tracking alignment due to moving buildings (wind, thermal expansion etc.), turbulence etc.

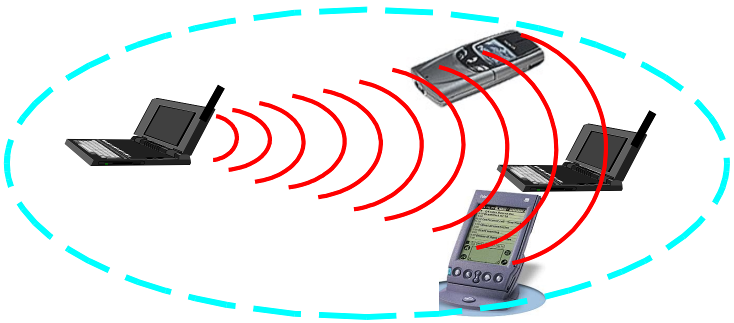


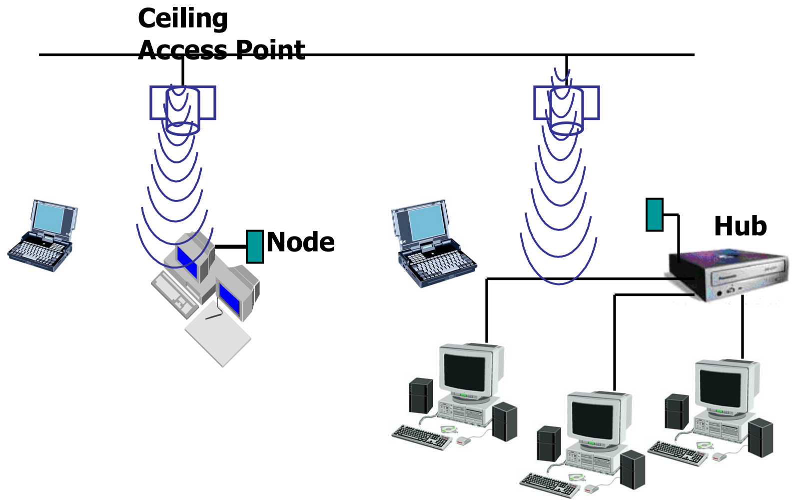
Can be reduced by using either multiple tx apertures or large receive aperture and automatic tracking.

Reduces the optical beam power at the receiver point and causes burst errors

5.4 Optical Wireless

- Most applications have been for indoor systems with coverage limited to a few meters
  - Billions of products shipped with infrared ports
  - "Point-and-shoot" inter-connection of laptops, PDAs, phones etc.
  - Infrared wireless LAN applications (e.g. 10 Mb/s iRLan)



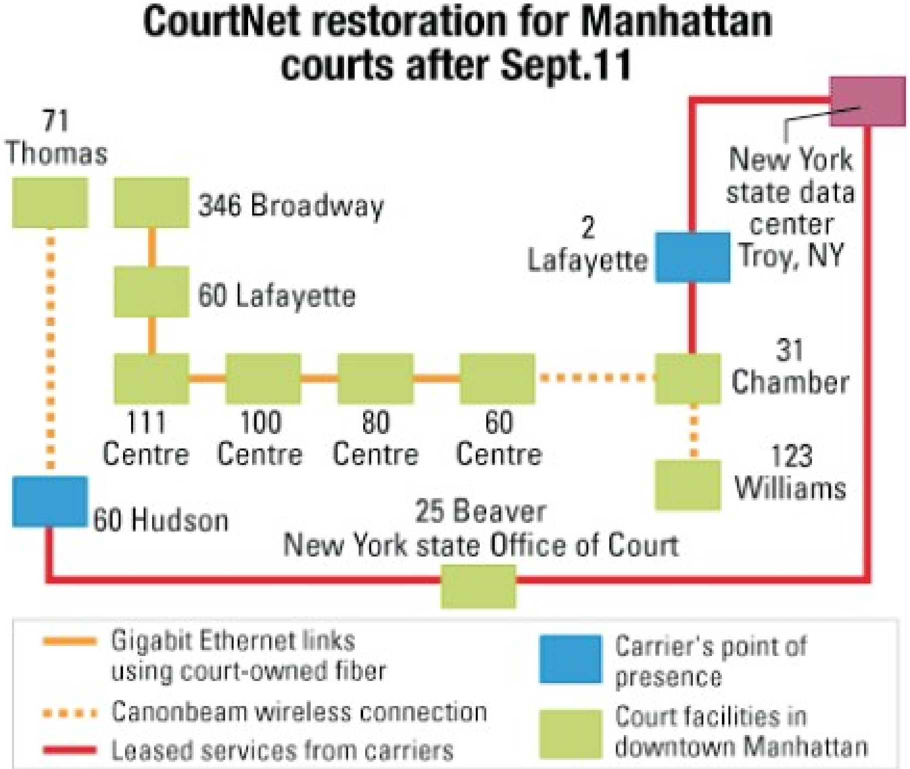


5.4 Optical Wireless

- Outdoor terrestrial FSO systems also gaining popularity
  - Advances in beam tracking and acquisition
  - Rapid provisioning of multi-Gbit/s links for post-disaster recovery, major sporting events, cellular back haul etc.

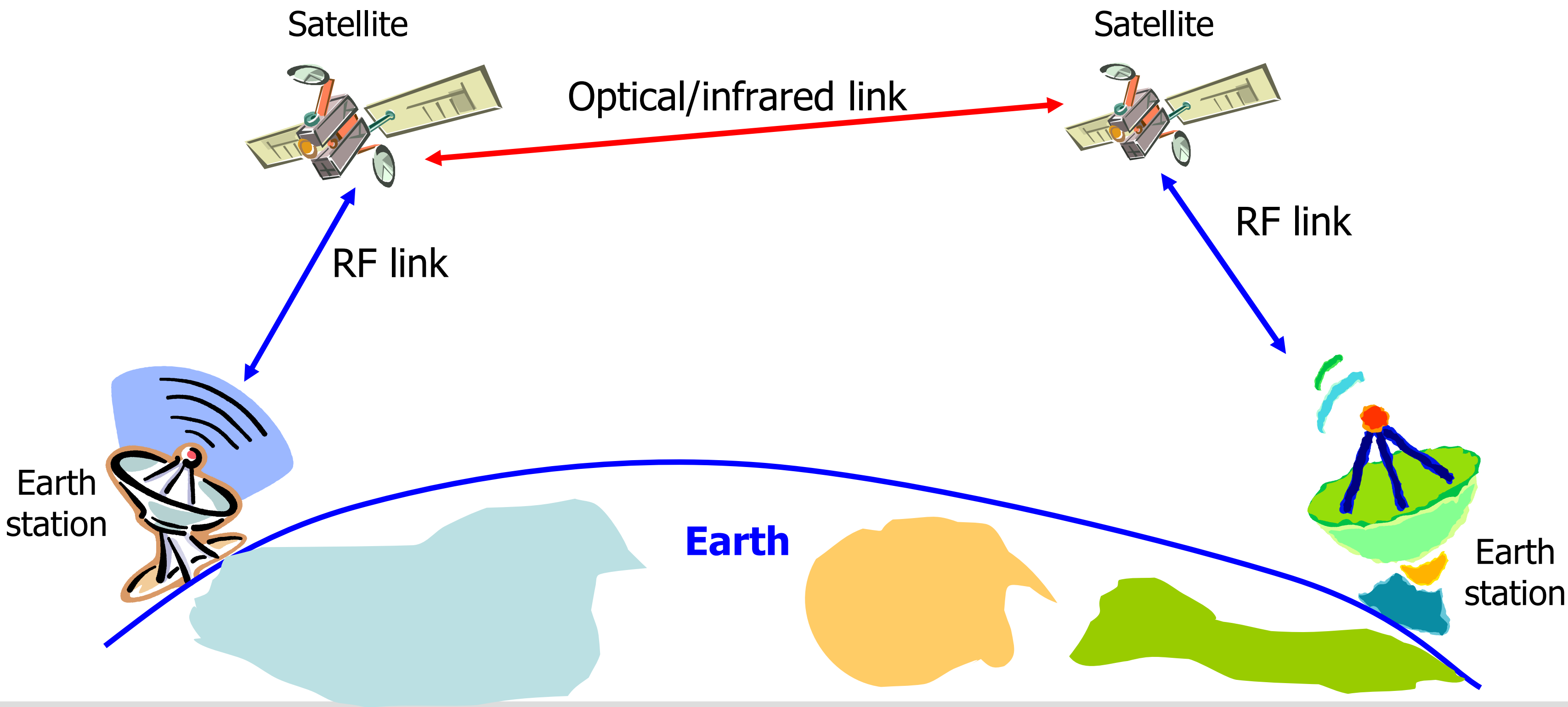
Figure: Rooftop FSO installation

Sources: Waseda University, Hamamatsu Photonics, IEEE/ConTEL conference



5.4 Optical Wireless

- **Inter-satellite links** also increasingly using optical wireless technologies
  - Orbiting satellites for broadband services require multi-Gb/s interconnections



Conclusions

- Optical networks are now an integral part of many current systems
- Fiber likely to get even closer to the user e.g. fiber-to-the-desk
- Next lecture on future directions of optical networking

Thank You!

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