Switching Schemes in Optical Networks

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Outline

1) Access/Backhaul networks

2) Metro networks

3) Core networks

4) Data center networks

Telecom Network Domains

- Access/Backhaul networks

connect end-users to the Central Office (CO) of service provider (few kilometers)

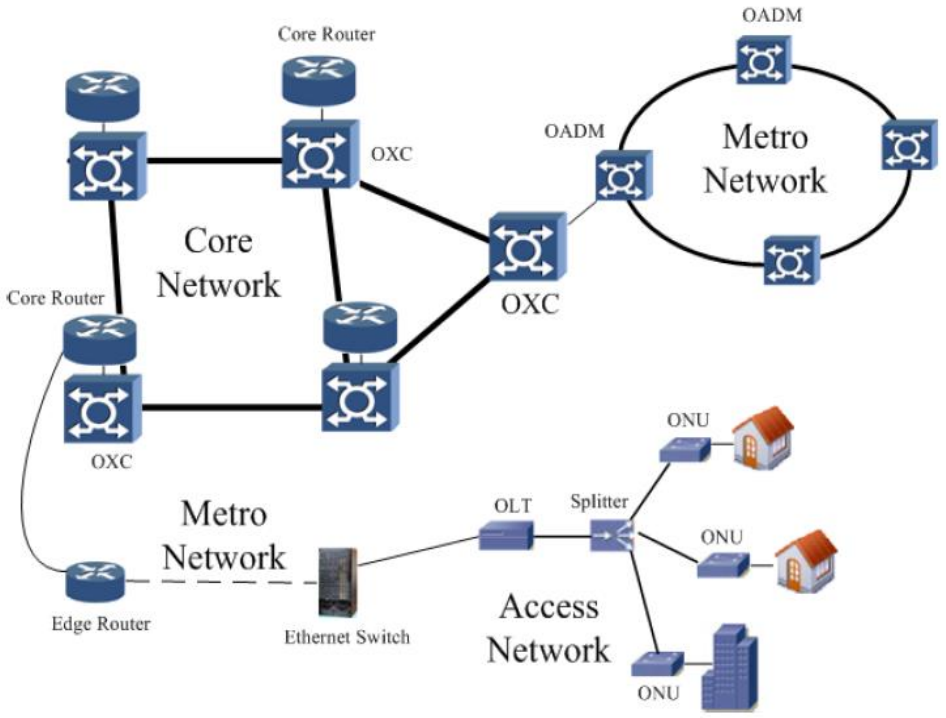
- Metro networks

Metropolitan region

(tens or hundreds of kilometers)

- Core networks:

Nationwide or global coverage (thousands of kilometers)



Access/Backhaul Networks

- Wireless

  Advantages: Mobility / Ubiquity / Easy deployment

  Drawbacks: Low energy efficiency

- Copper

  Advantages: Low cost / High reliability

  Drawbacks: Limited capacity / Low energy efficiency / No mobility

- Fiber

  Advantages: Almost unlimited data rate / High reliability / High energy efficiency

  Drawbacks: High cost / No mobility

Access/Backhaul Networks

- Wireless

1) Long Term Evolution (LTE)
2) Wi-Fi
3) WiMax
4) Microwave (6 – 42 GHz)

Access/Backhaul Networks

- Wireless
  - LTE (Long Term Evolution)
    - Improvements: higher data rates, improve spectral efficiency, reduce network latency, support flexible channel bandwidths, simplify and flatten the network by utilizing an all-packet (Ethernet/IP) architecture.

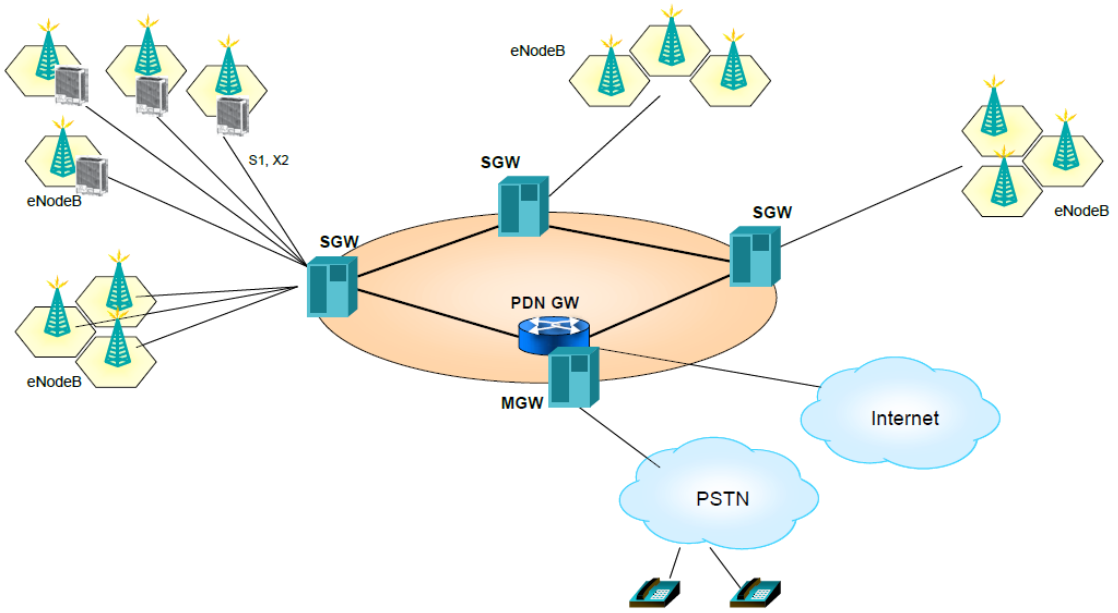
- Components:

  1) EnodeB

  2) Serving Gateway (SGW)

  3) Packet data network gateway (PDN GW)

  4) Mobile gateway (MGW)



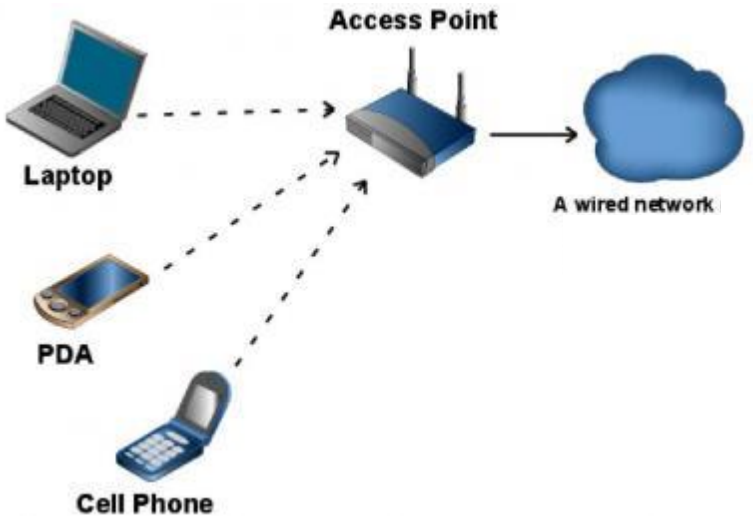
Access/Backhaul Networks

- Wireless
  - LTE (Long Term Evolution)
    - SOFDMA (Scalable Orthogonal Frequency Division Multiple Access).
    - MIMO (Multiple Input Multiple Output).
    - Heterogeneous network deployment.

Wireless Capacity Requirements								
	Voice Spectrum (MHz)	Data Spectrum (MHz)	Voice Spectral Efficiency (bit/s/Hz)	Data Efficiency (bit/s/Hz)	# Sectors	Traffic Eng % Peak	Total Bandwidth (Mbps)	# T1s
GSM 2G	1.2		0.52		3	70%	1.3	1
GSM / Edge 2.75G	1.2	2.3	0.52	1	3	70%	6.1	4
HSDPA 3G		5	0	2	3	70%	21.0	14
LTE 4G		**5**	**0**	**3.8**	**3**	70%	**39.9**	**n/a**
LTE 4G		**10**	**0**	**3.8**	**3**	70%	**79.8**	**n/a**

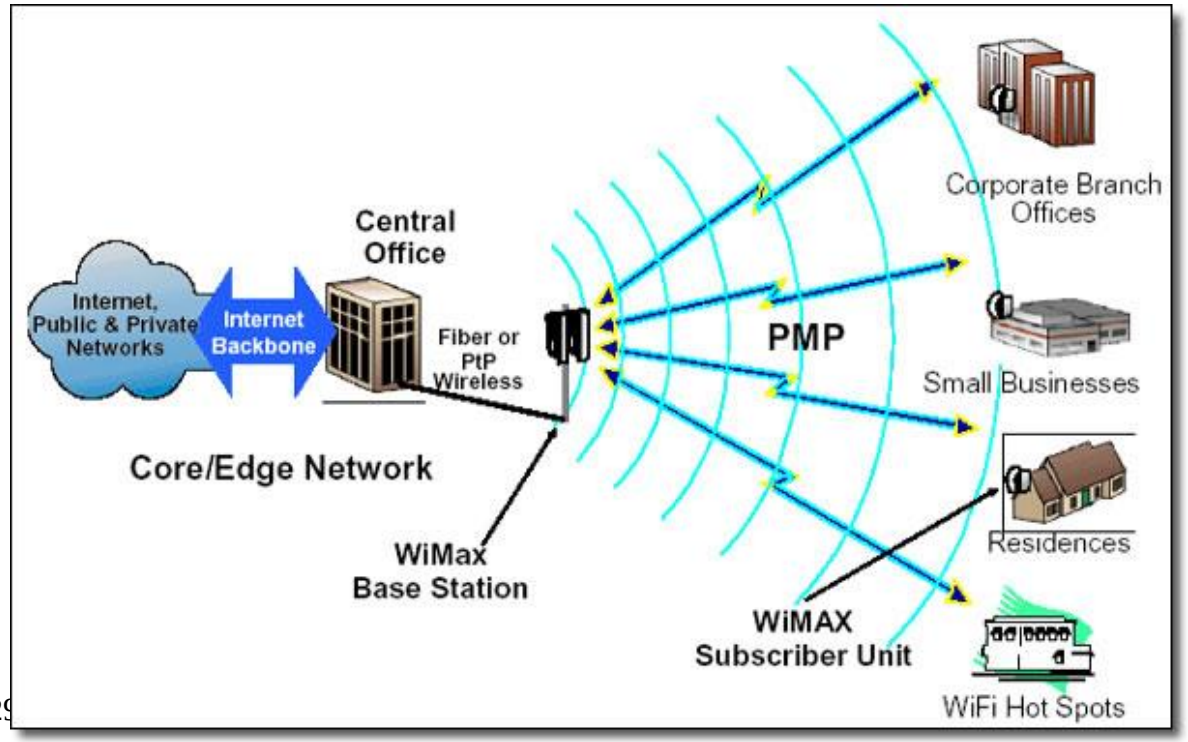
Access/Backhaul Networks

- Wireless
  - Wi-Fi
    - IEEE 802.11 a,b,g,n.
    - Frequency bands: 2.4 GHz – 5 GHz.
    - IEEE 802.11n maximum data rate up to 600 Mbps.



Access/Backhaul Networks

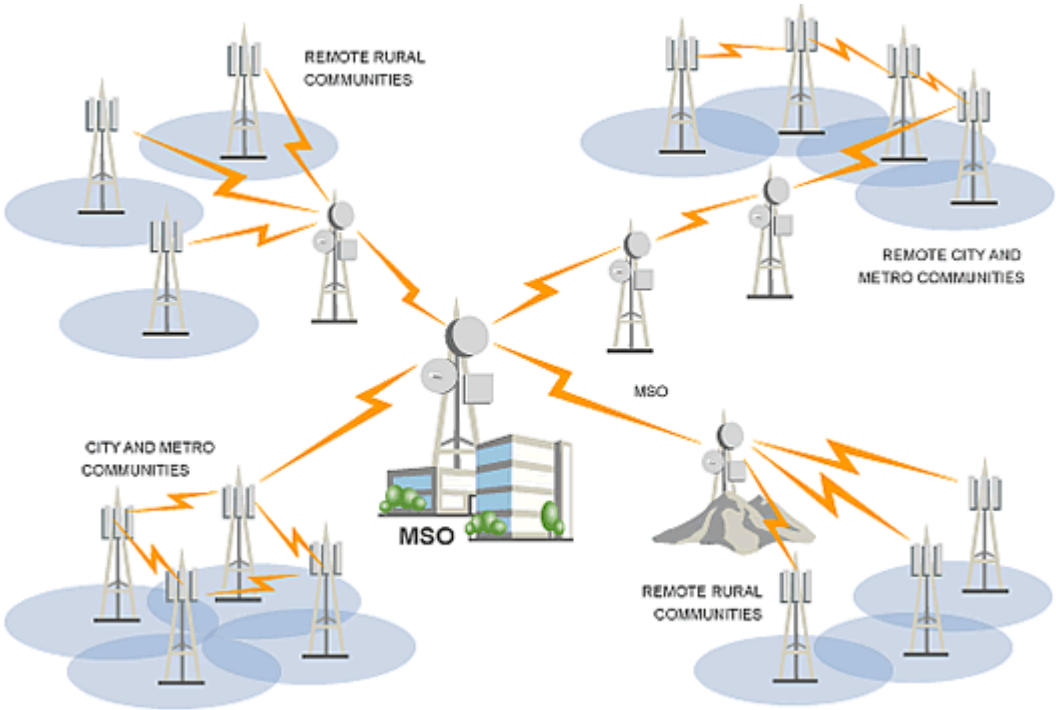
- Wireless
  - WiMax
    - IEEE 802.16
    - The standards allow operation in any band from 2 to 66 GHz.
    - IEEE 802.11m-2011 maximum data rate up to 1 Gbps.



Access/Backhaul Networks

- Wireless
  - Microwave (6 – 42 GHz)

- Cellular backhaul
- Connect each cellular base station site to a hub (Multi-Service Operator - MSO) that is in turn connected to the metro network.
- Star, tree-and-branch, ring topologies.



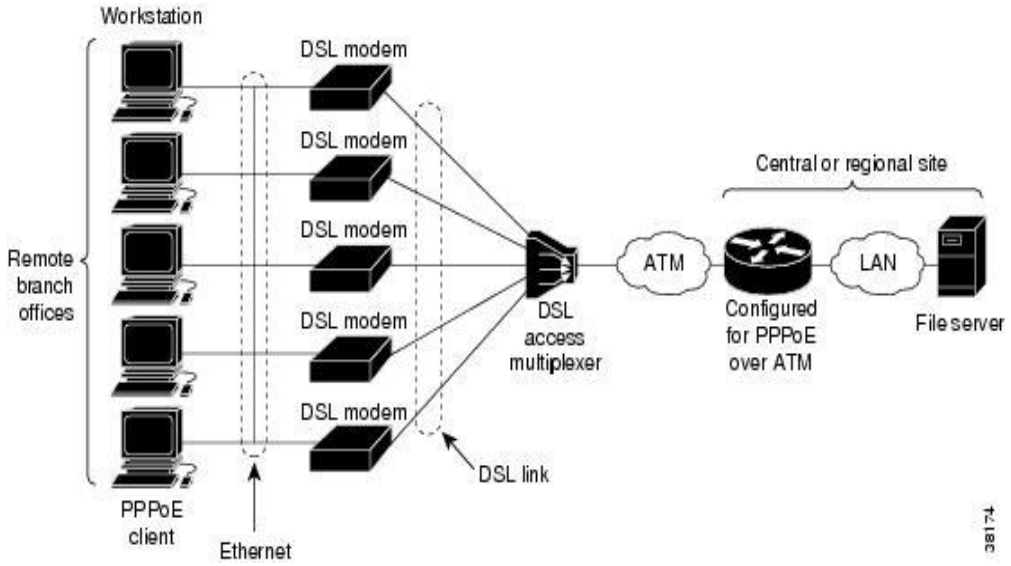
Access/Backhaul Networks

- Copper

  1) Digital Subscriber Line (DSL)
  2) Hybrid Fiber-Coaxial (HFC)

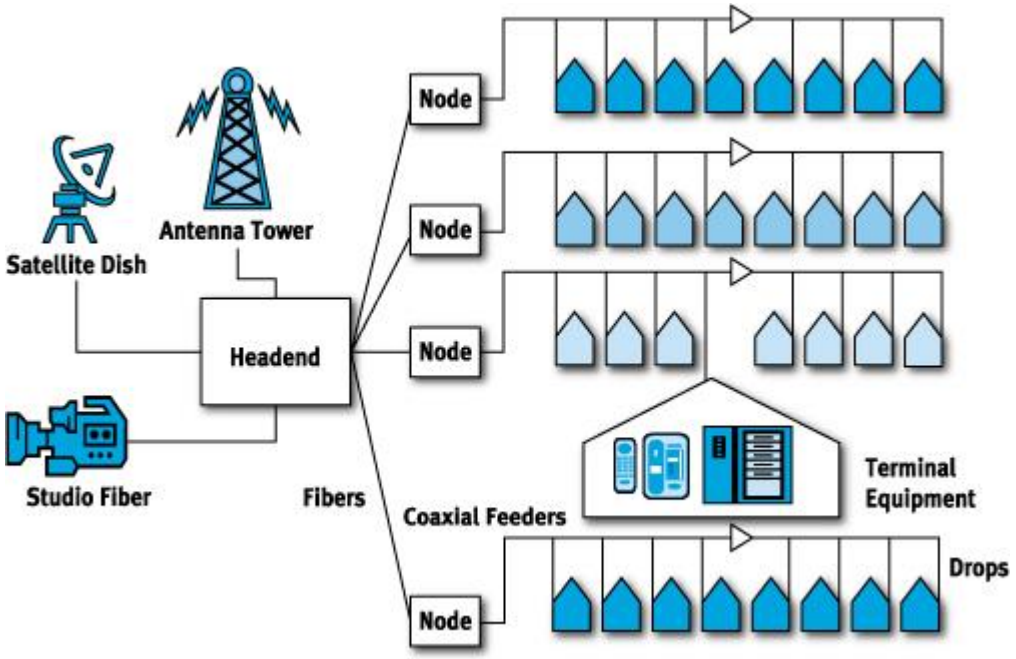
Access/Backhaul Networks

- Copper
  - DSL (Digital Subscriber Line)
    - DSL is provided through copper pairs originally installed to deliver a fixed-line telephone service
    - Include: ADSL, ADSL2, ADSL2+ (24 Mbps downstream – 1 Mbps upstream), VDSL (26 Mbps), VDSL2 (250 Mbps).



Access/Backhaul Networks

- Copper
  - HFC (Hybrid Fiber-Coaxial)
    - Cable distribution networks were initially deployed to deliver television services.
    - Use fiber from Headend office to a remote Node and coaxial link from node to end-users.



Access/Backhaul Networks

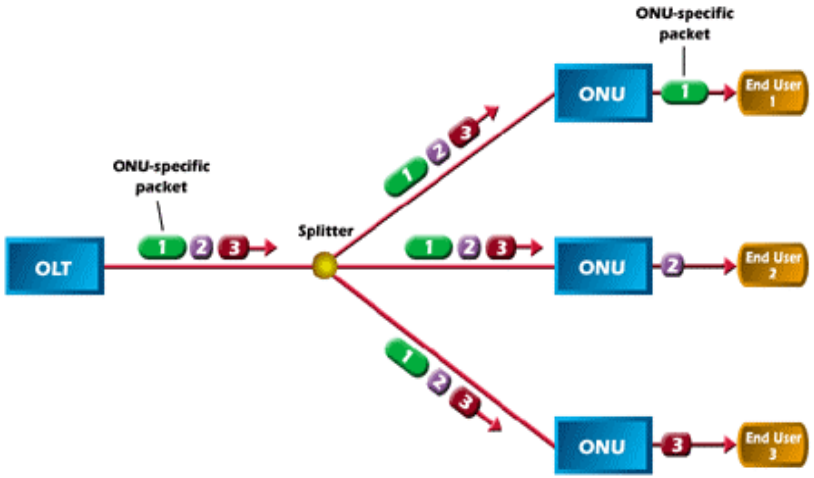
- Fiber

  1) Passive Optical Networks (PON)
  2) Point-to-point Ethernet

Access/Backhaul Networks

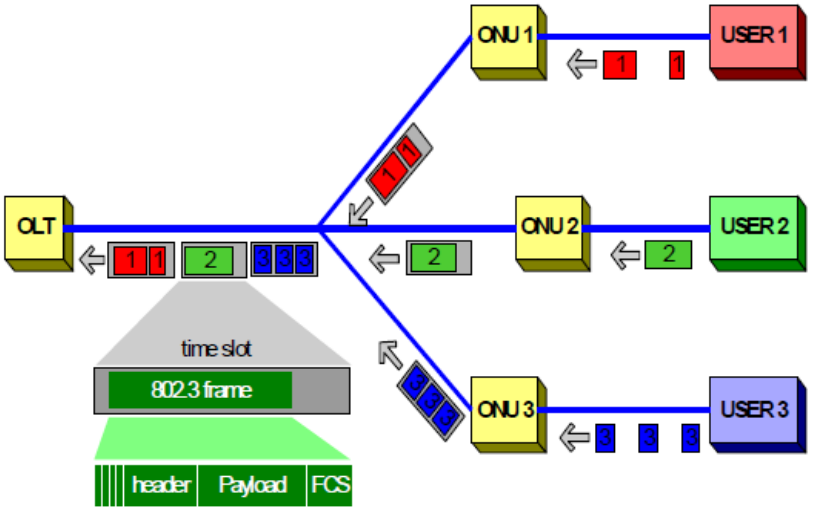
- Fiber
  - PON (Passive Optical Networks)

- Components:
  - *1) Optical Line Terminal (OLT)*
  - *2) Optical Networking Unit (ONU)*
  - *3) Passive optical splitter*



- Downstream: broadcast from OLT to ONU.

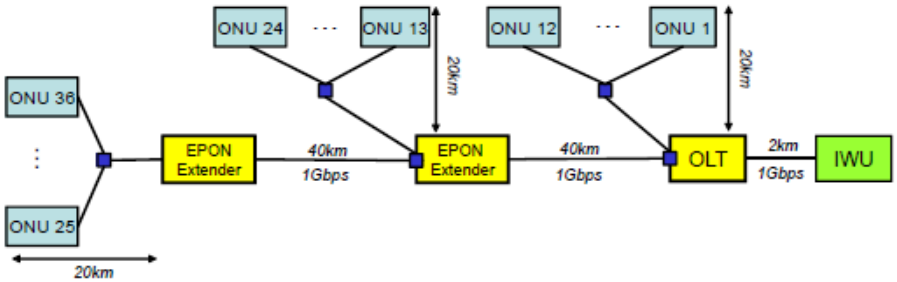
- Upstream: the OLT assigns the turns to the ONU using a Dynamic Bandwidth Assignment (DBA) algorithm.
  - EX: Interleaved Polling with Adaptive Cycle Time (IPACT)



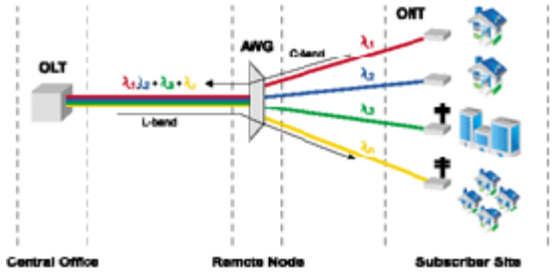
Access/Backhaul Networks

- Fiber
  - PON (Passive Optical Networks)

1) EPON (IEEE 802.3ah) and GPON (ITU-T G.984)
2) 10G-EPON (IEEE 802.3av) and XGPON (ITU-T G.987)
3) Wavelength Division Multiplexing PON (WDM-PON)
4) Orthogonal Frequency Division Multiple Access PON (OFDMA-PON)
5) Long Reach PON (LR-PON)



LR-PON

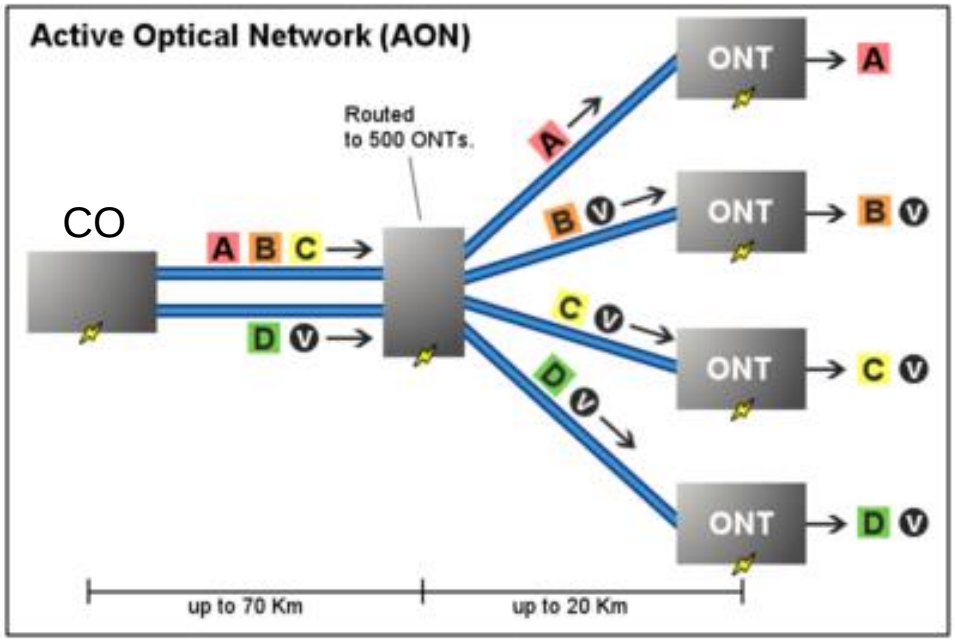


WDM-PON

Access/Backhaul Networks

- Fiber
  - Point-to-point Ethernet

- Uses optical Ethernet switches to distribute the signal to end users.
- The Ethernet switch is powered and employs electronic buffers to avoid collisions in upstream and downstream.



Metro Networks

1) SONET/SDH

2) Metro Ethernet

3) Optical WDM link

Metro Networks

- SONET/SDH

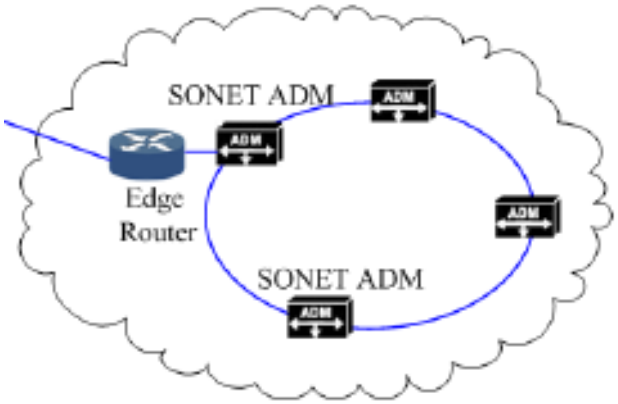
1) Aggregate low-bit-rate traffic flows into high-bandwidth optical pipes using SONET/SDH ADMs (Add and Drop Mux).

2) Advantages:

a) each of the aggregated flow can be retrieved without de-multiplexing the entire frame,

b) control info for fast network recovery.

3) Drawbacks: Coarse bandwidth granularity and high energy consumption



SONET ADM (Ciena CN 3600 Intelligent Multiservice Switch)

Metro Networks

- Metro Ethernet

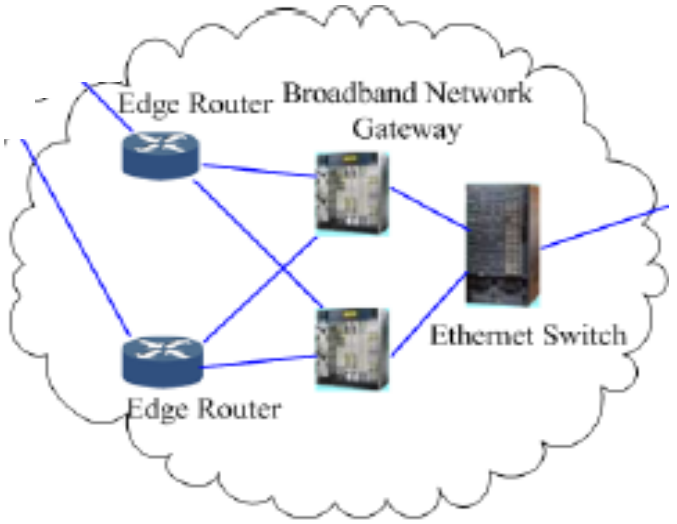
1) Metropolitan area network (MAN) that is based on Ethernet standards.

2) Advantages:

a) An Ethernet interface is much less expensive than a SONET/SDH interface of the same bandwidth.

b) Ethernet supports high bandwidths with fine granularity.

3) Drawbacks: very power consuming.



Ethernet switch (Cisco Catalyst 6513)

Metro Networks

- Optical WDM Ring

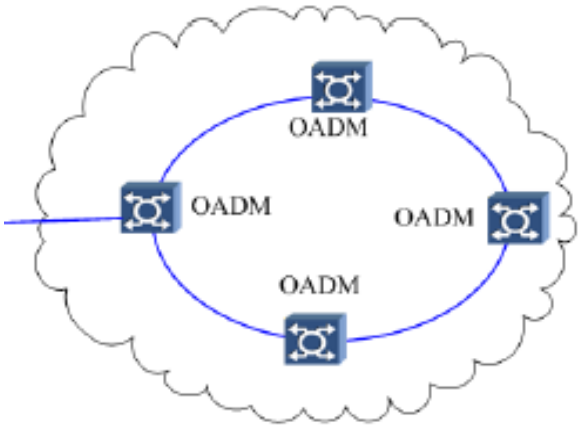
1) Optical WDM Ring employs OADMs (Optical Add and Drop Mux) to add and drop optical signals directly in the optical domain.

2) Advantages:

   a) very high capacity,

   b) low energy consumption.

3) Drawbacks: coarse granularity and high costs.

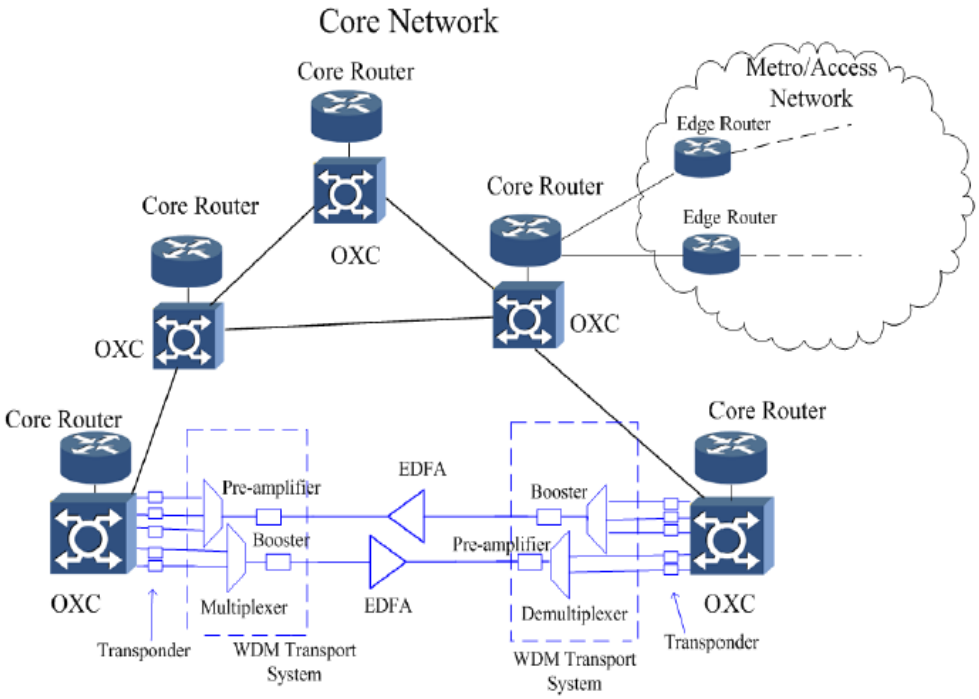


Ciena Select OADM

Core Networks

- IP over WDM (Wavelength Division Multiplexing):

- DWDM: the optical fiber is divided into multiple independent wavelength channels.
- Today up to 96 wavelength channels per fiber. Each channel run at 40 Gbps (soon 100 Gbps).
- Overlay model: IP layer and optical layer.
- Control plane (e.g. MPLS) to integrate IP and optical layers.



Core Networks

- IP over WDM (Wavelength Division Multiplexing):

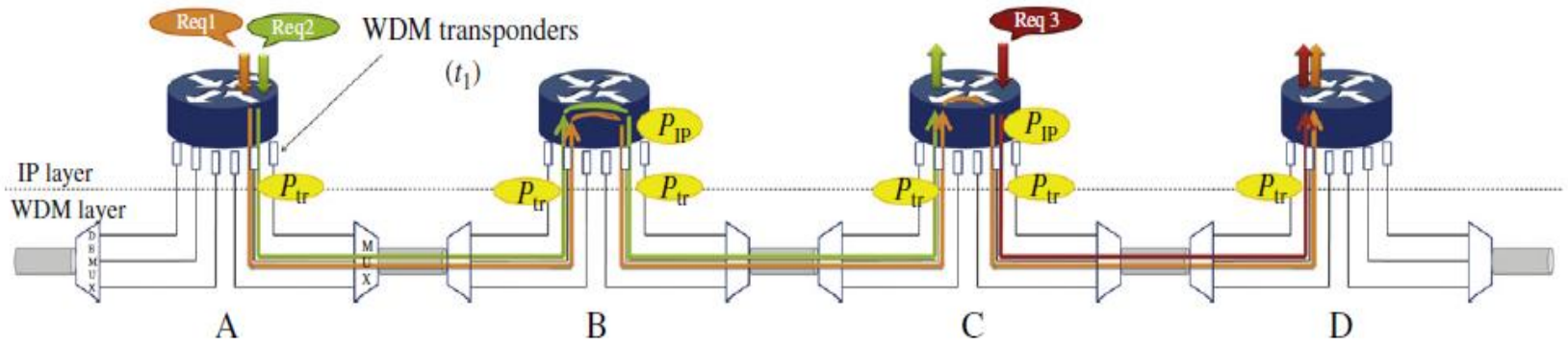
  - Electronic switching
  - Optical switching:
    1) Optical Circuit Switching (OCS)
    2) Optical Burst Switching (OBS)
    3) Optical Packet Switching (OPS)

Core Networks

- IP over WDM with electronic switching

- Transmission in the optical domain
- Switching and control information processing in the electronic domain
- Data are O/E/O converted at each node along the path

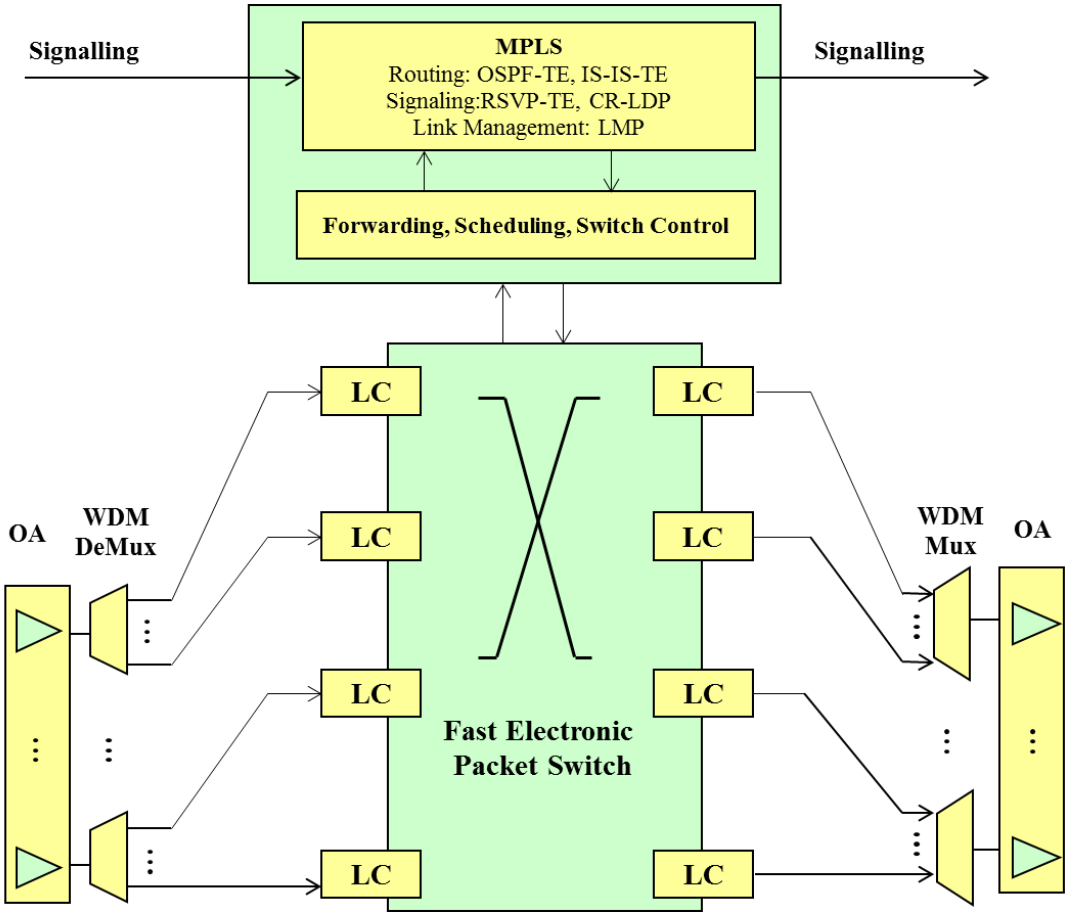
- The optical layer provides lightpath (high capacity optical pipes)
  - The IP layer performs routing and forwarding decisions
- Traffic grooming: many low bit-rate flows are multiplexed on the same lightpath



Core Networks

- IP over WDM with electronic switching

- Electronic node architecture:
  - Control logic
  - Switching fabric
  - Optical WDM interface



Core Networks

- IP over WDM with electronic switching

Juniper T series

TX Matrix Plus

6.4 Tbps

Alcatel-Lucent

1870 Transport Tera Switch

8 Tbps

Cisco CRS (Carrier Routing System) - 3

Up to 322 Tbps

"The Cisco CRS-3 triples the capacity of its predecessor, the Cisco CRS-1 Carrier Routing System, with up to 322 Terabits per second, which enables the entire printed collection of the Library of Congress to be downloaded in just over one second; every man, woman and child in China to make a video call, simultaneously; and every motion picture ever created to be streamed in less than four minutes"

Core Networks

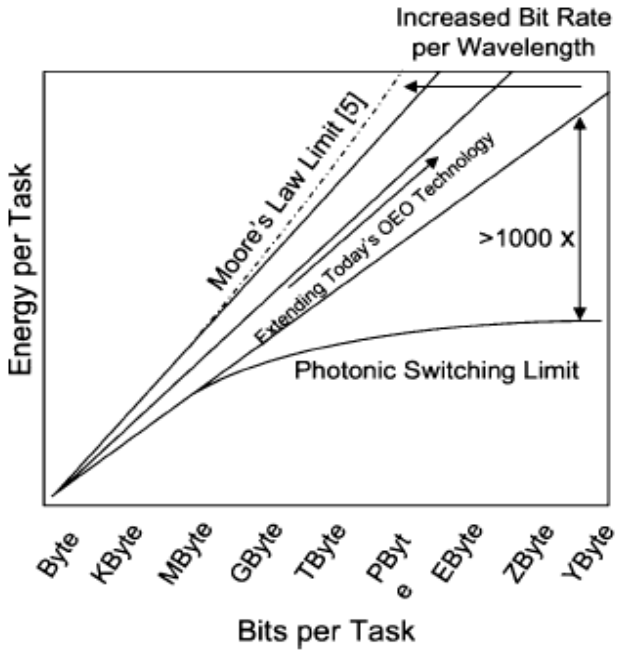
- IP over WDM with electronic switching

Advantages:

- High performance (negligible data losses using efficient scheduling algorithms)
- High bandwidth utilization (statistical mux)
- QoS and traffic engineering policies

Drawbacks:

- Power consumption (up to 1 MW per node)
- Low scalability (power consumption increases linearly with the bit-rate)



Core Networks

- IP over WDM with optical switching

To decrease power consumption → Optical switching solutions

Optical switching:

- Transmission and switching in the optical domain
- Control information processing in the electronic domain

Optical switching in IP over WDM networks:

- Optical Circuit Switching (OCS)
- Optical Burst Switching (OBS)
- Optical Packet Switching (OPS)

Core Networks

- IP over WDM with optical switching

Advantages:

- Low power consumption
- High scalability (energy consumption does not increase significantly with the bit-rate).
- No need for O/E/O conversion in the core network

Drawbacks:

- Lack of optical buffering solutions (No optical RAMs)

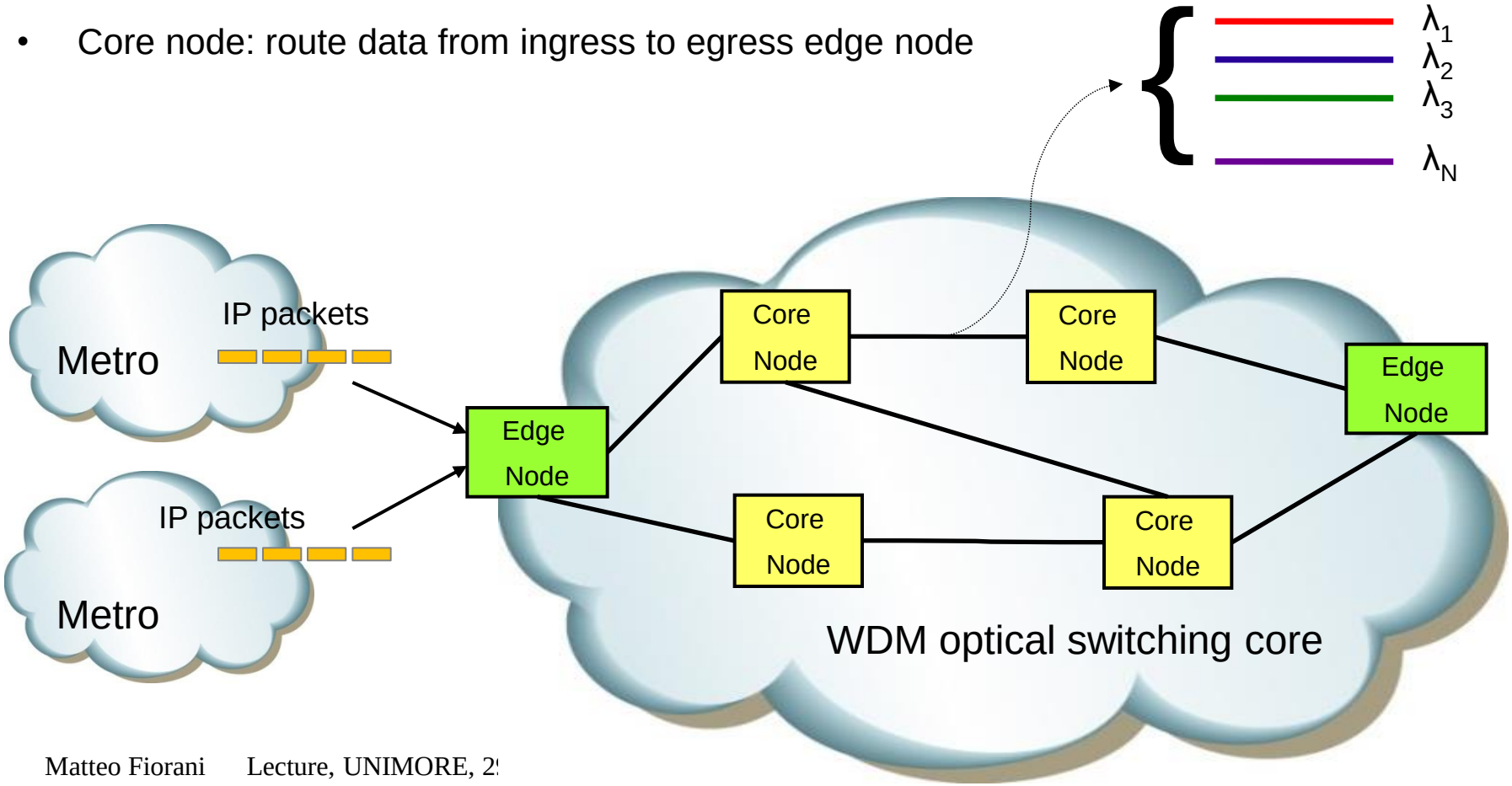
Fiber Delay Lines (FDLs):

- Data cannot be accessed at any time but only after fixed intervals
- Large physical size that limits the storage capacity (for 10 Gb → 50000 km)

- Lower performance (non negligible data losses)
- Difficult to implement QoS and traffic engineering policies

Core Networks

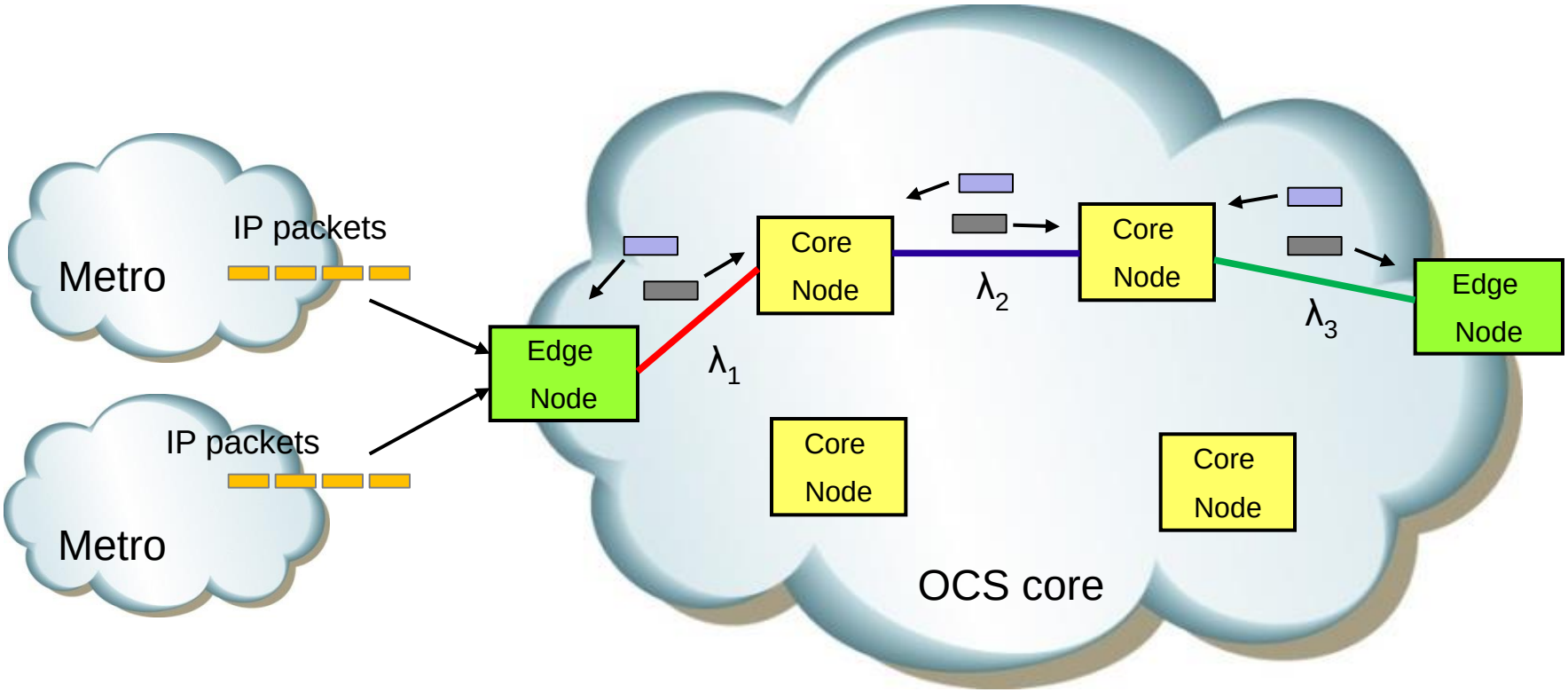
- IP over WDM with optical switching
  - Edge node: located at the periphery of the network are used to connect to metro/access networks
  - Core node: route data from ingress to egress edge node



Core Networks

- IP over WDM with OCS

- Control information are sent over dedicated wavelengths (out-of-band signaling).
- Two-way reservation mechanism: the source edge node waits for the acknowledgment from the destination edge node before starting data transmission.

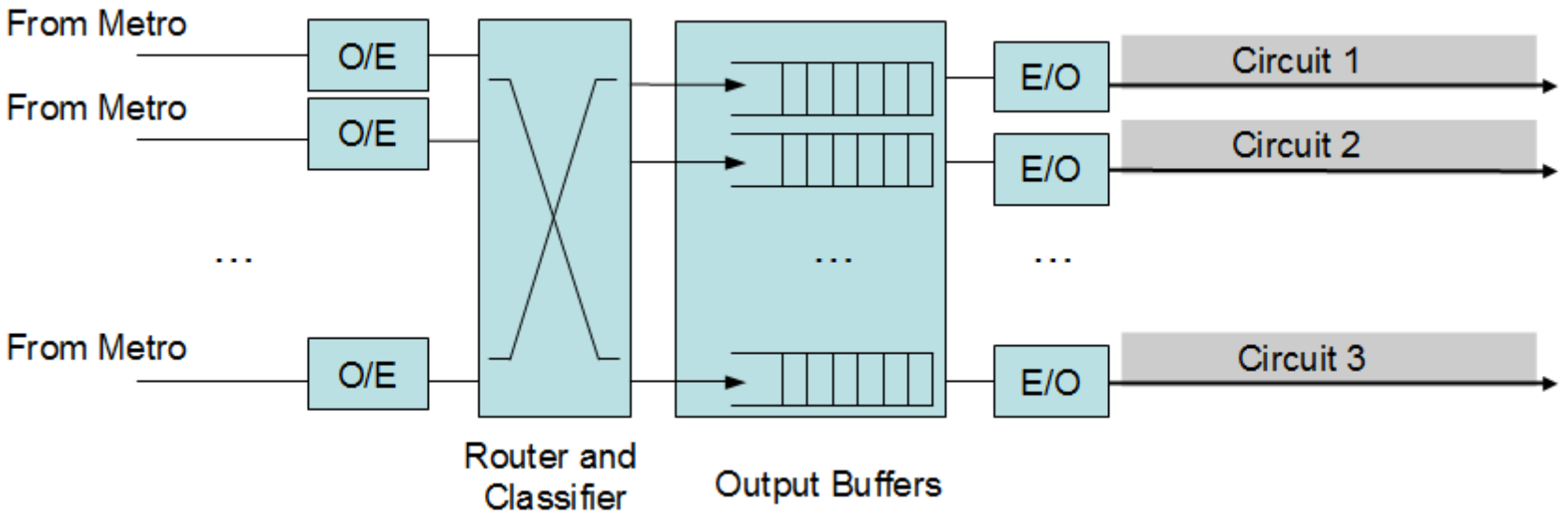


Core Networks

- IP over WDM with OCS

OCS edge node architecture:

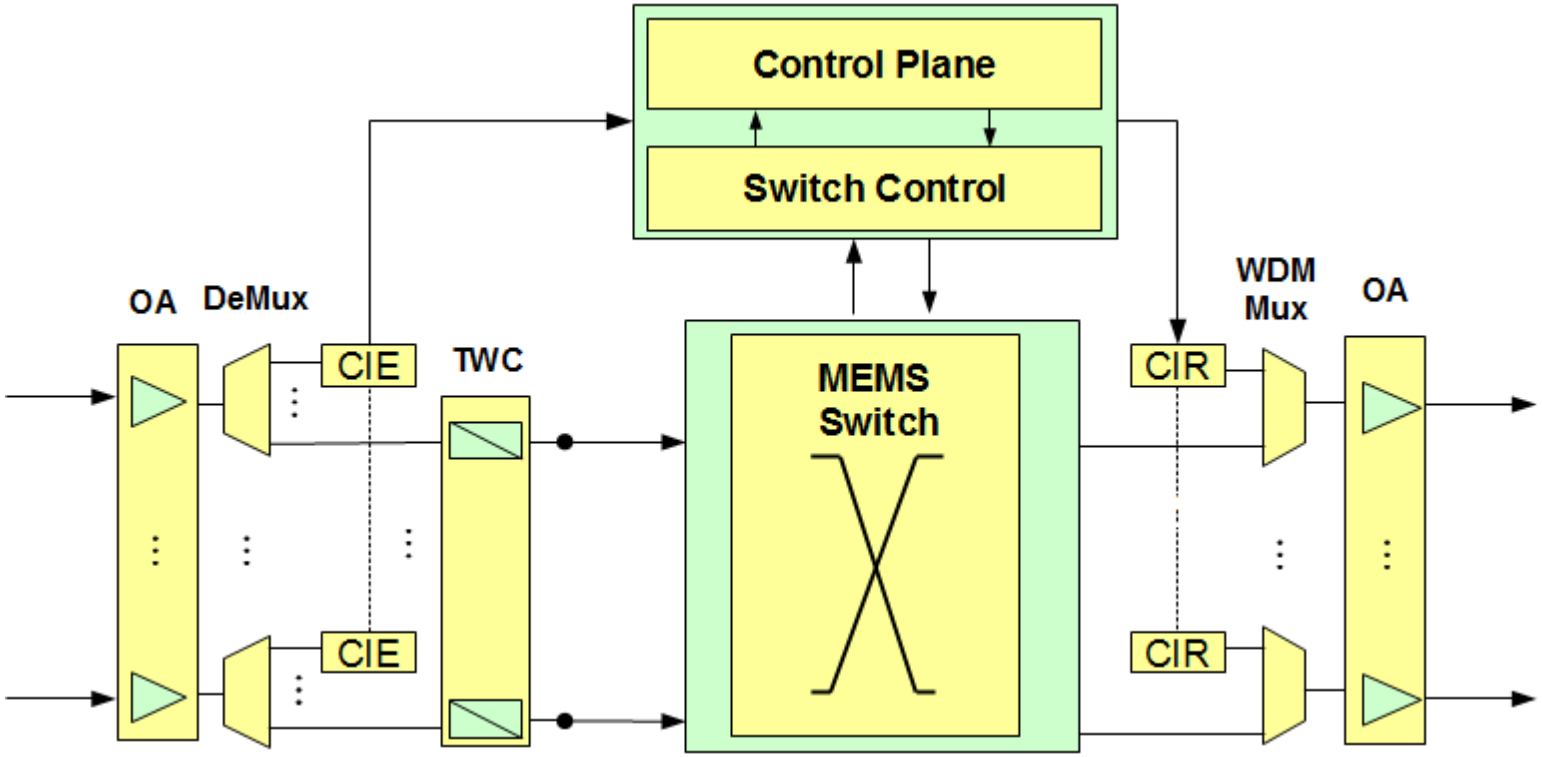
- Data are buffered until the circuit has been established
- If the circuit establishment fails no data is lost



Core Networks

- IP over WDM with OCS

OCS core node architecture:



Core Networks

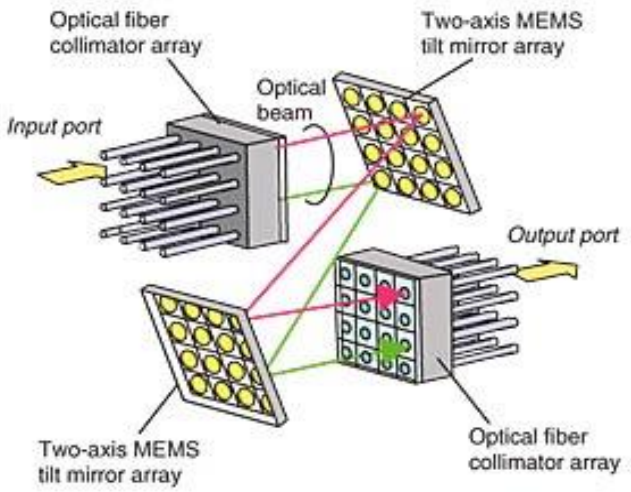
- IP over WDM with OCS

  - Switching fabric:

    - MEMS – Micro electro-mechanical systems
      - Miniature movable mirrors made in silicon
      - Transmit or deflect optical signal depending on the position

    - Why MEMS:
      - It is possible to build switching fabrics of large size (up to 1000×1000)
      - Low power consumption

    - Drawback of MEMS:
      - Switching time is in the order of milliseconds



Core Networks

- IP over WDM with OCS

Advantages:

- ✓ High reliability: based on mature optical technology
- ✓ Low power consumption: using slow optical switches (MEMS)
- ✓ Fits large and stable traffic flows: suitable for multimedia applications

Drawbacks:

- Low bandwidth utilization with bursty source: not suitable for short and high variable traffic
- Low network flexibility: not easily adaptable to new applications services

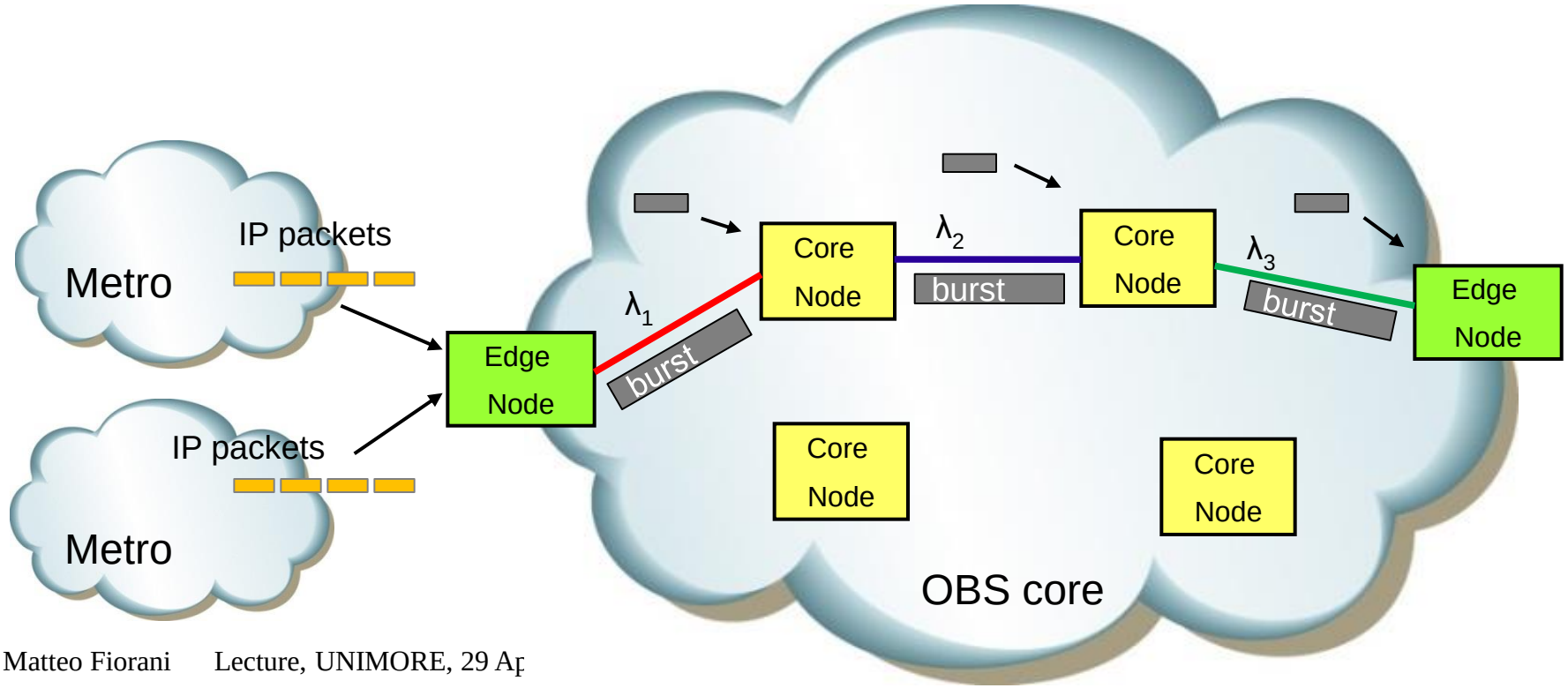
- Today:

  Optical Bypass ⇨ integrates electronic switching and OCS

Core Networks

- IP over WDM with OBS

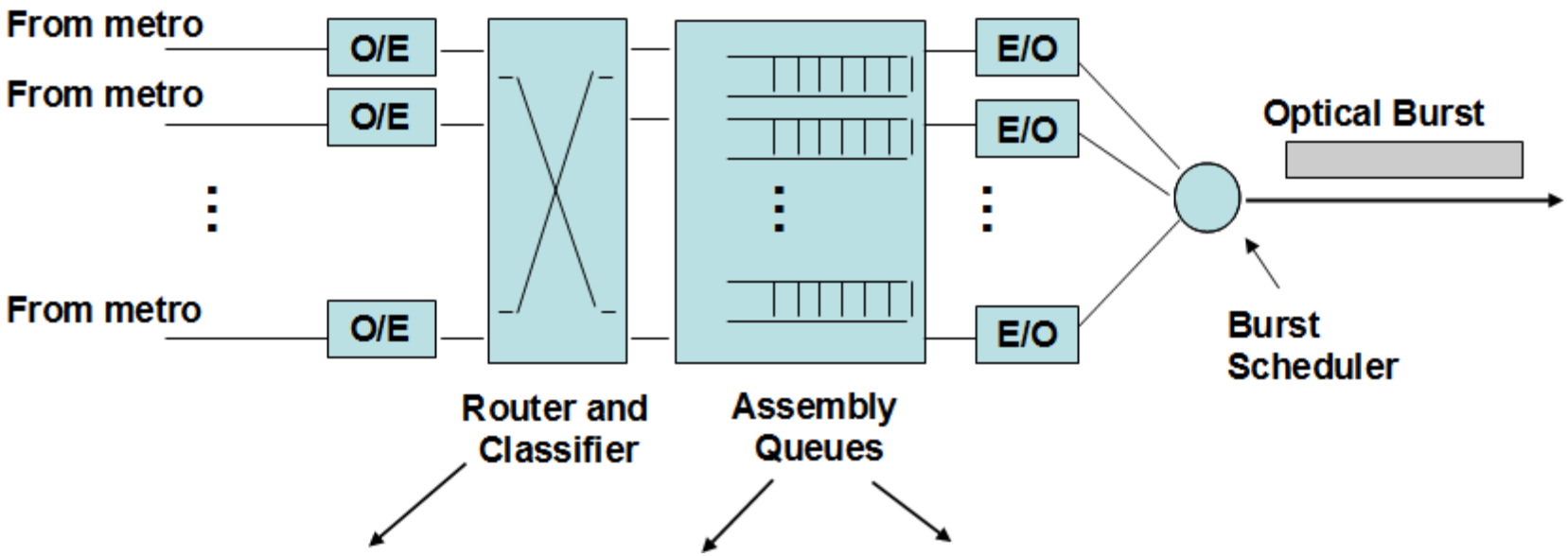
- Data are gathered at the edge node and assembled into bursts
- Out-of-band signaling
- One-way reservation mechanism: burst sent after a fixed delay (offset-time)



Core Networks

- IP over WDM with OBS

OBS edge node architecture:



Select the assembly queue:

1) Destination node
2) Class of service

Queue discipline:

1) Per flow
2) Mixed flow

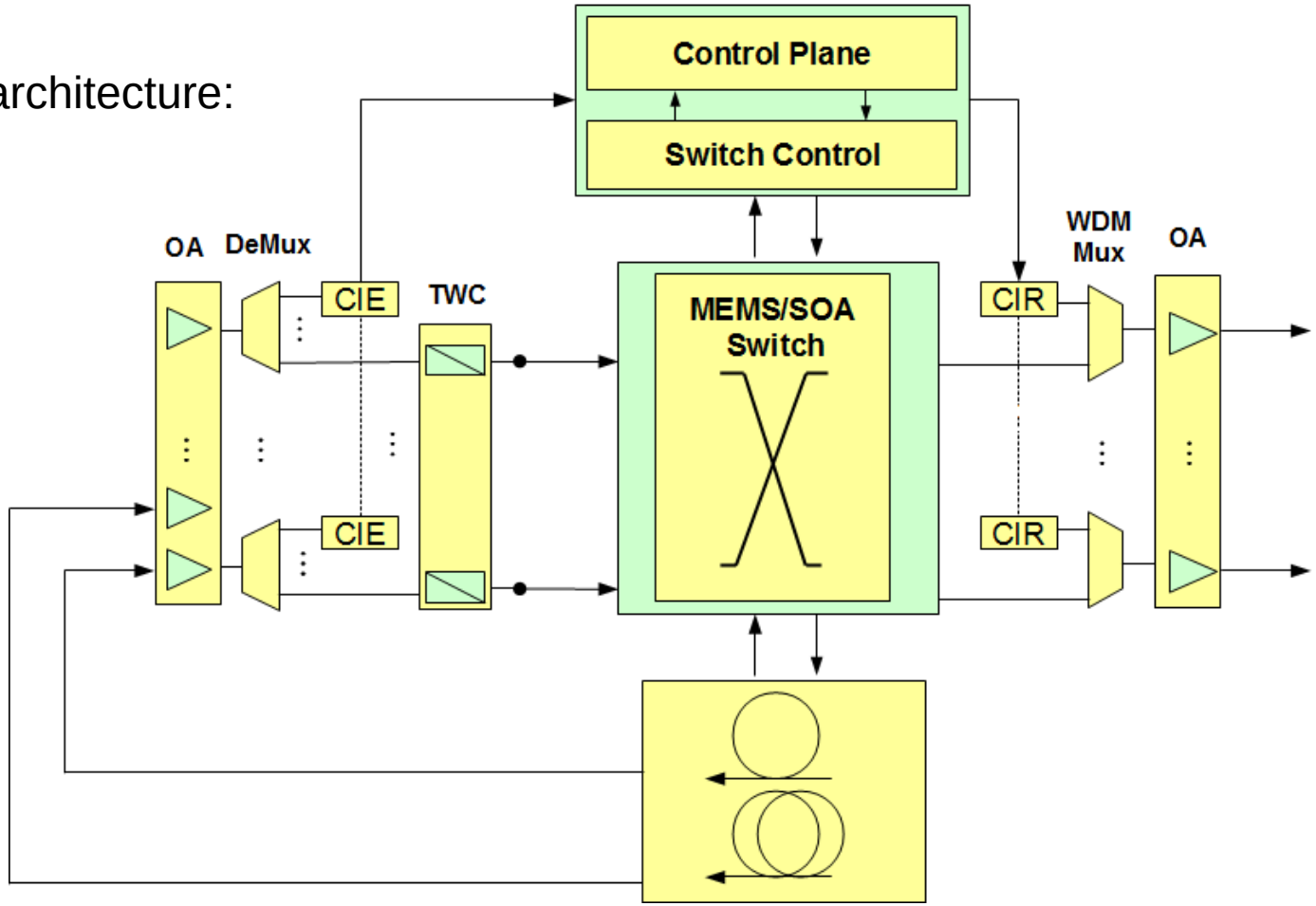
Assembly algorithms:

1) Timer based
2) Length based
3) Mixed timer/length

Core Networks

- IP over WDM with OBS

OBS core node architecture:



Core Networks

- IP over WDM with OBS

  - Switching fabric:
    - SOA – Semiconductor Optical Amplifiers
    - Switching capacity in the order of nanoseconds
    - Drawbacks of SOAs :
      - must be organized in complex multi-stages networks
      - higher energy consumption than MEMS

Core Networks

- IP over WDM with OBS

  - Reservation mechanisms:
    1) Just-In-Time (JIT) immediate setup and explicit release
    2) Just-Enough-Time (JET) delayed setup and implicit release

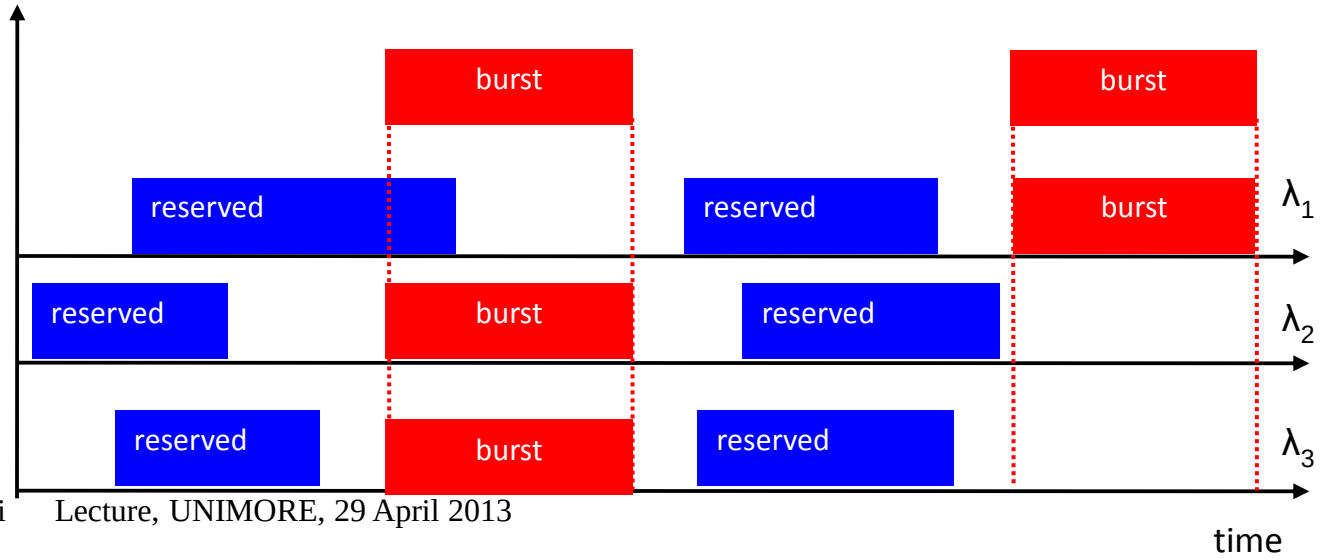
  - Contention resolution techniques:
    1) Time domain: use optical buffers (FDLs)
    2) Wavelength domain: use all-optical wavelength converters
    3) Space domain: data is transmitted over an alternative route (deflection routing)
    4) Segmentation: only the conflicting part of the burst is dropped

Core Networks

- IP over WDM with OBS

- Using JET the core nodes must implement burst scheduling
- Trade-off: efficiency VS processing time
- Scheduling algorithms:

  1) Horizon
  2) First-Fit Unscheduled Channel with Void Filling (FFUC-VF)
  3) Best-Fit with void filling (BF-VF)



Core Networks

- IP over WDM with OBS

Advantages:

- ✓ High bandwidth utilization (statistical multiplexing)
- ✓ No need for optical buffers (FDLs)
- ✓ Low power consumption

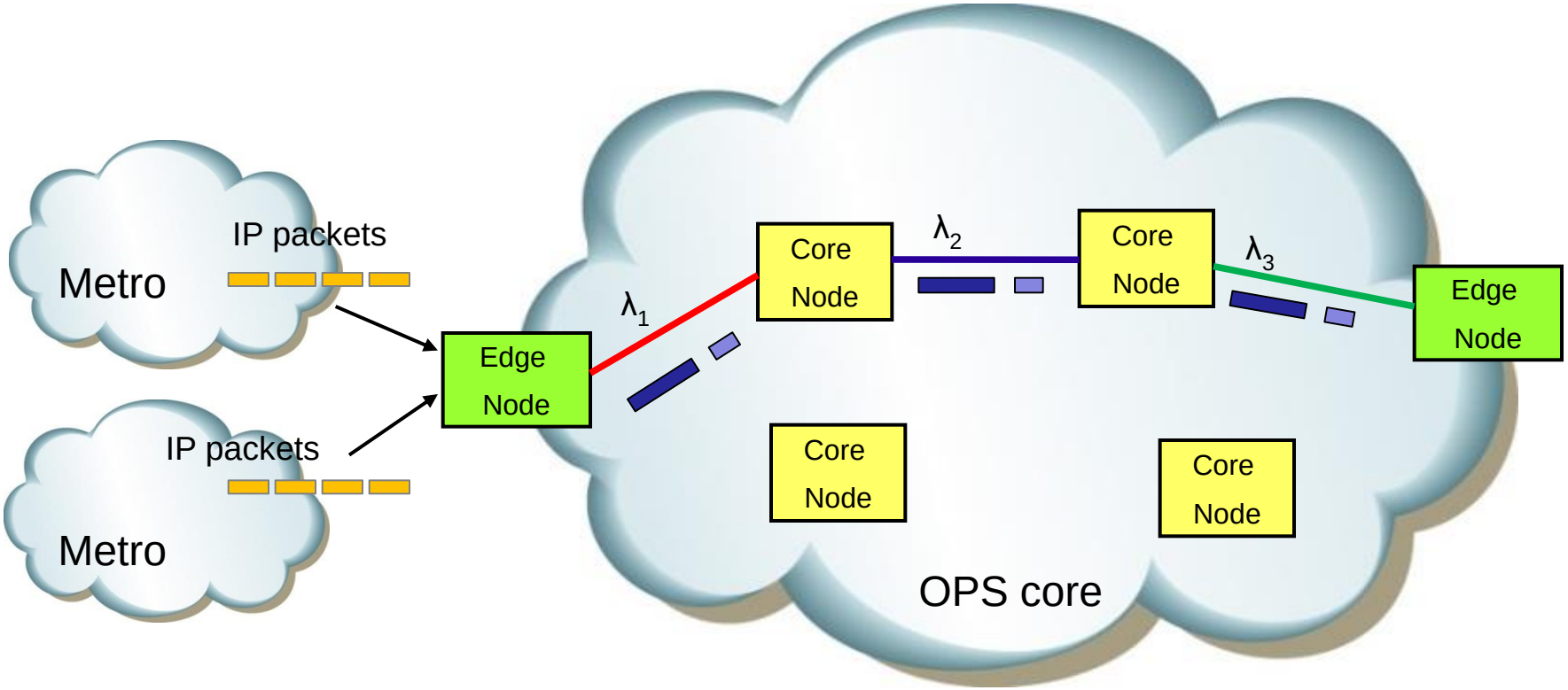
Drawbacks:

- High burst blocking probability, that can be solved only with expensive and power consuming techniques
- High complexity of the control logic

Core Networks

- IP over WDM with OPS

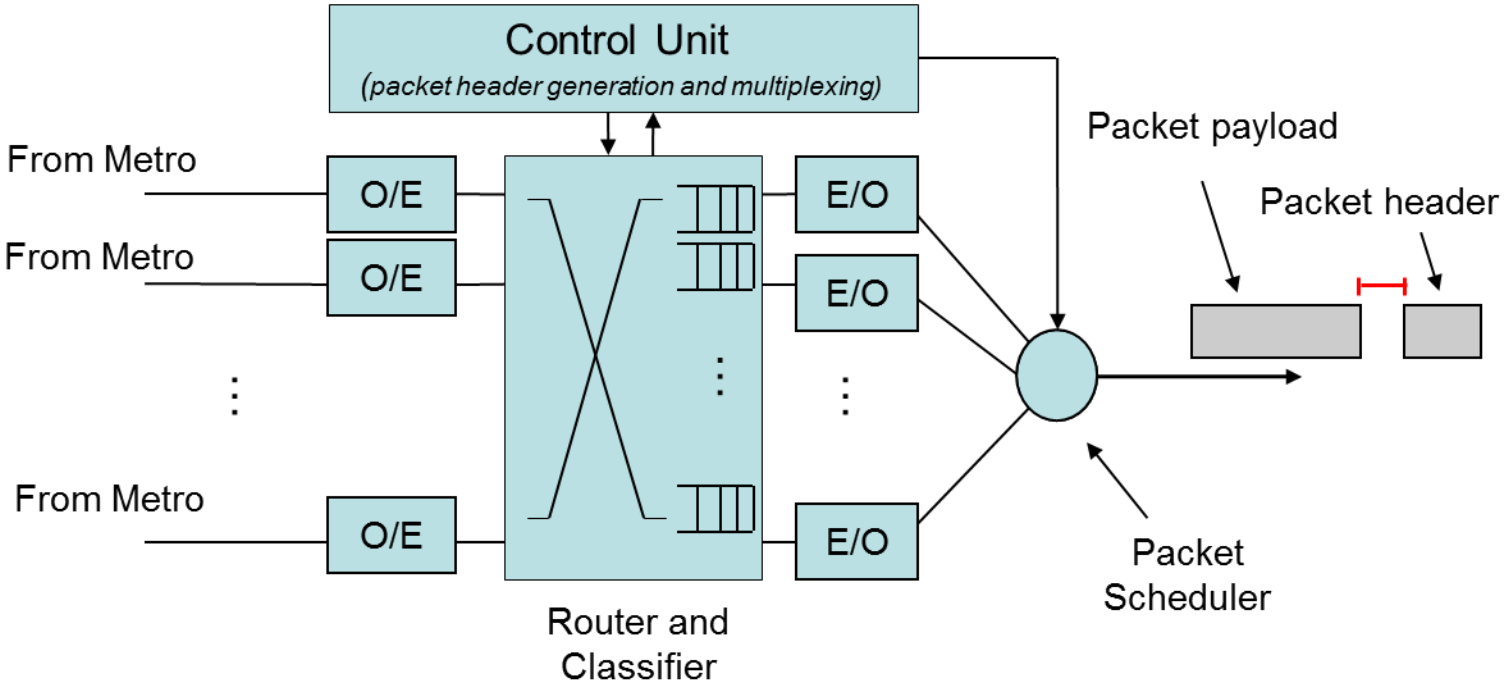
- The resources are reserved on-the-fly using the optical packet header (in-band signaling)
- Packet header and payload are separated by a time guard



Core Networks

- IP over WDM with OPS

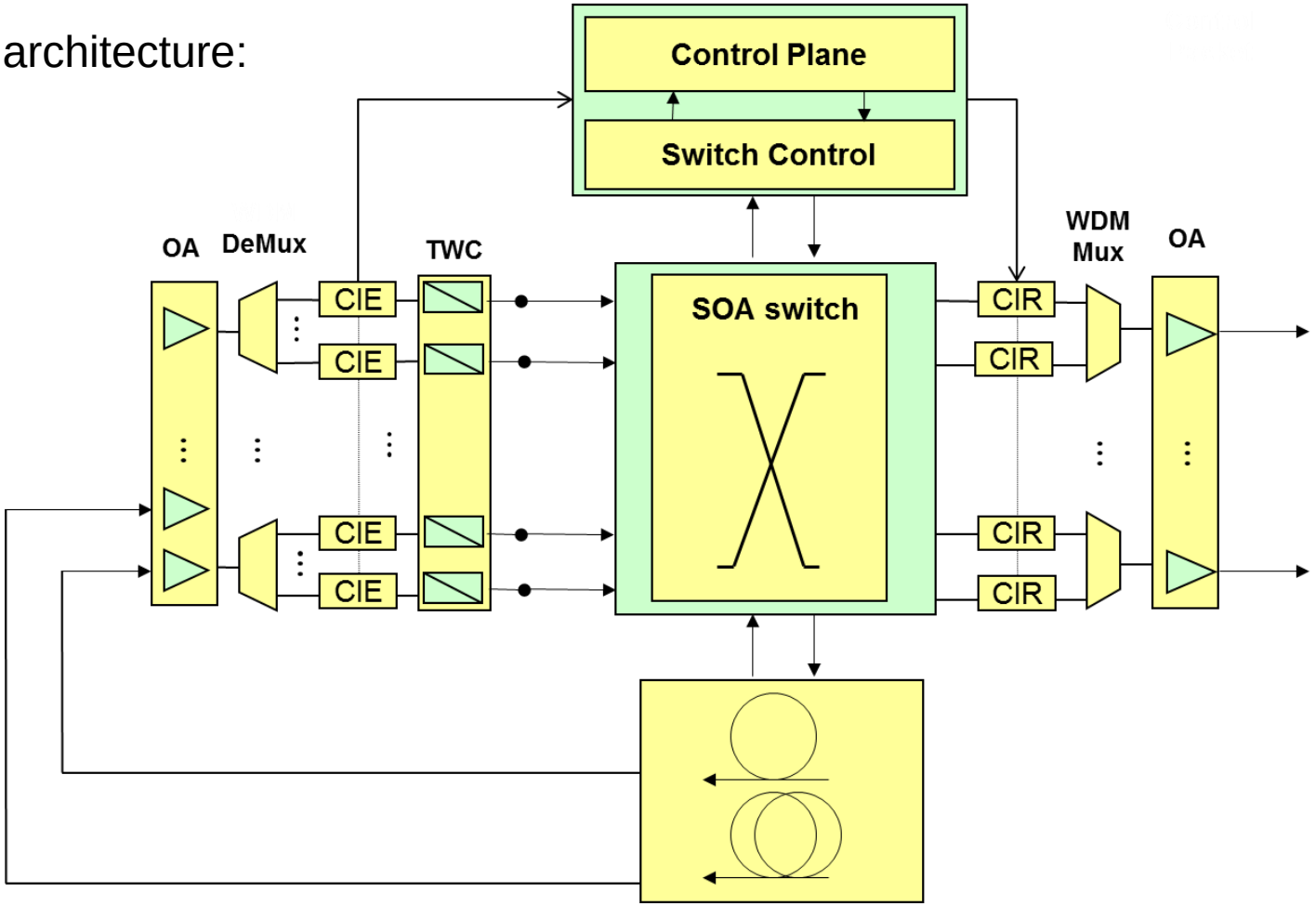
OPS edge node architecture:



Core Networks

- IP over WDM with OPS

OPS core node architecture:



Core Networks

- IP over WDM with OPS

Advantages:

- ✓ Very high bandwidth utilization (statistical multiplexing)
- ✓ High network flexibility (suites perfectly IP data traffic)

Drawbacks:

- Need for optical buffers (FDLs)
- Based on immature and expensive optical components

Core Networks

- IP over WDM with Hybrid Optical Switching
  - Integrates on the same network: *OCS* + *OBS and/or OPS*
  - Large and stable traffic flows (e.g. multimedia traffic) are carried over circuits or long bursts
  - Short and dynamic traffic flows (e.g. IP data traffic) are carried over packets or short bursts

High bandwidth utilization -> packets/bursts can fill unused slots of circuits with the same destination

Low power consumption -> using hybrid switches that combine slow switching elements for circuits/long bursts and fast switching elements for packets/short bursts

High network flexibility -> each new application or service can be served using the more suitable switching scheme for it

Data Center

- Data Center: large dedicated cluster of computers owned and operated by a single organization.
- Blade servers are hosted in racks.
- Servers typology:
  1) web server
  2) application
  3) database

- The servers are interconnected through the data center interconnection network.

Data Center

- Data center categories:
  1) University campus (up to few thousands of servers)
  2) Private enterprise (up to few thousands of servers)
  3) Cloud computing (up to hundreds of thousands of servers)

- Data center traffic
  - For every Byte of data transmitted over the Internet, 1 GByte are transmitted within or between data center.
  - Data center traffic will quadruple by the year 2016 mainly driven by cloud computing traffic. (6.6 zettabyte in 2016)
  - To keep up:
    1) Design more efficient data center networks
    2) Reduce energy consumption (green data center)

Data Center

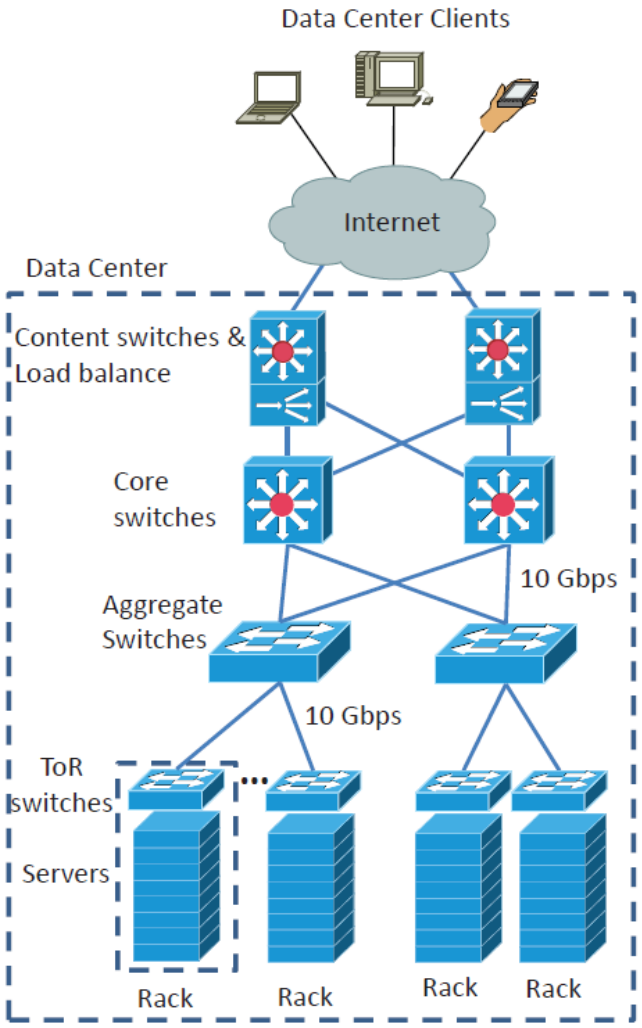
- Data center network

- Transmission in optical domain
- Switching and control information processing in the electronic domain
- Tiers of the data center network:
  - Edge tier

    Top-of-Rack (ToR) switches interconnect the blade servers within the rack using 1 Gbps links.
  - Aggregation tier

    Aggregate switches interconnect the ToR switches using 10 Gbps links.
  - Core tier

    Core switches interconnect the aggregate switches and connect the data center to the Internet using 40 or 100 Gbps links.

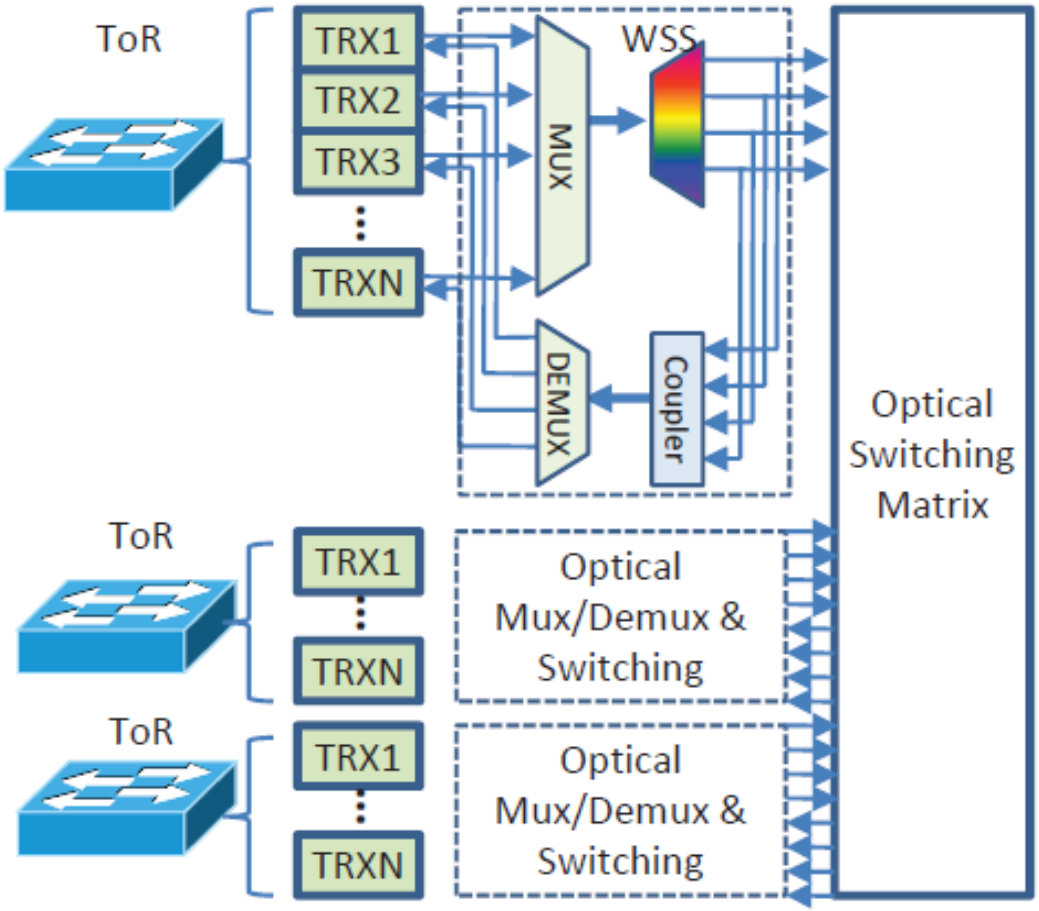


Data Center

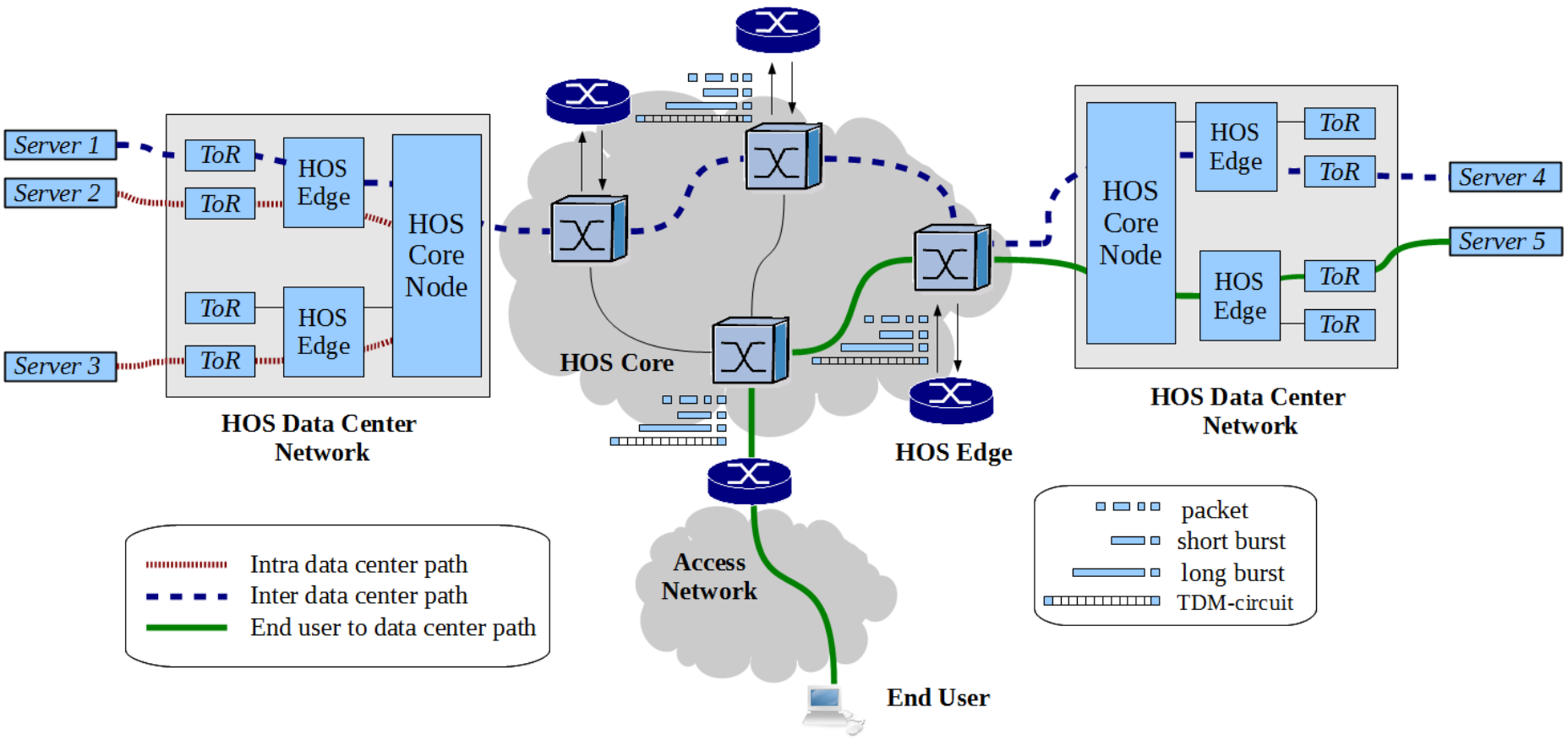
- Data center network

- Optical switched interconnect
  - Optical switching
  - WDM transmission technology

- Higher capacity
- Lower latency
- Lower energy consumption



End-to-end HOS network



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