Optical Communications
Lecture 9

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Passive Optical Networks

- The primary applications for fiber-optic networks are in wide-area networks such as long-distance telephone service and the Internet backbone.
- As speeds have increased and prices have declined, fiber-optic technology has been adopted into MANs, storage-area networks (SANs), and LANs.

Passive Optical Networks

- A newer and growing fiber-optic system is the passive optical network (PON), a type of MAN technology.
- This technology is also referred to as fiber to the home (FTTH). Similar terms are fiber to the premises or fiber to the curb, designated as FTTP or FTTC.

Passive Optical Networks

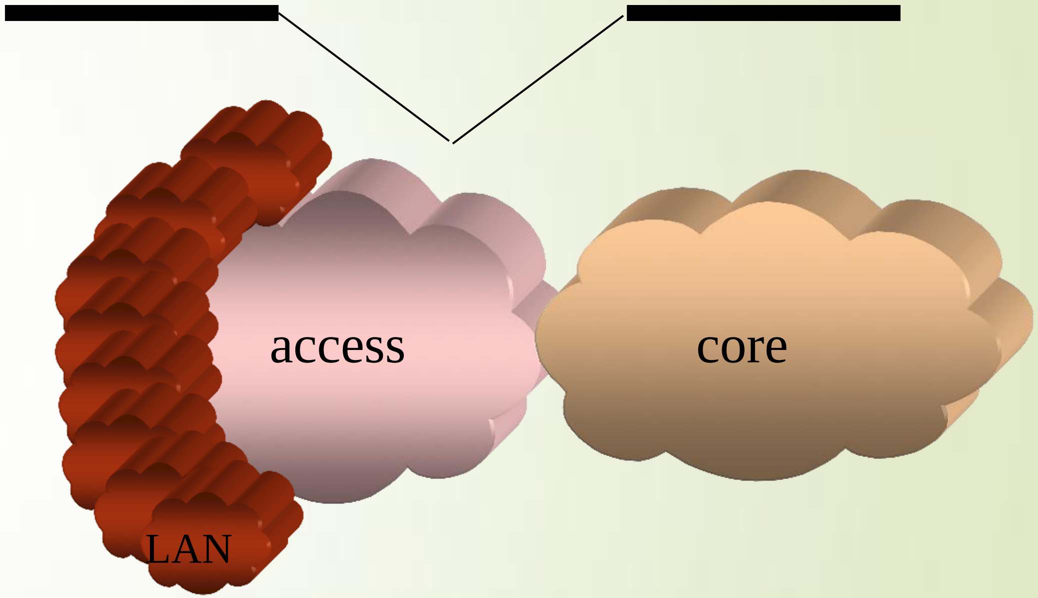
- An active optical system uses electrically powered switching equipment, such as a router or a switch aggregator, to manage signal distribution and direct signals to specific customers.
- This switch opens and closes in various ways to direct the incoming and outgoing signals to the proper place.
- Most optical networking uses active components to perform optical-to-electrical and electrical-to-optical (OEO) conversions during transmission and reception.
- This is an expensive and problematic structure.

Passive Optical Networks

- One solution to this problem is to use a passive optical network.
- The term passive implies no OEO repeaters, amplifiers, or any other device that uses power.
- PON uses optical splitters to separate and collect optical signals as they move through the network.
- A PON shares fiber optic strands for portions of the network.
- Powered equipment is required only at the source and receiving ends of the signal.

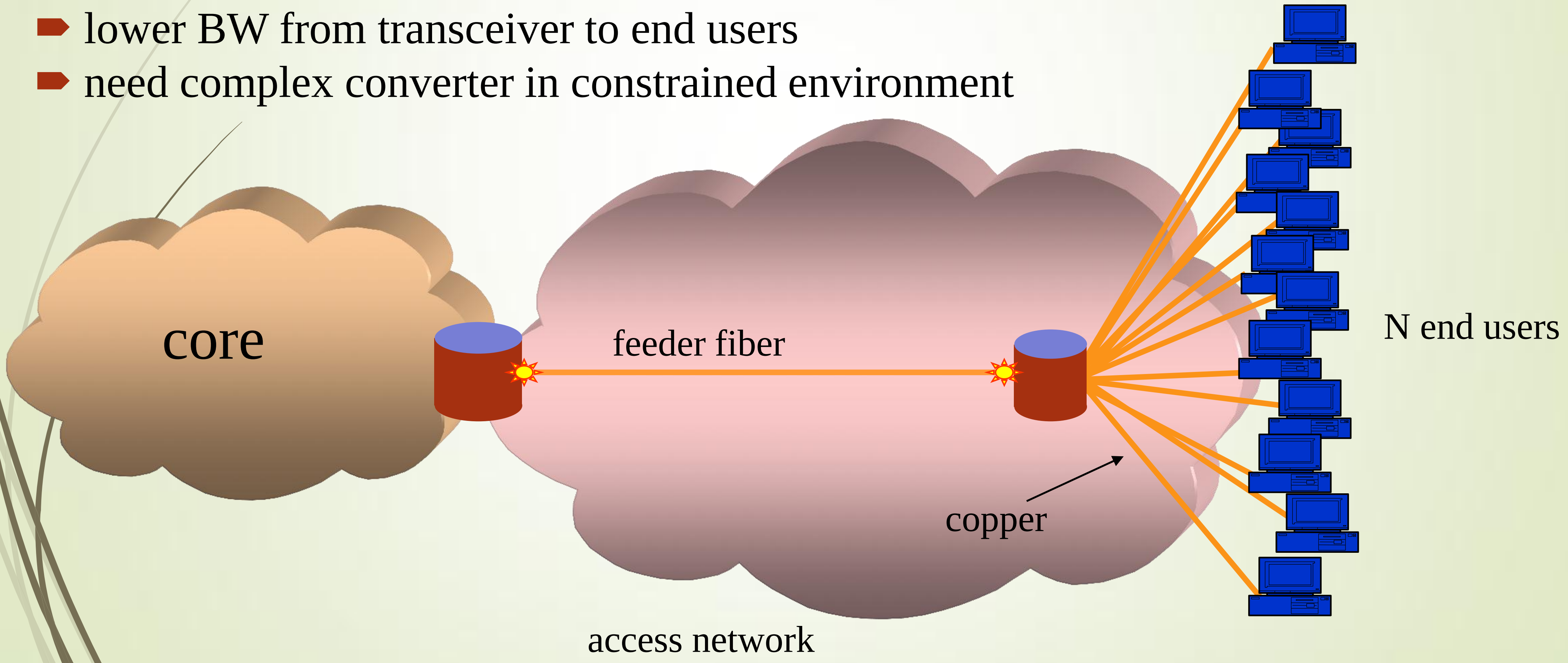
Access network bottleneck

- Hard for end users to get high data rates because of the access bottleneck.
- local area networks
  - use copper cable
  - get high data rates over short distances
- core networks
  - use fiber optics
  - get high data rate over long distances
  - small number of active network elements
- access networks (first/last mile)
  - long distances
  - so fiber would be the best choice
  - many network elements and large number of endpoints
  - if fiber is used then need multiple optical transceivers
  - so copper is the best choice but this severely limits the data rates.



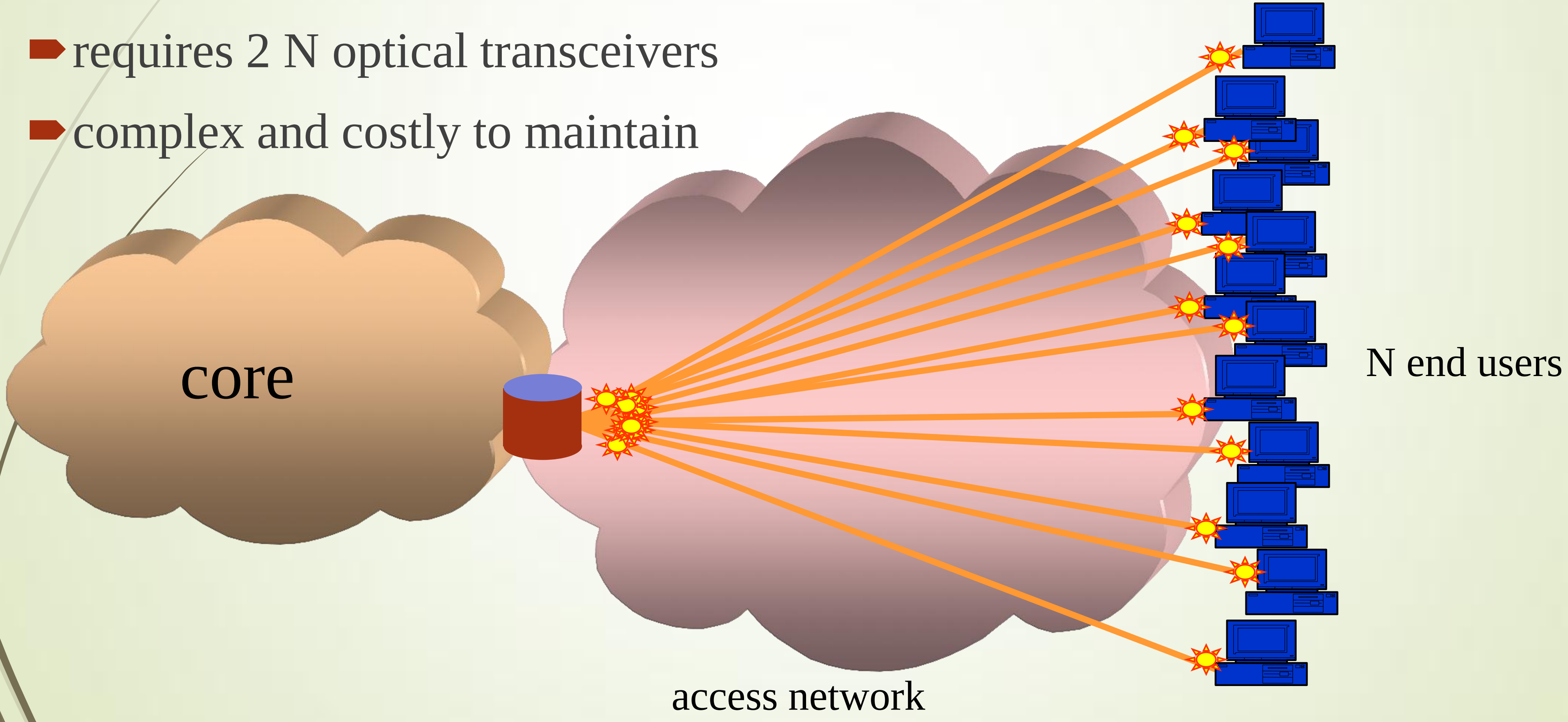
Fiber To The Curb

- Hybrid Fiber Coax and VDSL
- switch/transceiver/miniDSLAM located at curb or in basement
- need only 2 optical transceivers but not pure optical solution
- lower BW from transceiver to end users
- need complex converter in constrained environment



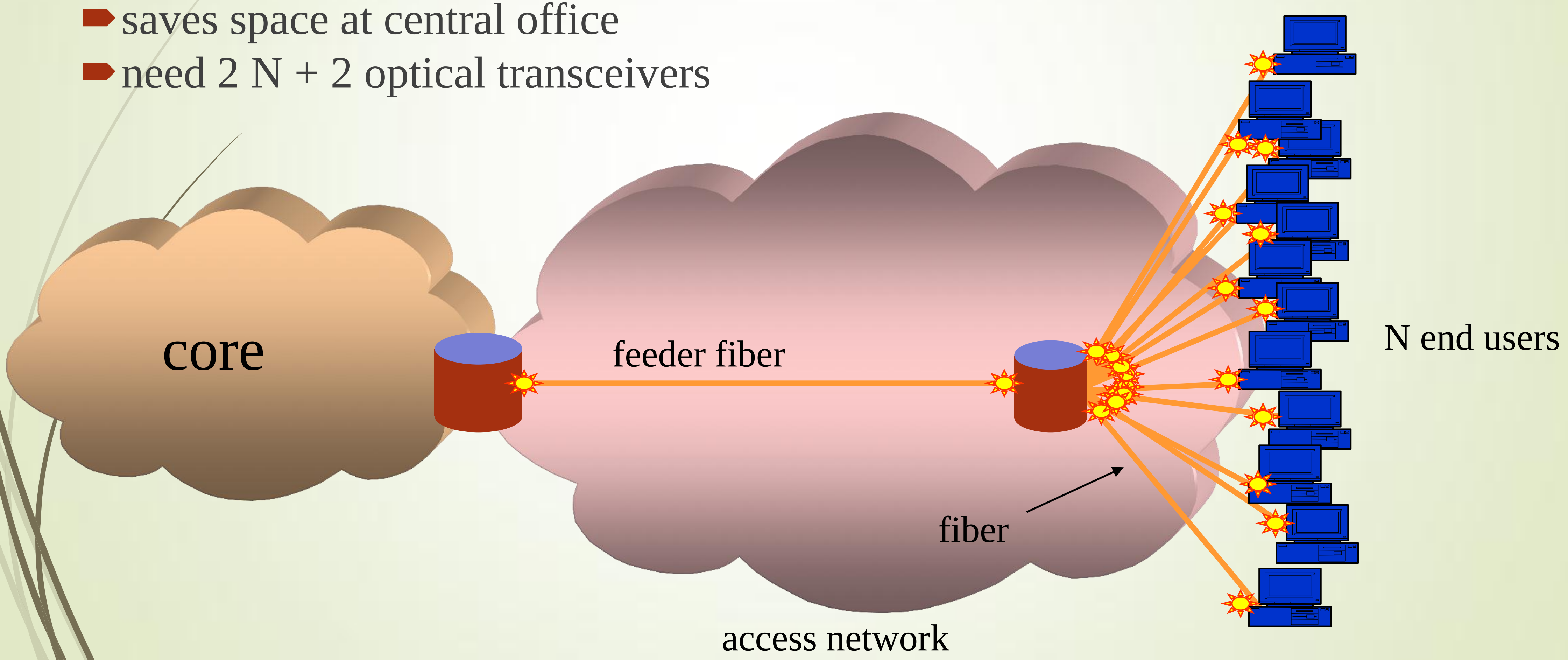
Fiber To The Premises

- We can implement point-to-multipoint topology purely in optics
  - but we need a fiber (pair) to each end user
  - requires 2 N optical transceivers
  - complex and costly to maintain



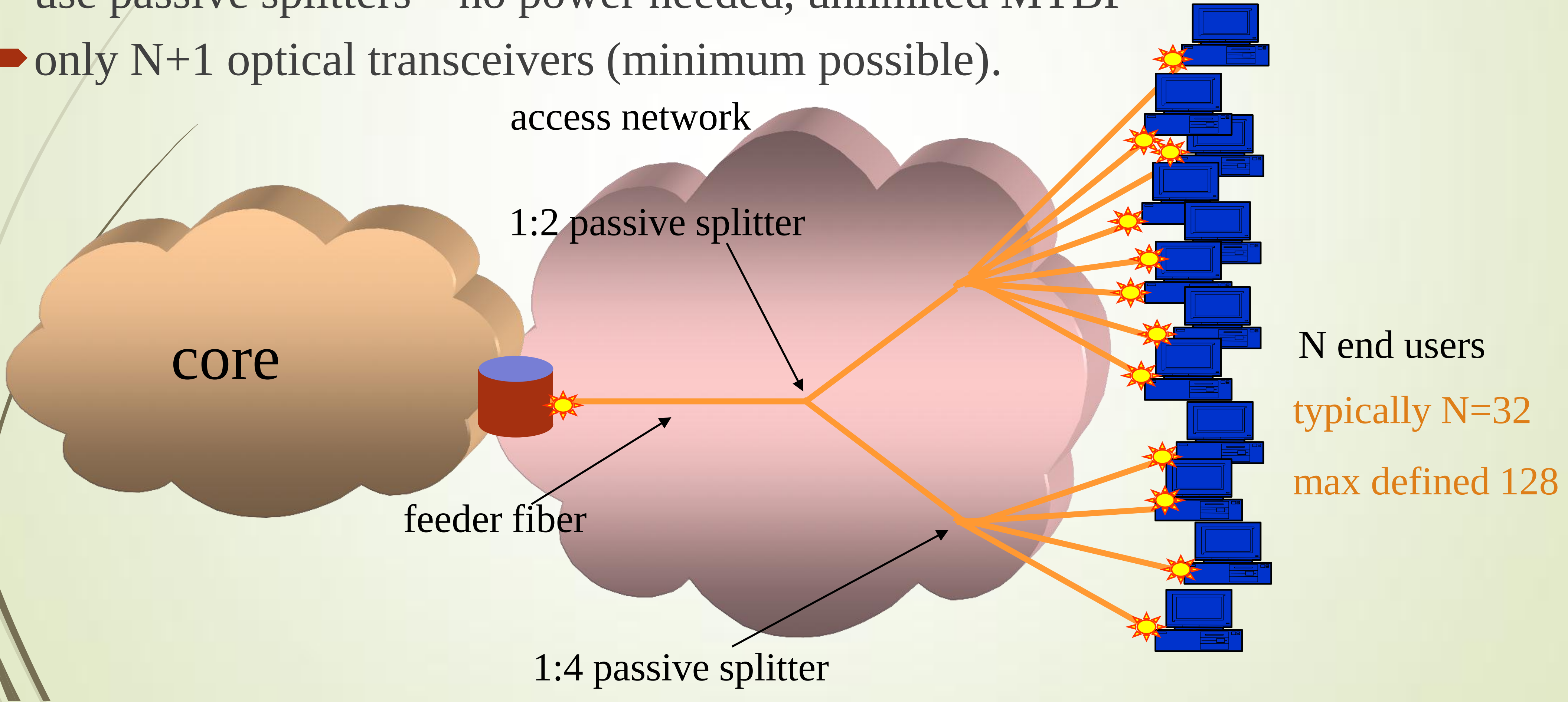
An Obvious Solution

- Deploy intermediate switches
  - (active) switch located at curb or in basement
  - saves space at central office
  - need 2 N + 2 optical transceivers



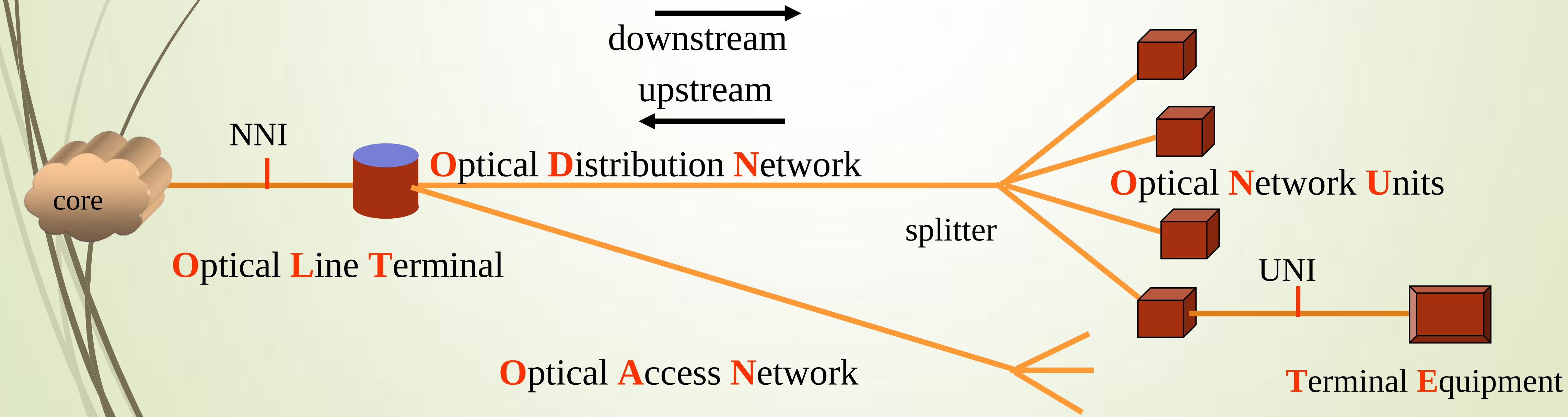
The PON Solution

- Another alternative - implement point-to-multipoint topology purely in optics
  - avoid costly optic-electronic conversions
  - use passive splitters – no power needed, unlimited MTBF
  - only N+1 optical transceivers (minimum possible).



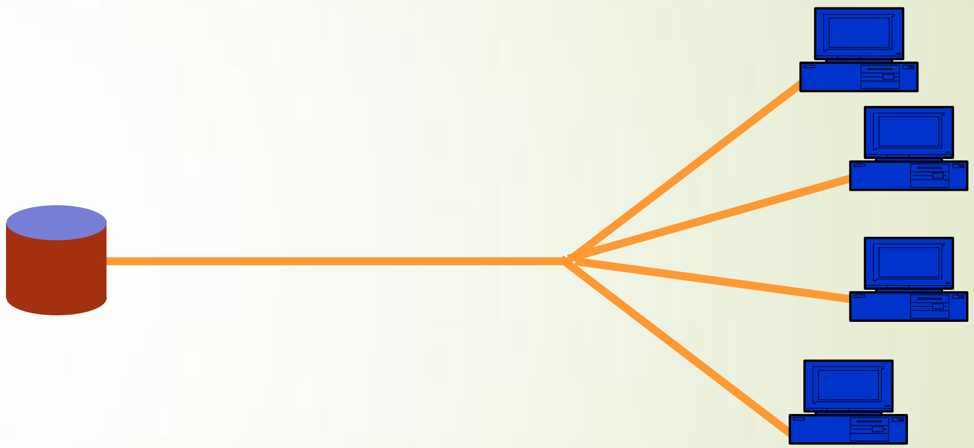
PON Architecture

- Like every other field, PON technology has its own terminology
  - Optical Line Terminal(OLT) is at the service provider's central office (hub)
  - A number of optical network units(sometimes called ONTs in ITU)
  - the entire fiber tree (incl. feeder, splitters, distribution fibers) is an ODN
  - all trees emanating from the same OLT form an OAN
  - downstream is from OLT to ONU (upstream is the opposite direction)



PON Types

- Many types of PONs have been defined
  - APON ATM PON
  - BPON Broadband PON
  - GPON Gigabit PON
  - EPON Ethernet PON
  - GEPON Gigabit Ethernet PON
  - CPON CDMA PON
  - WPON WDM PON



PON Principles

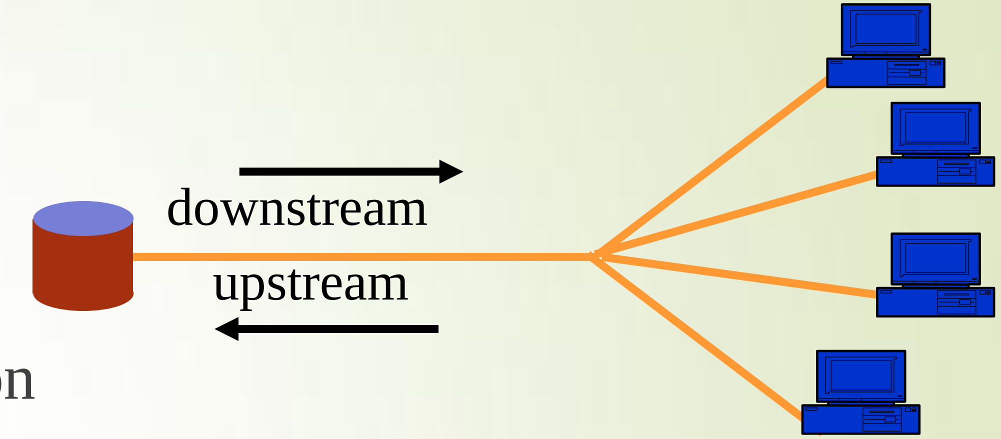
- (Almost) All PON types obey the same basic principles
  - OLT and ONU consist of
  - Layer 2 (Ethernet MAC, ATM adapter, etc.)
  - optical transceiver using different ls for transmit and receive
  - optionally: Wavelength Division Multiplexer
- Downstream transmission:
- OLT broadcasts data downstream to all ONUs in ODN
- ONU captures data destined for its address, discards all other data
- Encryption needed to ensure privacy.

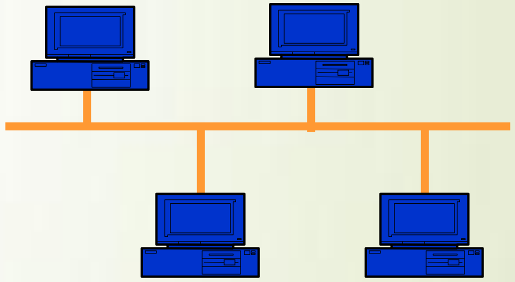
PON Principles

- Upstream transmission
  - ONUs share bandwidth using Time Division Multiple Access
  - OLT manages the ONU timeslots
  - ranging is performed to determine ONU-OLT propagation time
- Additional functionality
  - Physical Layer OAM
  - Auto discovery
  - Dynamic Bandwidth Allocation

Why a new protocol

- PON has a unique architecture
- (broadcast) point-to-multipoint in DS direction
- (multiple access) multipoint-to-point in US direction
- Contrast that with, for example
- Ethernet - multipoint-to-multipoint
- ATM - point-to-point
- This means that existing protocols do not provide all the needed functionality.
- e.g. receive filtering, ranging, security, BW allocation.





BPON history

- 1995 : 7 operators and a few vendors form Full Service Access Network Initiative to provide business customers with multiservice broadband offering.
- Obvious choices were ATM (multiservice) and PON (inexpensive) which when merged became APON.
- 1996 : name changed to BPON to avoid too close association with ATM
- 1997 : FSAN proposed BPON to ITU SG15

BPON history

1998 : BPON became G.983

- G.982 : PON requirements and definitions
- G.983.1 : 155 Mbps BPON
- G.983.2 : management and control interface
- G.983.3 : WDM for additional services
- G.983.4 : DBA
- G.983.5 : enhanced survivability
- G.983.1 amd 1 : 622 Mbps rate
- G.983.1 amd 2 : 1244 Mbps rate

EPON History

- 2001: IEEE 802 LMSC WG accepts Ethernet in the First Mile Project Authorization Request becomes EFM task force (largest 802 task force ever formed).
- EFM task force had 4 tracks
  - DSL (now in clauses 61, 62, 63)
  - Ethernet OAM (now clause 57)
  - Optics (now in clauses 58, 59, 60, 65)
  - P2MP (now clause 64)
- 2002 : liaison activity with ITU to agree upon wavelength allocations
- 2003 : WG ballot
- 2004 : full standard
- 2005: new 802.3 version with EFM clauses

GPON History

- 2001 : FSAN initiated work on extension of BPON to > 1 Gbps
- Although GPON is an extension of BPON technology and reuses much of G.983 (e.g. linecode, rates, band-plan, OAM) decision was not to be backward compatible with BPON
- 2001 : GFP developed (approved 2003)
- 2003 : GPON became G.984
- G.984.1 : GPON general characteristics
- G.984.2 : Physical Media Dependent layer
- G.984.3 : Transmission Convergence layer
- G.984.4 : management and control interface

Basic Configuration of PON

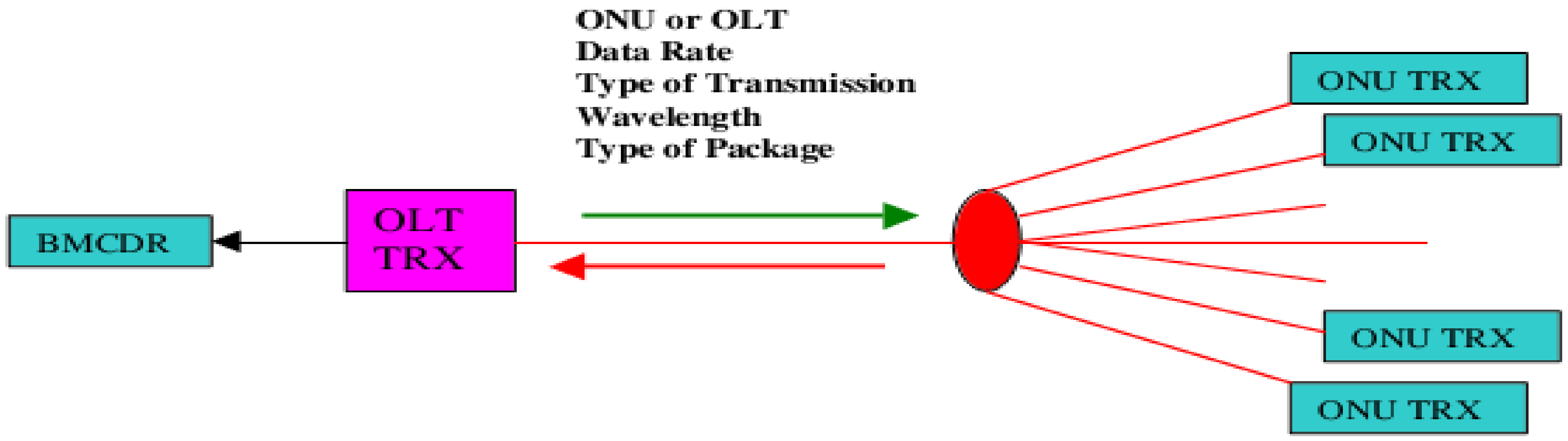


Figure 1: Basic configuration of PON

OLT = Optical Line Termination

ONU = Optical Network Unit

BMCDR = Burst Mode Clock Data Recovery

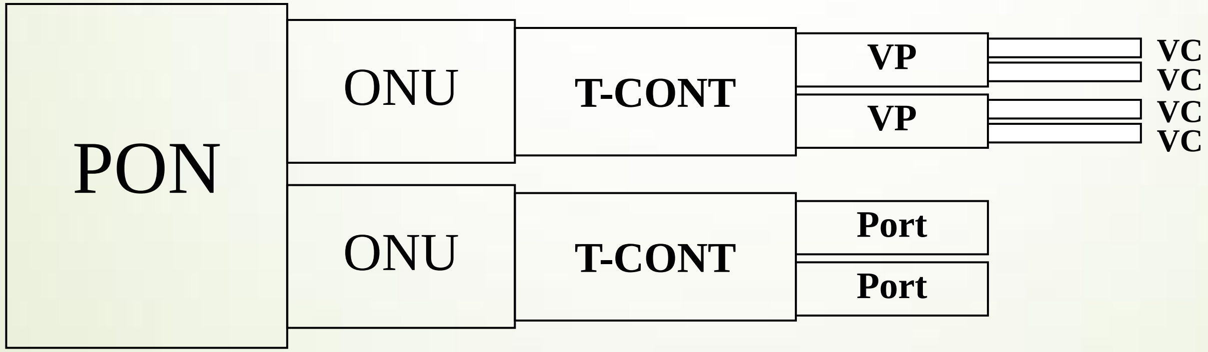
How does it work

- ONU stores client data in large buffers (ingress queues)
- ONU sends a high-speed burst upon receiving a grant/allocation
  - Ranging must be performed for ONU to transmit at the right time
  - DBA - OLT allocates BW according to ONU queue levels
- OLT identifies ONU traffic by label
- OLT extracts traffic units and passes to network

- OLT receives traffic from network and encapsulates into PON frames
- OLT prefixes with ONU label and broadcasts
- ONU receives all packets and filters according to label
- ONU extracts traffic units and passes to client

Labels

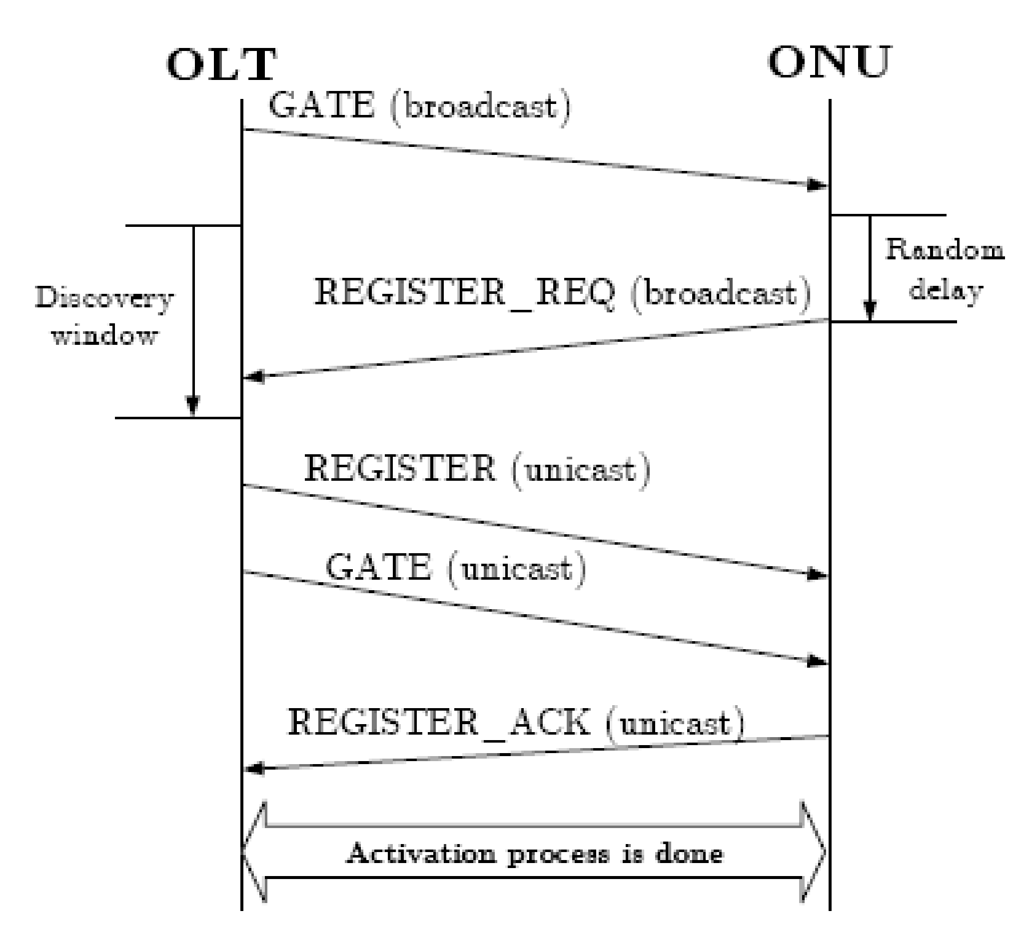
- In an ODN there is 1 OLT, but many ONUs
- ONUs must somehow be labeled for
  - OLT to identify the destination ONU
  - ONU to identify itself as the source
- EPON assigns a single label Logical Link ID to each ONU.



EPON Activation Steps

- The MPCP defines the auto discovery mechanism used to detect the newly-connected ONUs, a circular delay and a MAC address.
- Auto discovery uses the following four messages: GATE, REGISTER REQ, REGISTER and REGISTER ACK.
- These messages are transmitted in the MPCP frame.
- The auto discovery process consists of four steps, which are illustrated in Figure:

EPON Activation Steps



EPON Activation Steps

- Step 1:
  - The Discovery Agent initiates the discovery process using the Discovery GATE message, which includes the starting time and the length of the slot.
- Step 2:
  - Only previously uninitialized ONUs respond to the GATE message. ONUs forwards the REGISTER REQ message.
  - Accidental delays can lead to collisions when initiating multiple ONUs.
  - When the OLT receives a REGISTER REQ message, it detects the MAC address and the circular delay.

EPON Activation Steps

- Step 3:
  - After analyzing and verifying the REGISTER REQ message, the OLT sends the message REGISTER directly to the given ONU using the MAC address obtained during the previous step.
  - The REGISTER message contains a unique logical link identifier (LLID) that is assigned to all ONUs.
- Step 4:
  - After the REGISTER and GATE ON messages are received, the REGISTER ACK confirms that an acceptance of the previous messages has been sent.
  - The REGISTER ACK should be sent in the time interval granted by the GATE message.

Security

- DS traffic is broadcast to all ONUs, so encryption is essential.
- Easy for a malicious user to reprogram ONU to capture desired frames
- US traffic not seen by other ONUs, so encryption is not needed
- do not take fiber-tappers into account
- EPON does not provide any standard encryption method
  - can supplement with IPsec or MACsec
  - many vendors have added proprietary AES-based mechanisms
  - in China special China Telecom encryption algorithm

Security

- BPON used a mechanism called churning.
- Churning was a low cost hardware solution (24b key) with several security flaws.
- So G.983.3 added AES support - now used in GPON.
- OLT encrypts using AES-128 in counter mode
- Only payload is encrypted (not ATM or GEM headers)
- Encryption blocks aligned to GTC frame

Dynamic Bandwidth Allocation

- MANs and WANs have relatively stationary BW requirements due to aggregation of large number of sources
- But each ONU in a PON may serve only 1 or a small number of users
- So BW required is highly variable
- It would be inefficient to statically assign the same BW to each ONU
- So PONs assign dynamically BW according to need.

Dynamic Bandwidth Allocation

- The need can be discovered
  - by passively observing the traffic from the ONU
  - by ONU sending reports as to state of its ingress queues
- The goals of a Dynamic Bandwidth Allocation algorithm are
  - maximum fiber BW utilization
  - fairness and respect of priority
  - minimum delay introduced

PON Advantages

- Shared infrastructure translates to lower cost per customer
  - minimal number of optical transceivers
  - feeder fiber and transceiver costs divided by N customers
- Passive splitters translate to lower cost
  - can be installed anywhere
  - no power needed
  - essentially unlimited MTBF

PON Advantages

- Fiber data-rates can be upgraded as technology improves
  - initially 155 Mbps
  - then 1.25 Gbps
  - now 2.5 Gbps and higher

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