Application Driven Petabit Optical Networking

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Outline

- Background
- Optical Networks - State-of-the Art
  - SDH/SONET
  - Wavelength Division Multiplexing (WDM)
  - Gigabit Ethernet (GbE)
- Optical Time Division Multiplexing (OTDM)
- ADAPTNet
- Conclusions

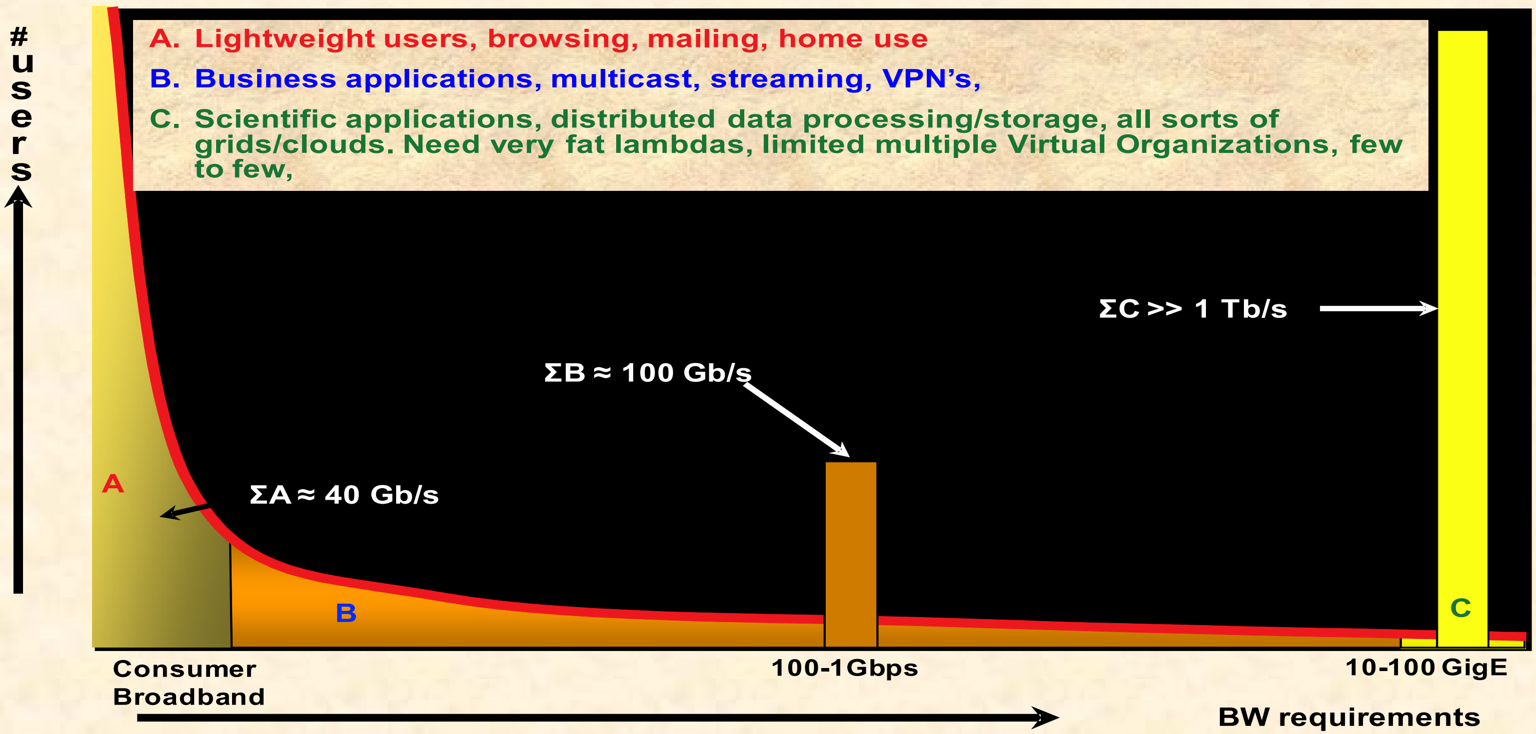
Background

Drivers

- network traffic will escalate dramatically to support multi-Zettabytes of data annually by 2015 (multi-million million billion bytes)
  - consumer applications
    - YouTube, IPTV, high-definition images, HDTV
    - 3D games, virtual worlds and photorealistic tele-presence
    - cloud computing

- specialized applications
  - e-Science
  - shared instrumentation infrastructures and large remote sensors
  - content distribution
  - grid computing
  - ultra-high resolution media distribution

New Wave of Applications



Source: de Laat, University of Amsterdam

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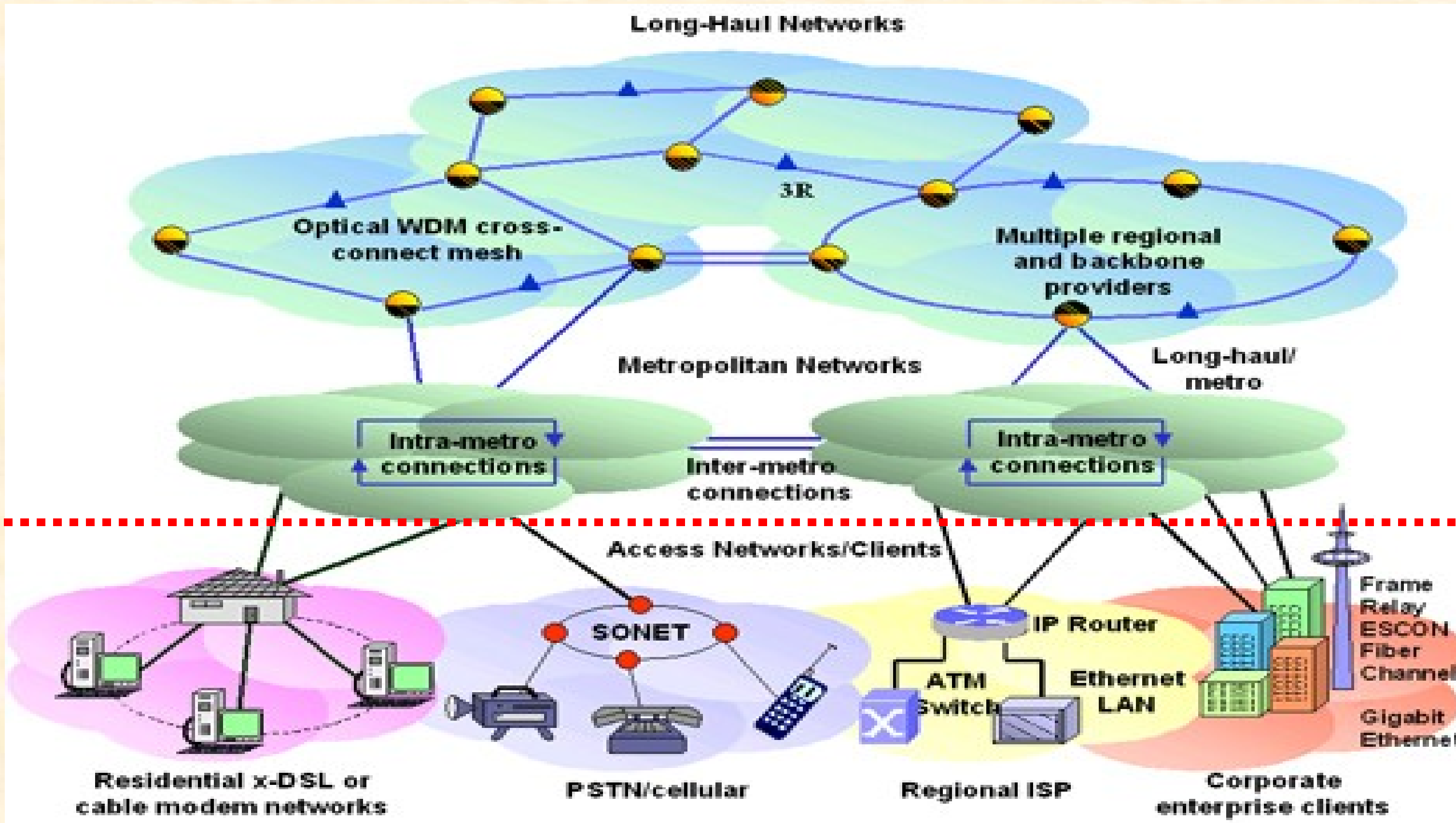
Network Layers

Optical Fibre Only

Fibre + Wireless



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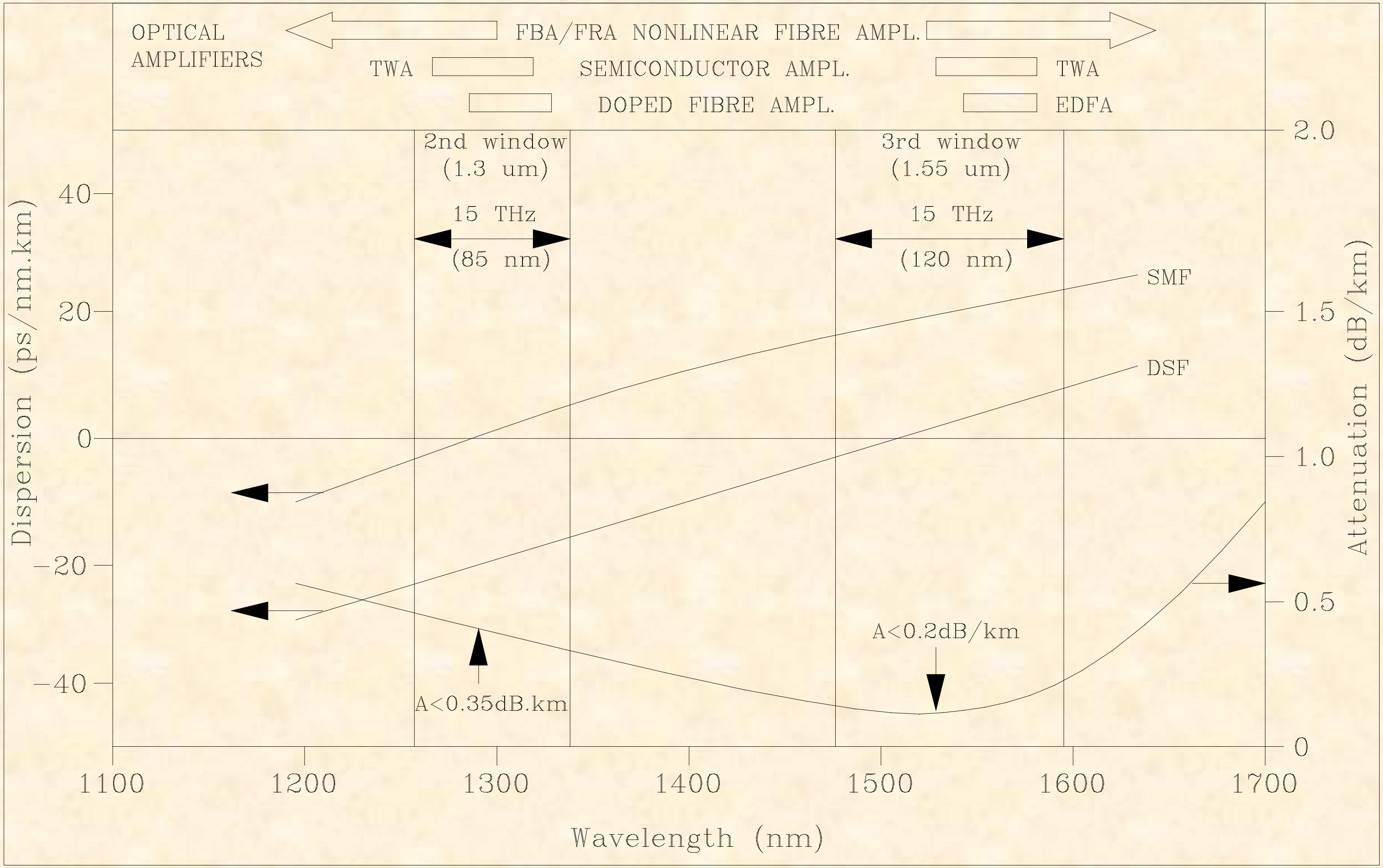
Optical Networks: State-of-the-Art

Transmission Medium; Optical Fibre

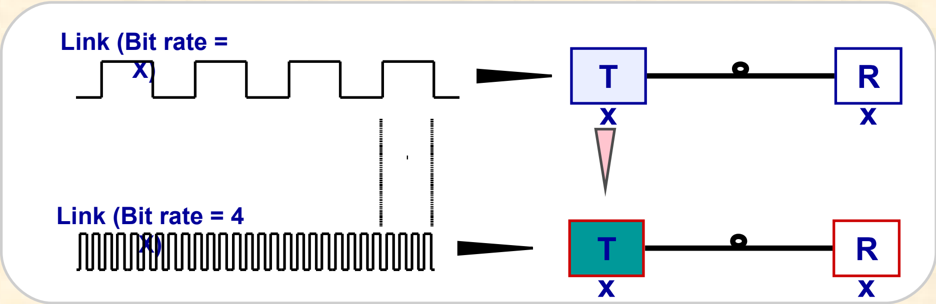


Optical Networking: Transparency

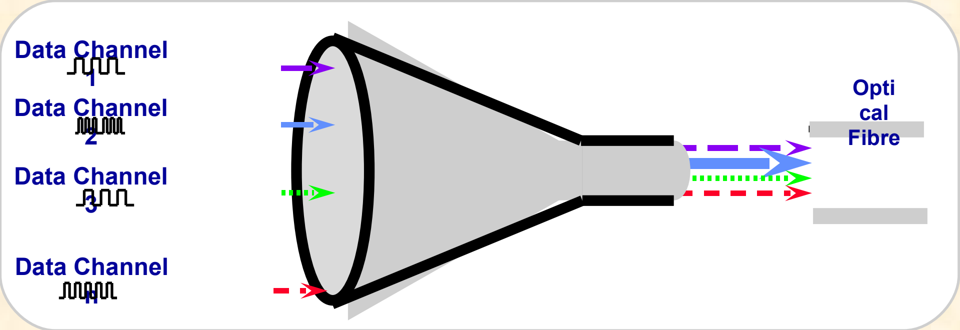
- allows format independence
  - flexibility for new traffic types
- minimizes the equipment in the signal path
  - cost advantage

TDM/WDM

- Time Division Multiplexing (TDM)



- Wavelength Division Multiplexing (WDM)



Capacity Upgrades

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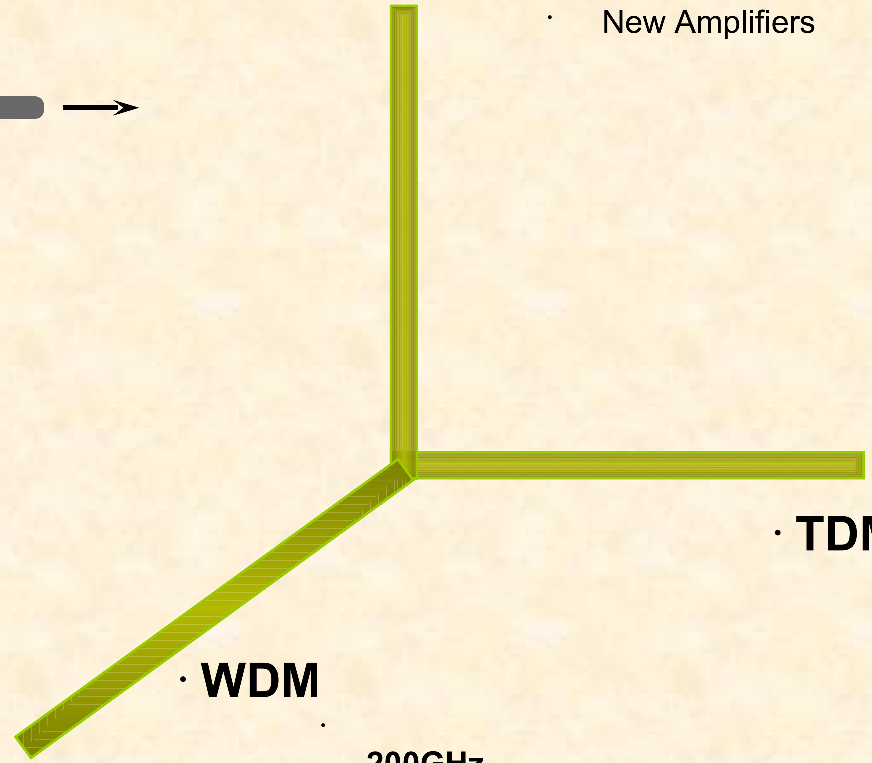
Fibre aggregate capacity

- **Spectral Window**
  - Transmission Fibre 100nm
  - Er3+ Doped Fibre Amplifier 32nm
  - New Amplifiers



Fibre window 1500 nm to 1600 nm - 13THz
Fibre window 1280 nm to 1320 nm - 7THz

EDFA window 1530 nm to 1560 nm - 4THz
Extended EDFA 1530 nm to 1600 nm - 9THz

- **TDM**
  - **10Gbit/s**
  - **40Gbit/s**
  - **Higher rates**

- **WDM**
  - **200GHz**
  - **100GHz**
  - **Denser grids**

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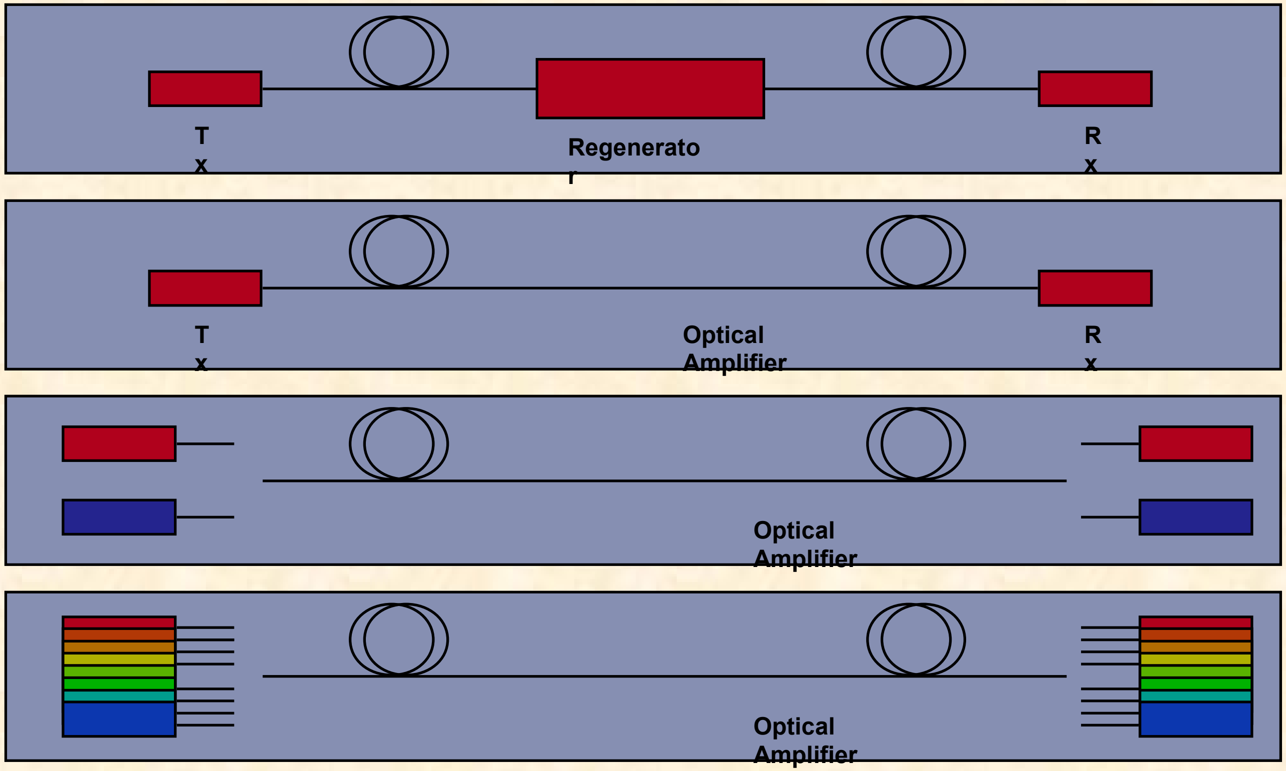
History



140Mbit/s - 2.5Gbit/s
- InP Lasers / Detectors

2.5Gbit/s - 10Gbit/s
- Er3+ Fibre Optical Amplifier

Bi-directional WDM
2-4xOC48, 2-4xOC192
5Gbit/s - 20Gbit/s
- Coarse WDM
- Filters

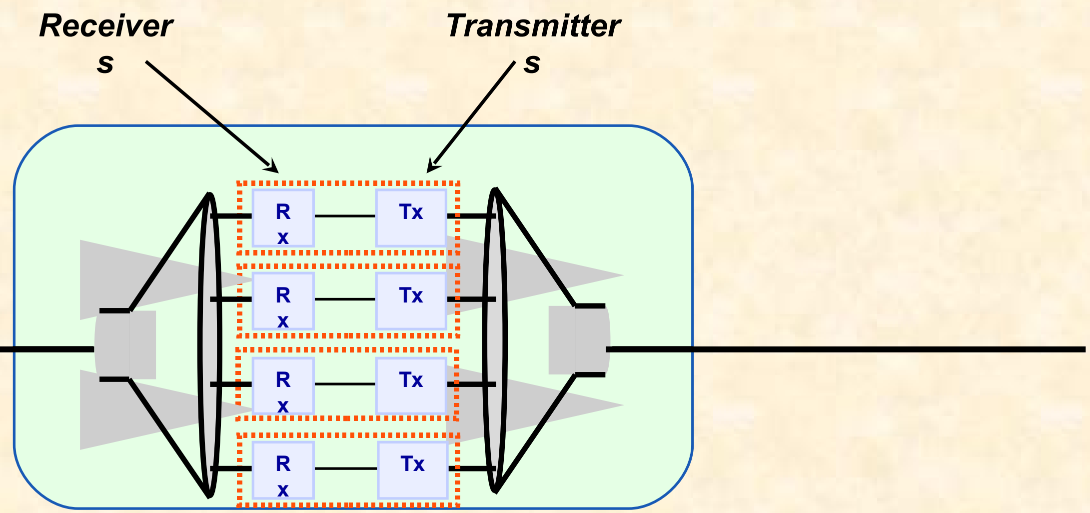
Uni- and Bi-directional D-WDM
16xOC48, 16xOC192
40Gbit/s - 160Gbit/s
- Precision Sources
- Precision Mux//Demux
- ITU grid

SONET/SDH; History

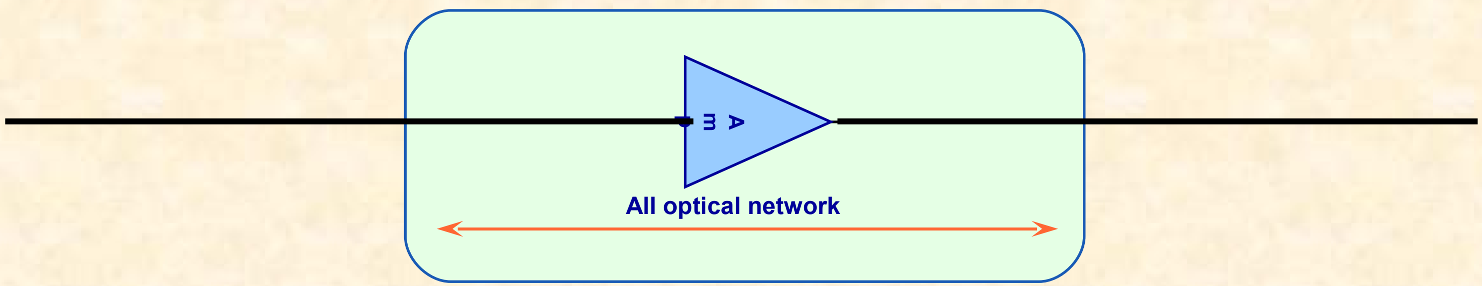
- Synchronous Optical Network - SONET
  - North American Standard (ANSI)
- Synchronous Digital Hierarchy - SDH
  - International Telecommunications Union (ITU)
  - SONET, Synchronous Transport Signal, STS1 = 51.84 Mb/s
  - SDH, Synchronous Transport Module , STM1 = 155.52 Mb/s
  - Optical Carrier
    - OC3 = 3 x STS 1 = STM 1 = 155.52Mbit/s
    - OC12 = 12 x STS 1= STM 4 = 622.08Mbit/s
    - OC48 = 48 x STS 1 = STM 16 = 2.488Gbit/s
    - OC192 = 192 x STS 1= STM 64 = 9.953Gbit/s
    - OC768 = 768 x STS 1= STM 256 = 39.813Gbit/s

Optical Amplifier/WDM Revolution

Repeater without optical amplifier

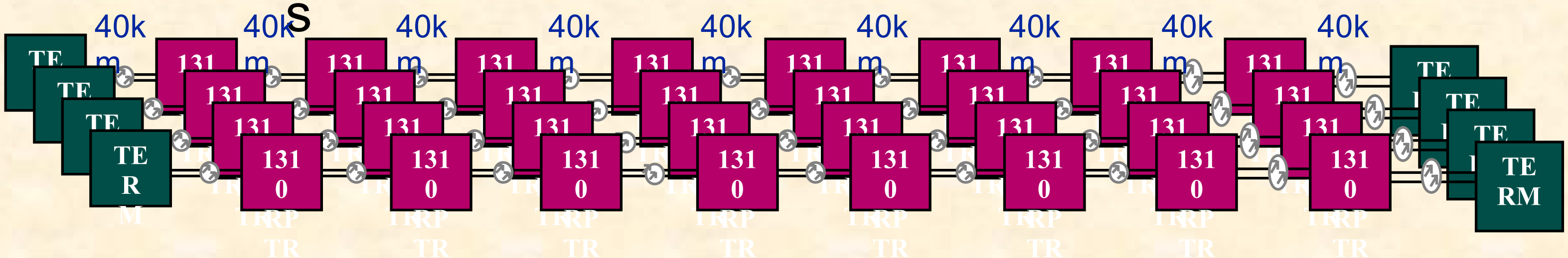


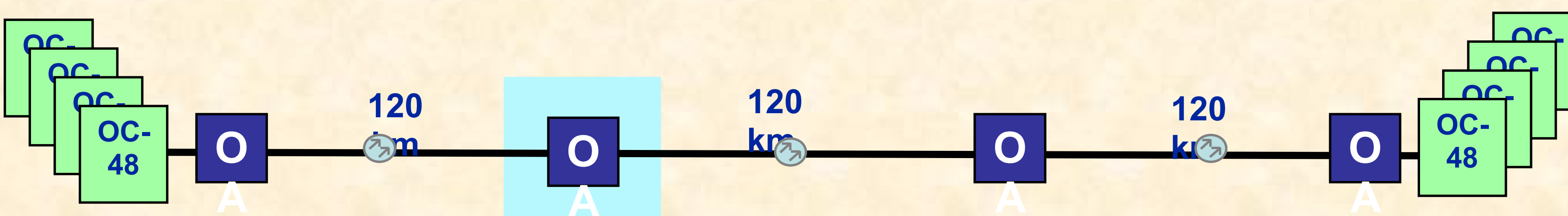
Repeater With optical amplifier



Optical Amplifier/WDM Revolution

Conventional Transmission - 10Gbit/s





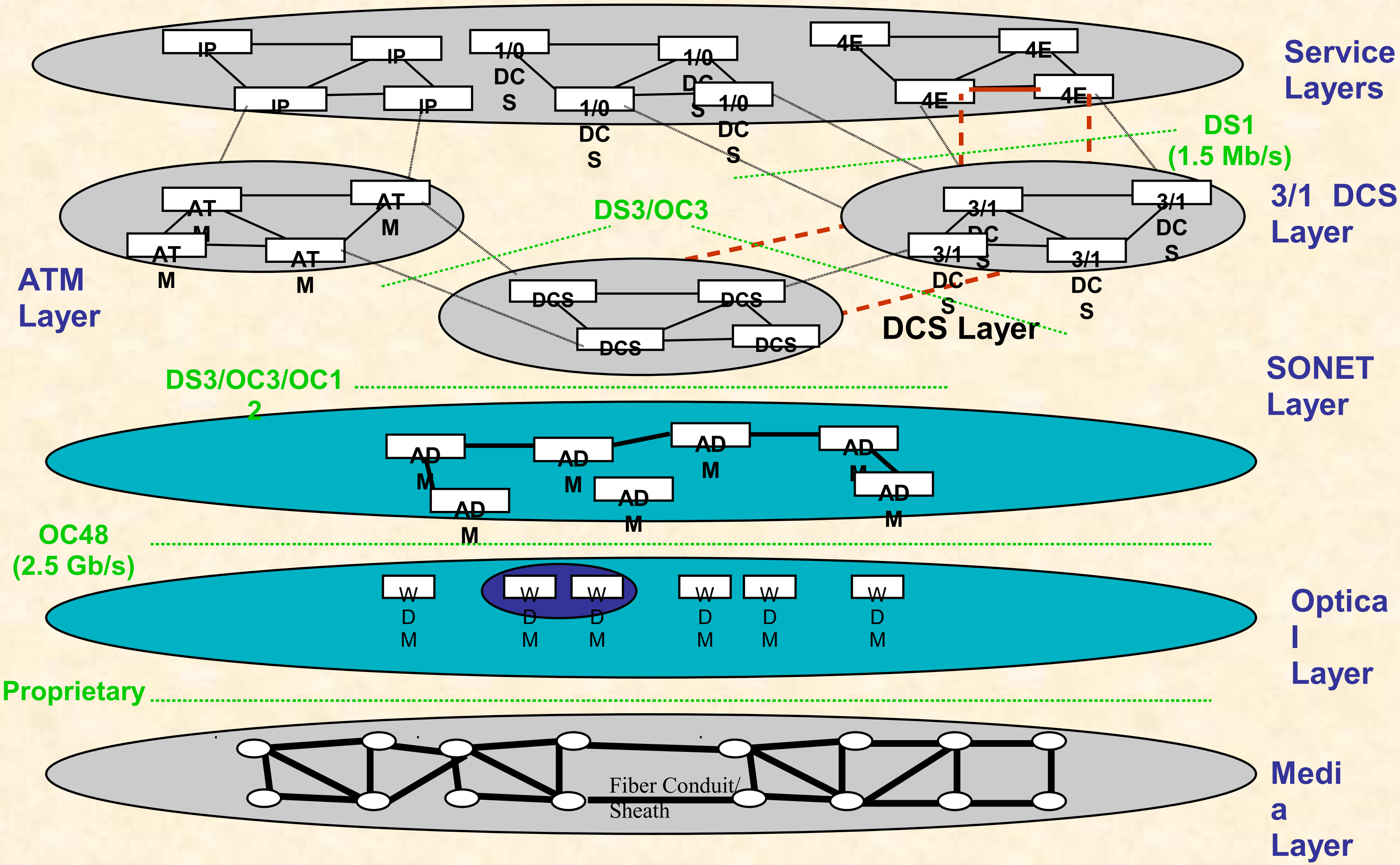
Optical Amplifiers and WDM - 10 Gb/s

4 fibers → 1 fiber; 12 regenerators → 1 optical amplifier

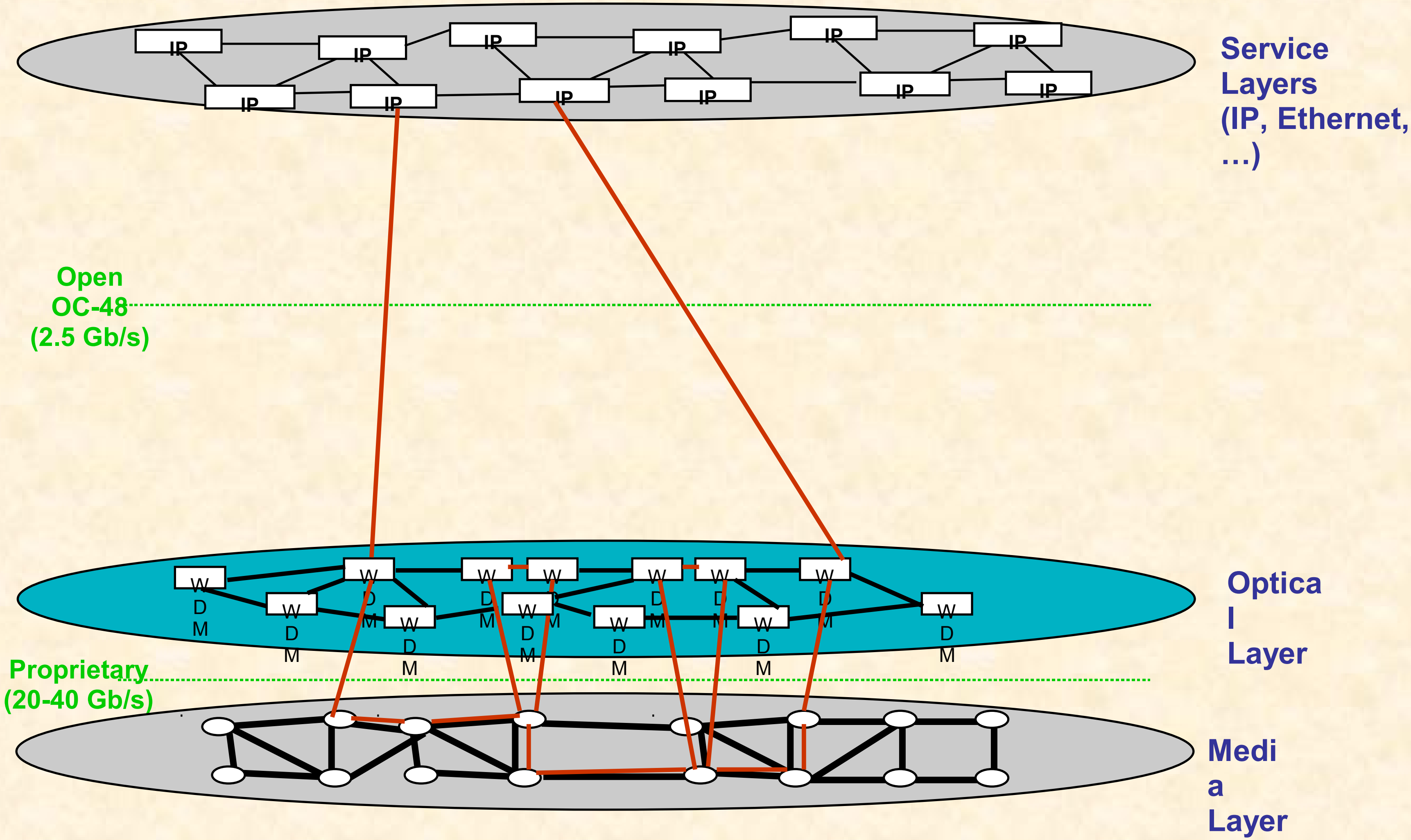
Technology Issues: Next Generation WDM systems

- Closer channel spacing
- More channels
  - Improved optical amplifiers
    - tighter power (pump lasers)
    - wider bandwidth
- Higher speeds (40 Gb/s)
  - Dispersion compensation
    - in amplifiers?

Transport Layer Model



Simpler Layered Model



Optical Layer:
Format-Independent Platform

- direct interconnection of IP or Ethernet or …
- allow provisioning and restoration to be removed from the data networking layer
- provide a flexible infrastructure for packet-based networks while still supporting legacy e.g. SONET formats
- optical network expansion beyond WDM
  - higher bitrates per wavelength through optical time division multiplexing (OTDM)
  - optical networks supporting burst or packet based transmission

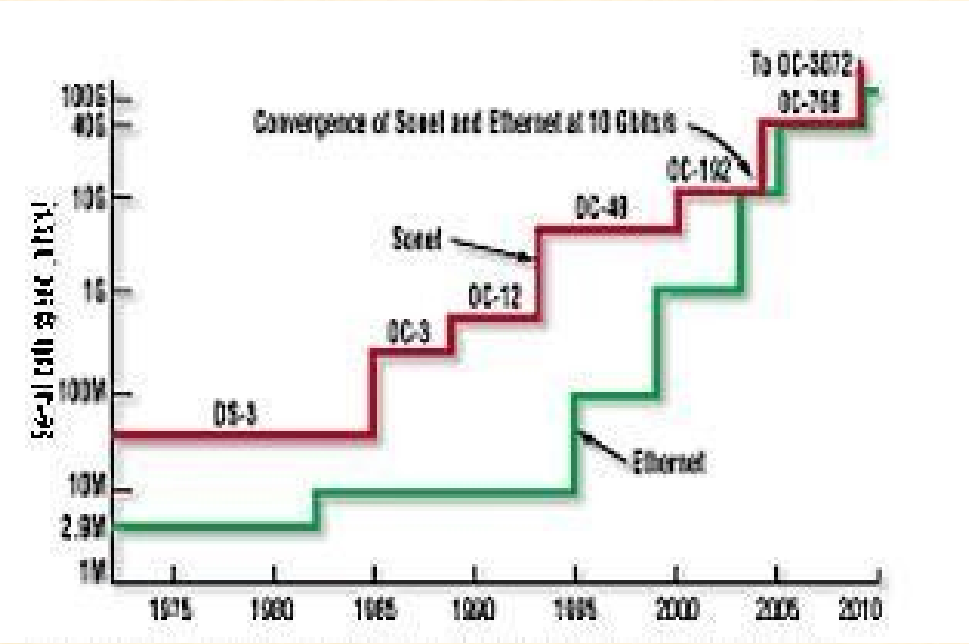
Ethernet; History

- developed at Xerox from 1973-1975, widely used since 1980
- largely replaced other LAN standards by "leapfrogging" competing developments such as Token ring, FDDI etc.
- originally based on CSMA/CD protocol broadcasting over a shared coaxial cable at 10Mbit/s
  - uses globally unique 48bit Ethernet interface addresses
  - fits into data link layer of OSI model (layer 2)
- later versions developed using twisted-pair cable with RJ45 connectors or optical fibre
  - 100Mbit/s Ethernet (Fast Ethernet)
  - 1Gbit/s Ethernet (Gigabit Ethernet)
  - 10Gbit/s and 100Gbit/s versions do not use CSMA/CD
    - point-to-point operation only, interconnecting Ethernet switches
    - CSMA/CD is inefficient for high data rates
- all versions of Ethernet are based on the original 10Mbit/s frame format
- recently, "Carrier class" extensions to the protocol have been developed so that Ethernet can be used as a cost-effective replacement for SDH

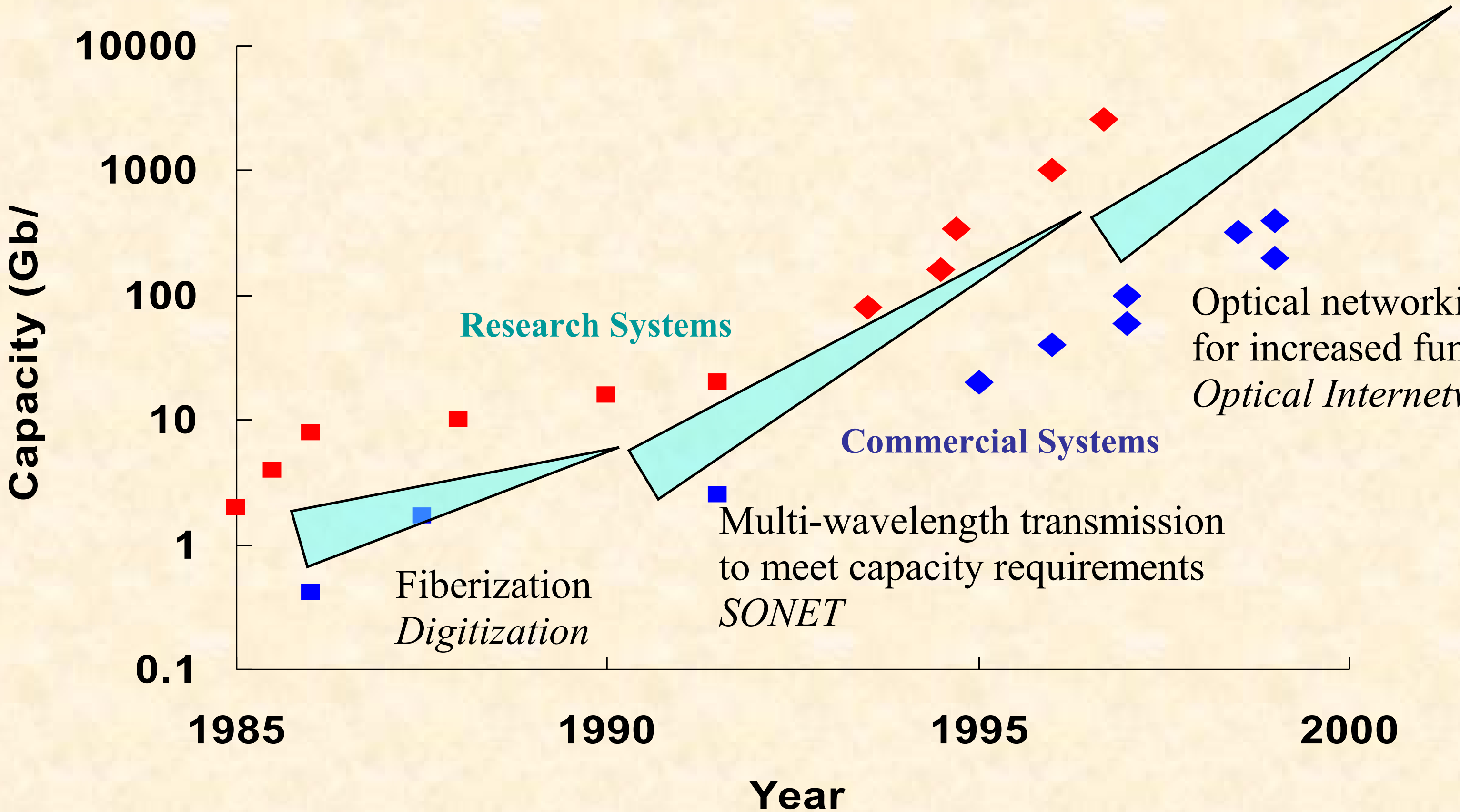
10G and 100G Ethernet

- 10Gbit/s Ethernet provides point-to-point connectivity between Ethernet switches, with CSMA/CD disabled
  - standardised as IEEE 802.3ae in 2002
  - LAN PHY – most common implementation, supporting existing Ethernet LAN applications; 2 × optical fibres, multimode (300 m) or single mode (10km)
  - WAN PHY – allows 10Gbit/s Ethernet terminals to be connected through 10Gbit/s SDH/SONET; 2 × single-mode optical fibres, up to 40km
  - Both LAN PHY and WAN PHY can use the same optics
  - Twisted pair operation also available over shorter distances
- 100Gbit/s Ethernet standard (IEEE 802.3ba) is due to be approved in June 2010; operation over
    - at least 40km on single-mode fibre (4 wavelengths carrying 25Gbit/s each)
    - at least 100m on multi-mode fibre
    - at least 10m on copper cable
  - a 100Gbit/s prototype Ethernet switch was demonstrated by Nortel in 2008

SONET/Ethernet Converge



Lightwave Technology Eras



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Optical Time Division Multiplexing (OTDM)

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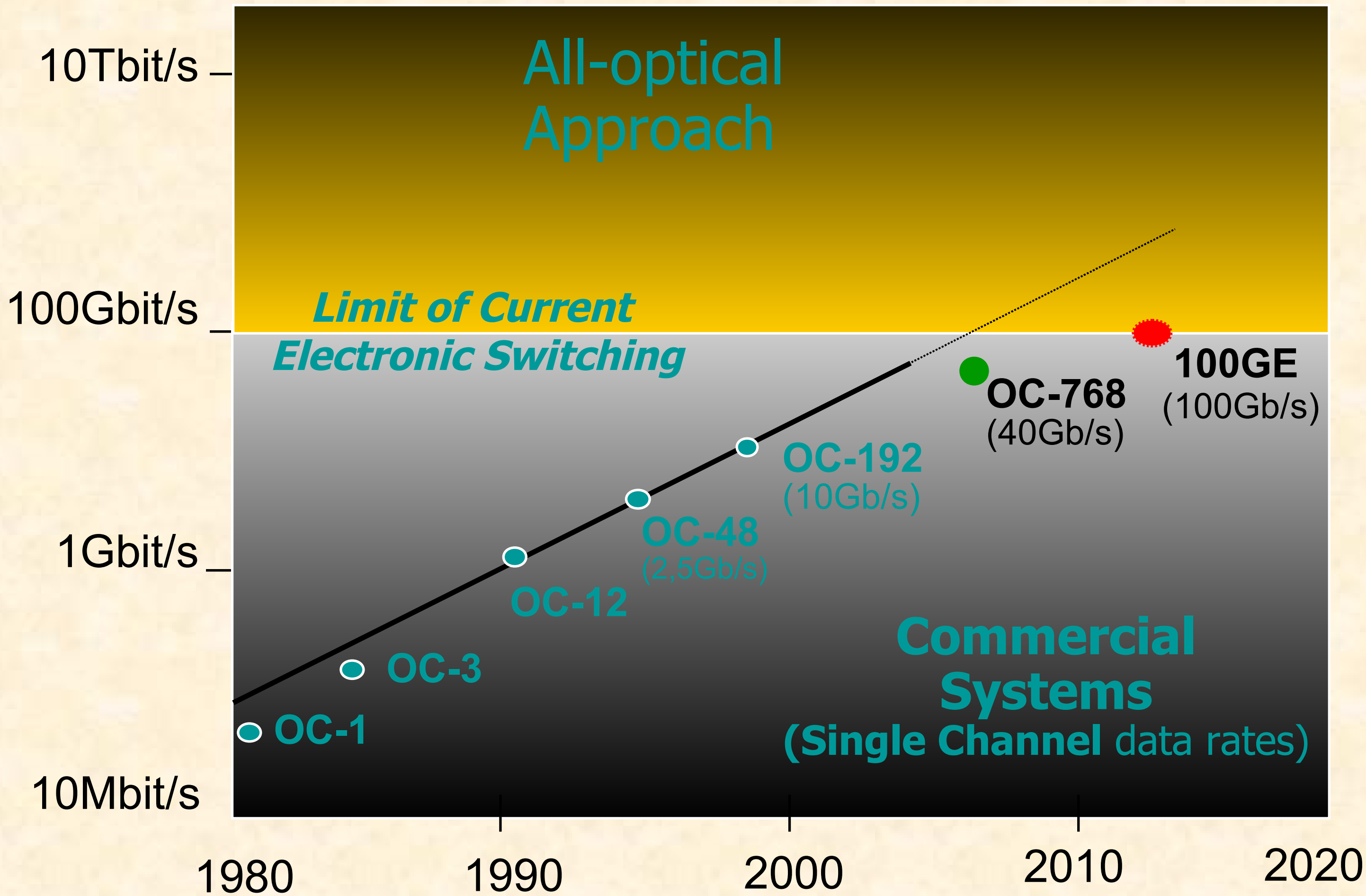
Bandwidth Bottleneck?



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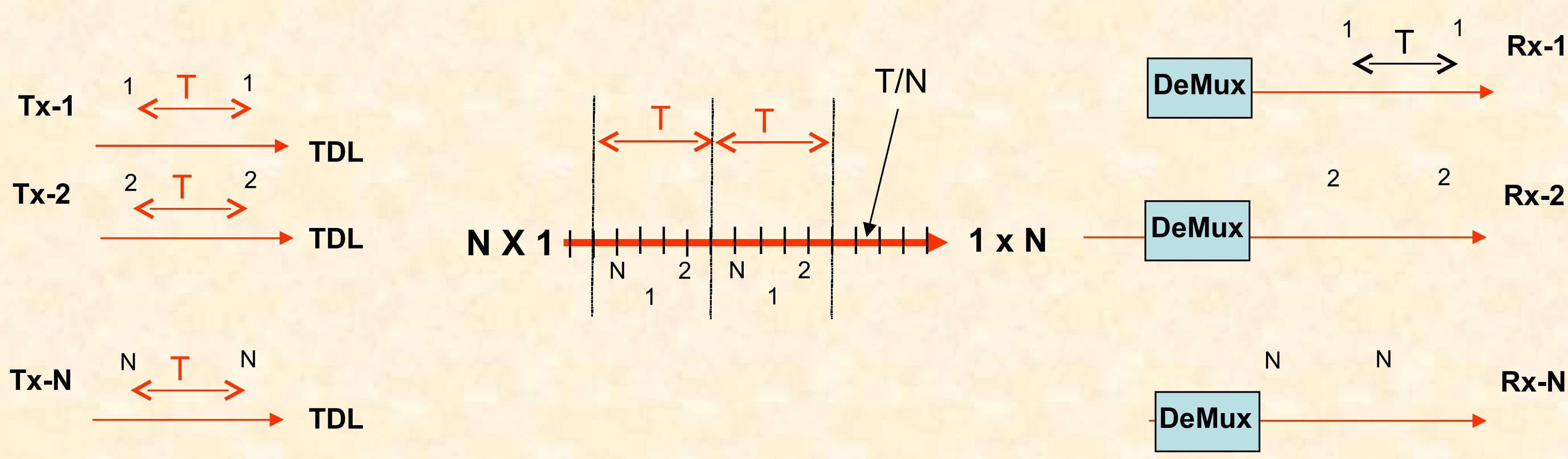
OTDM



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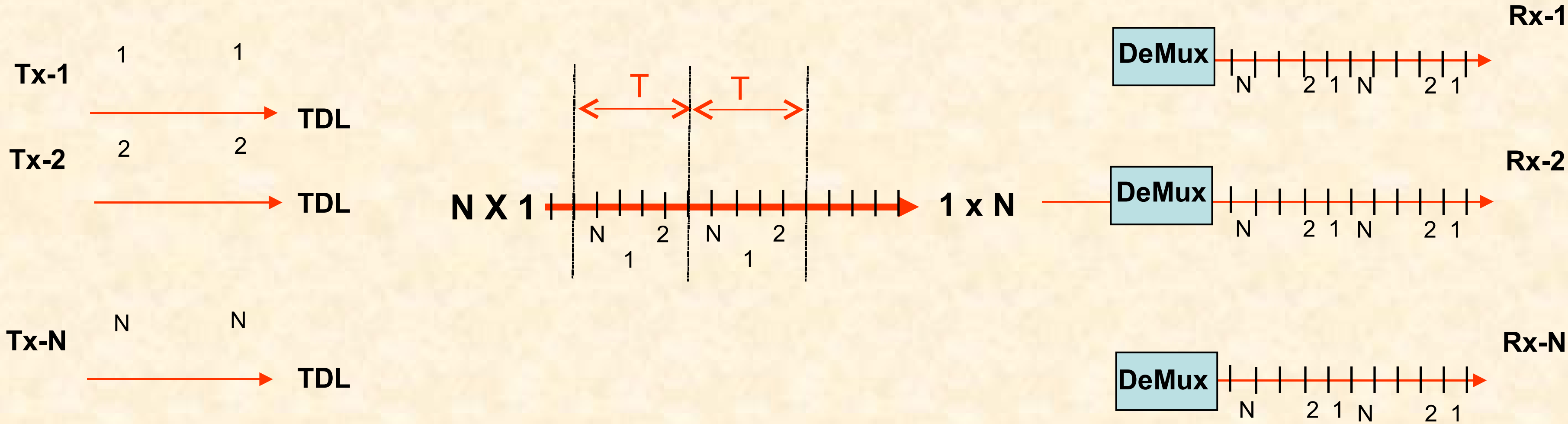

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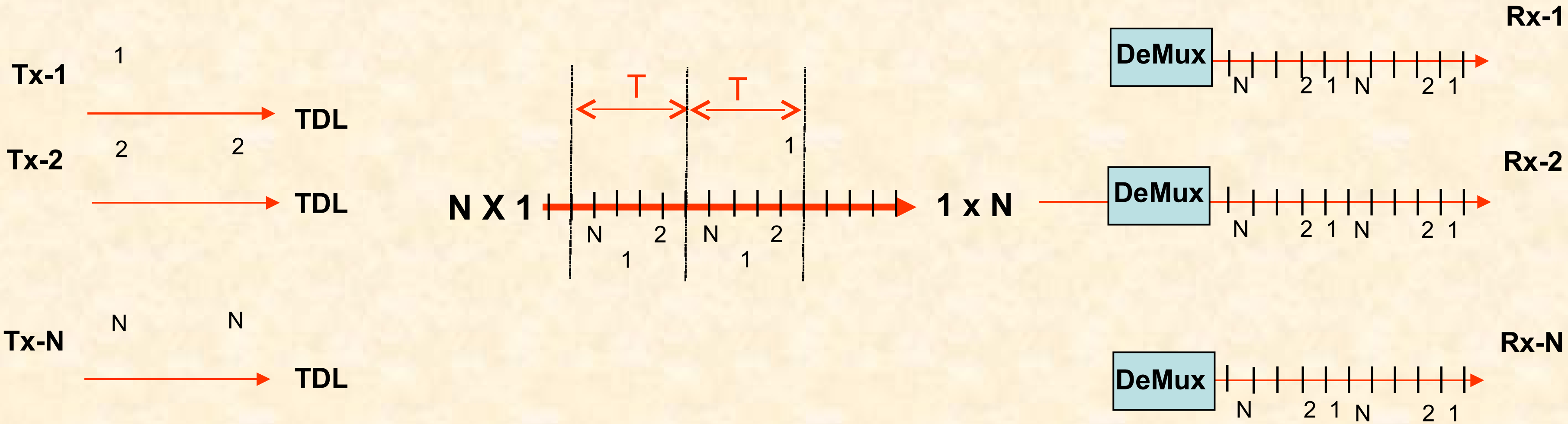
OTDM



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OTDM

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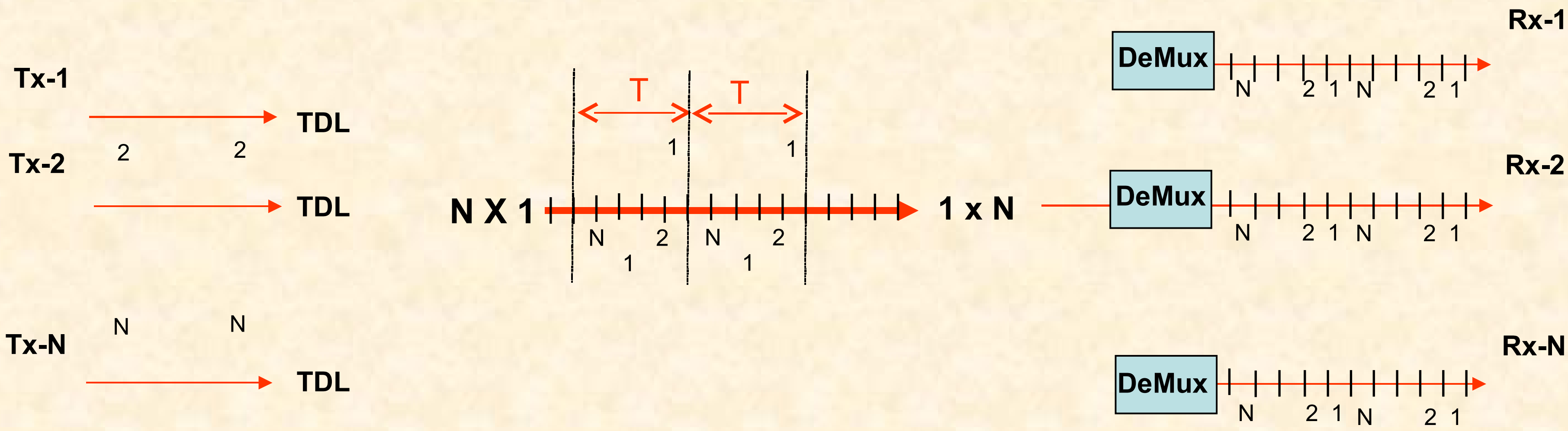

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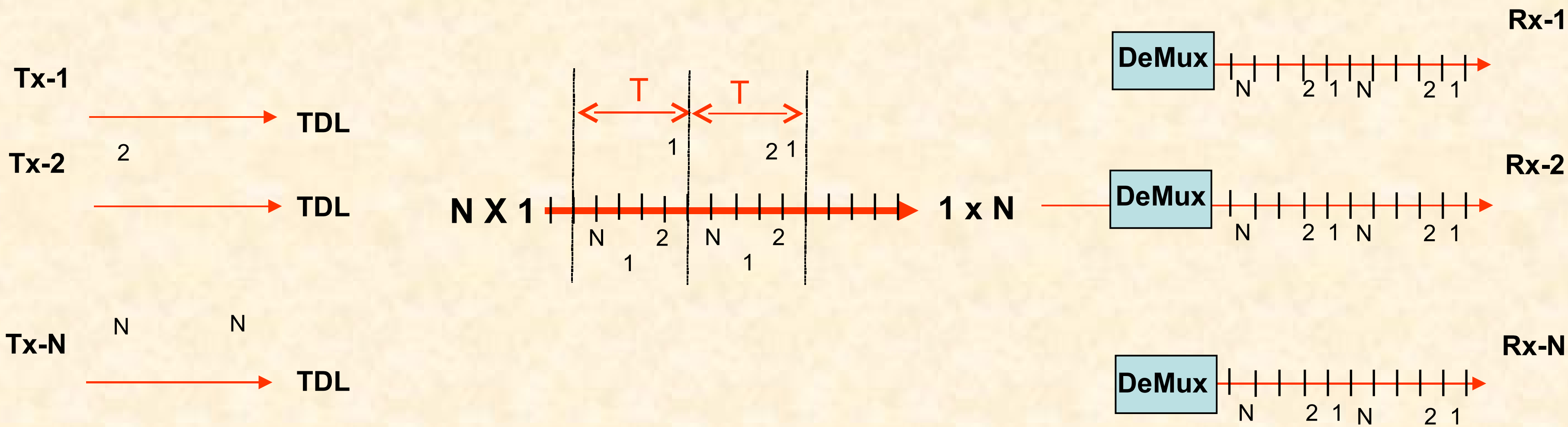
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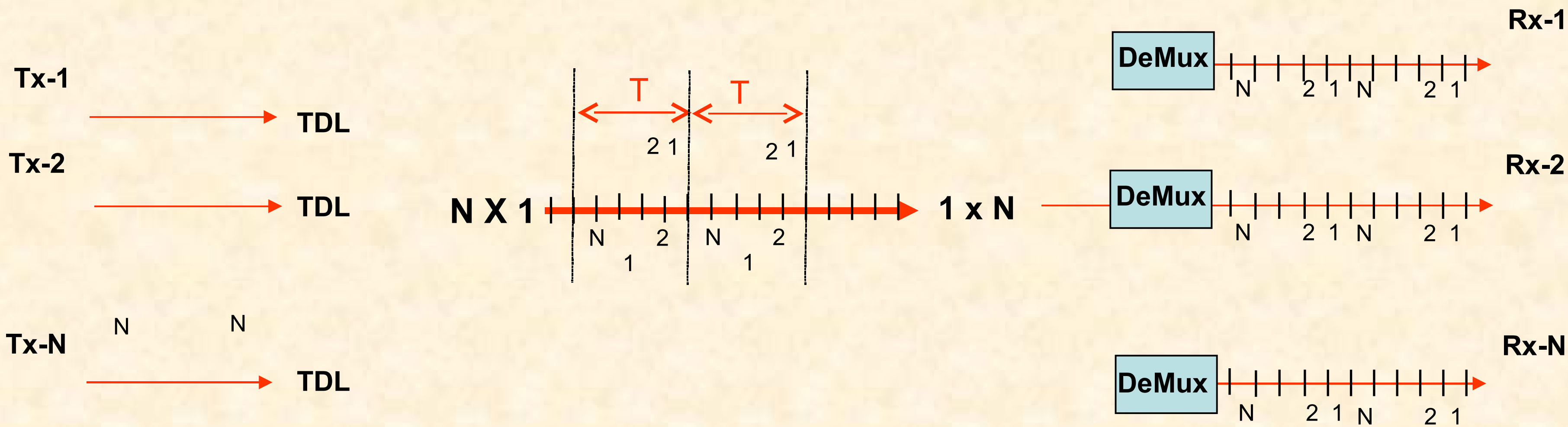
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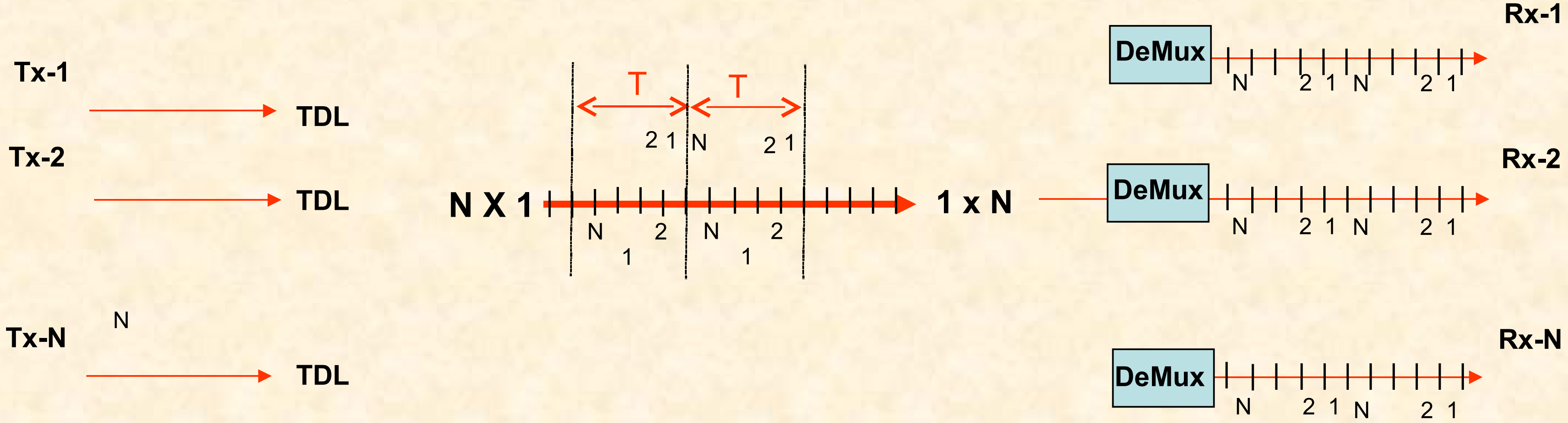
OTDM



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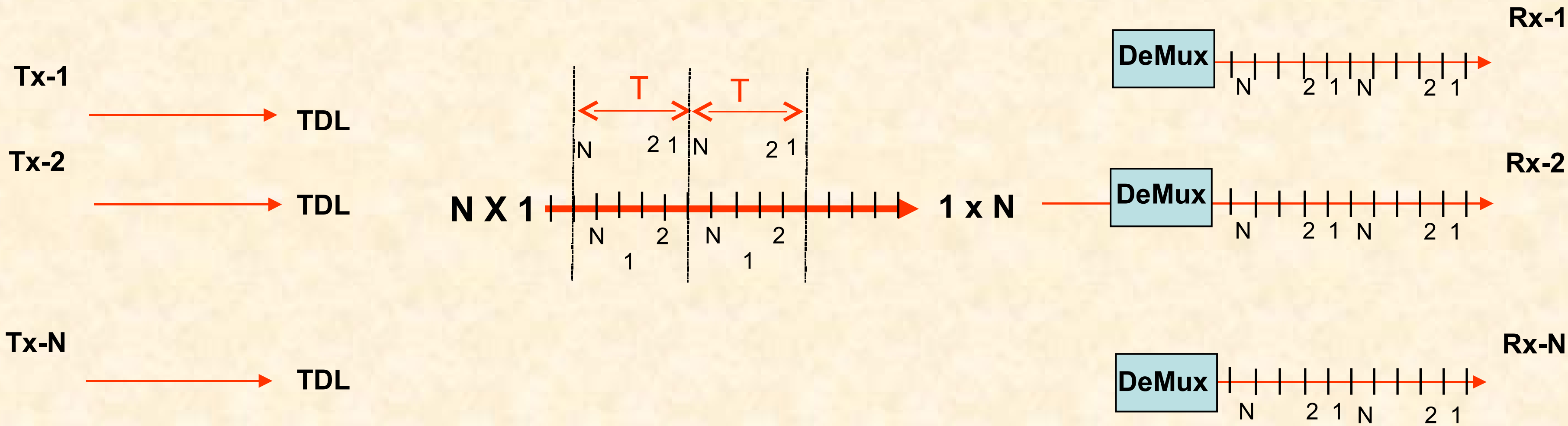
OTDM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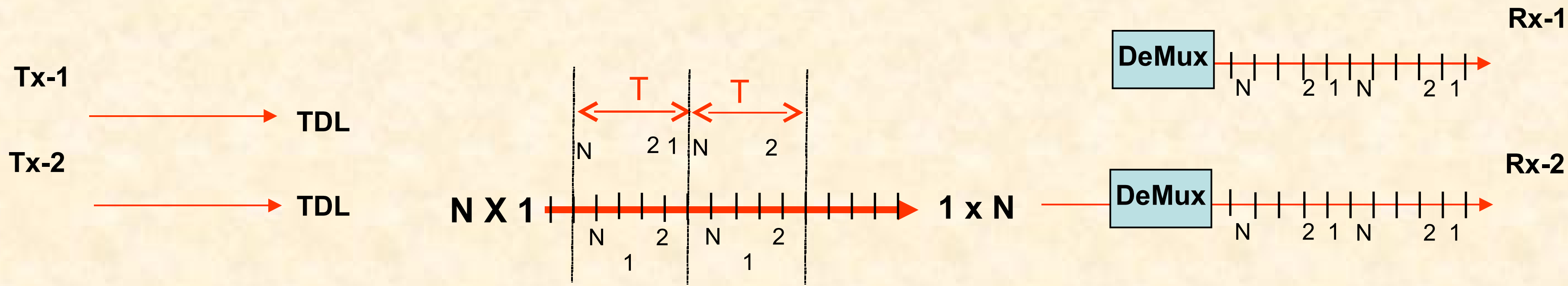
OTDM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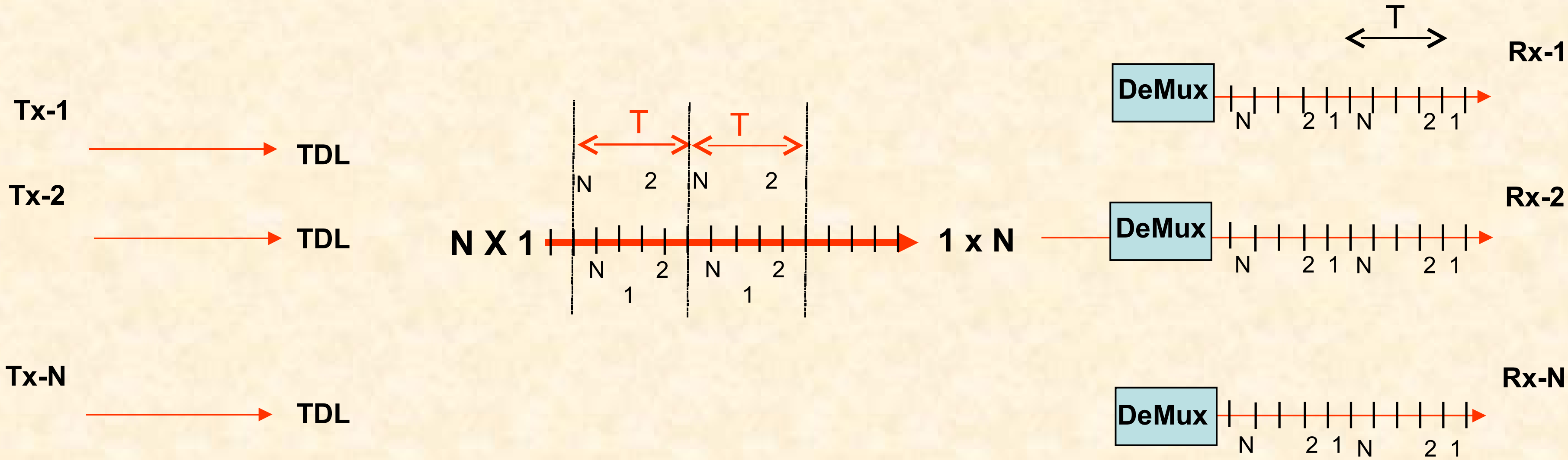

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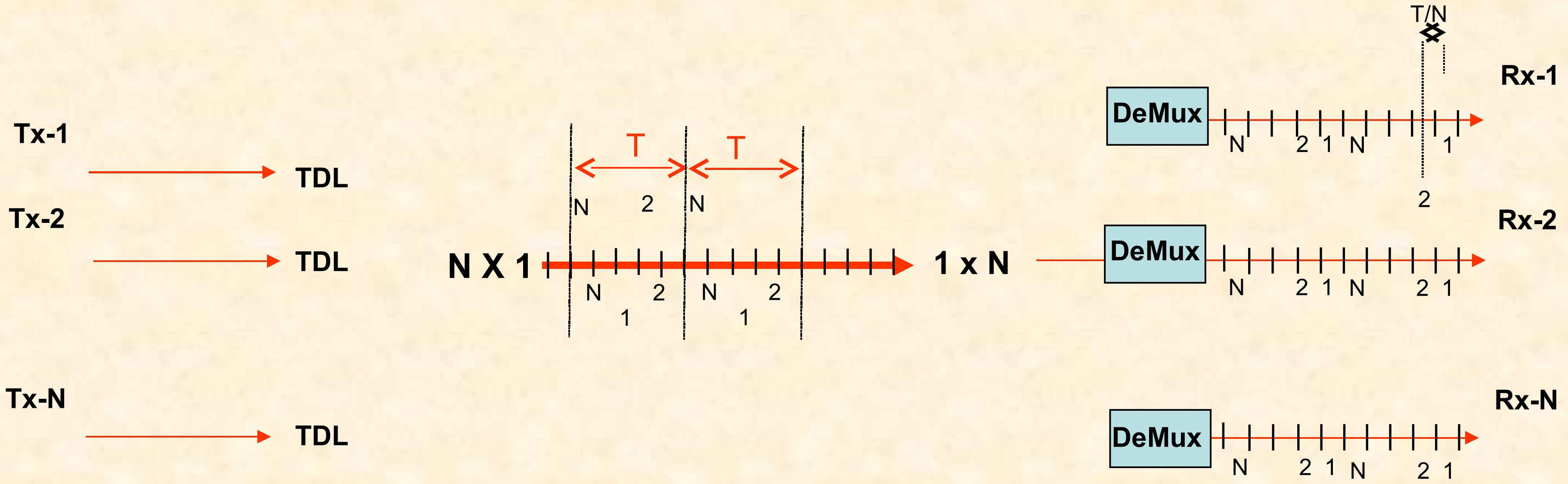

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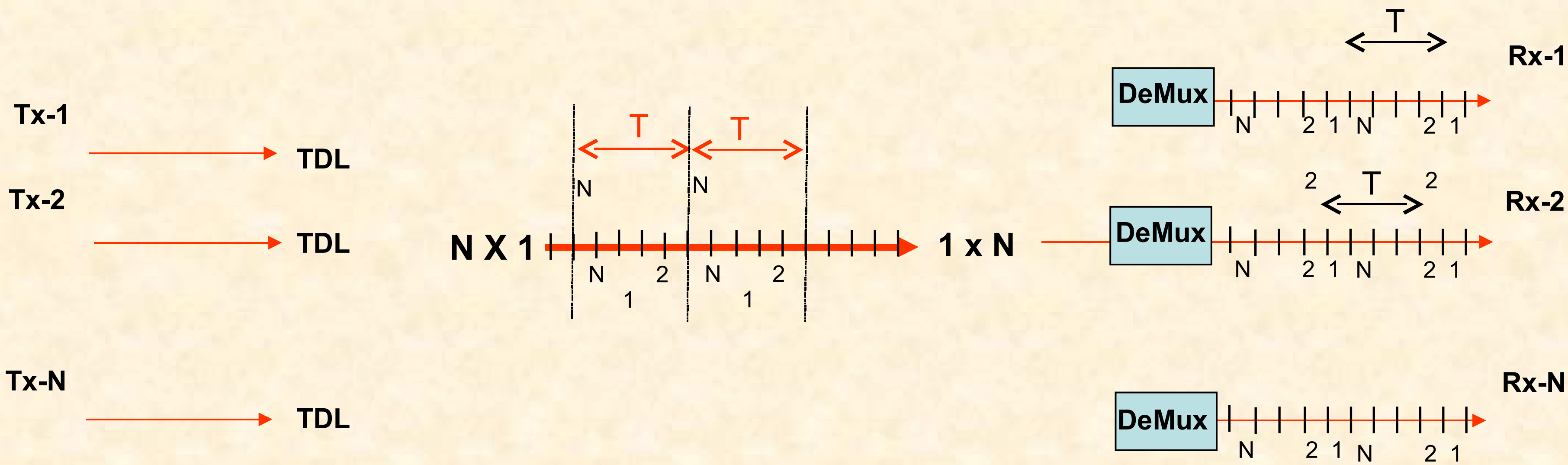

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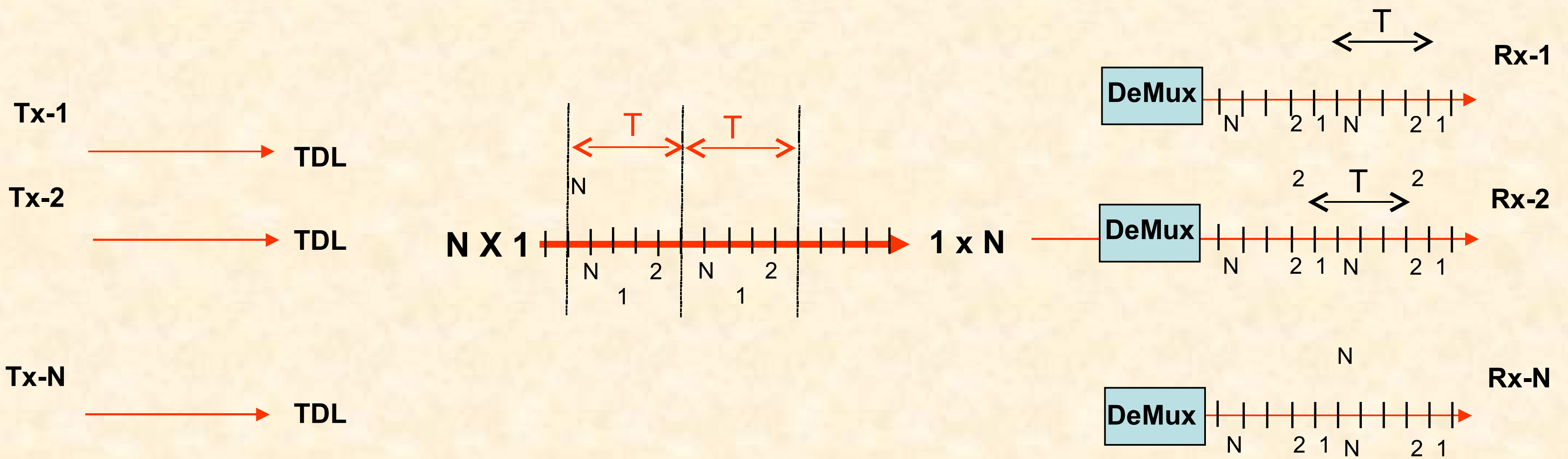

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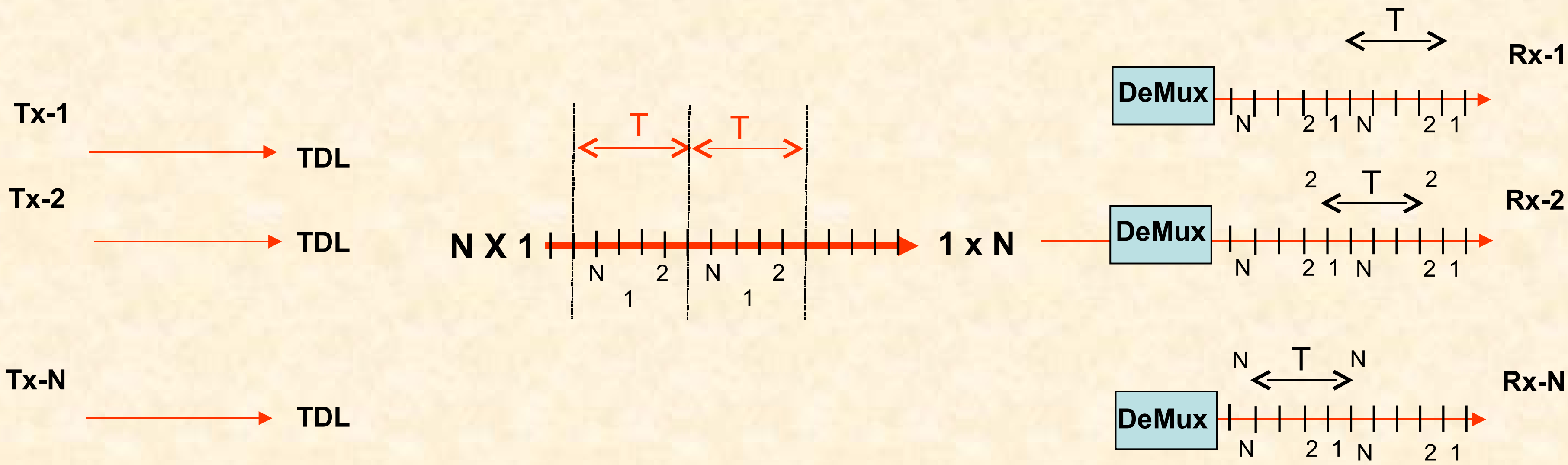
OTDM



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OTDM; Transmitter

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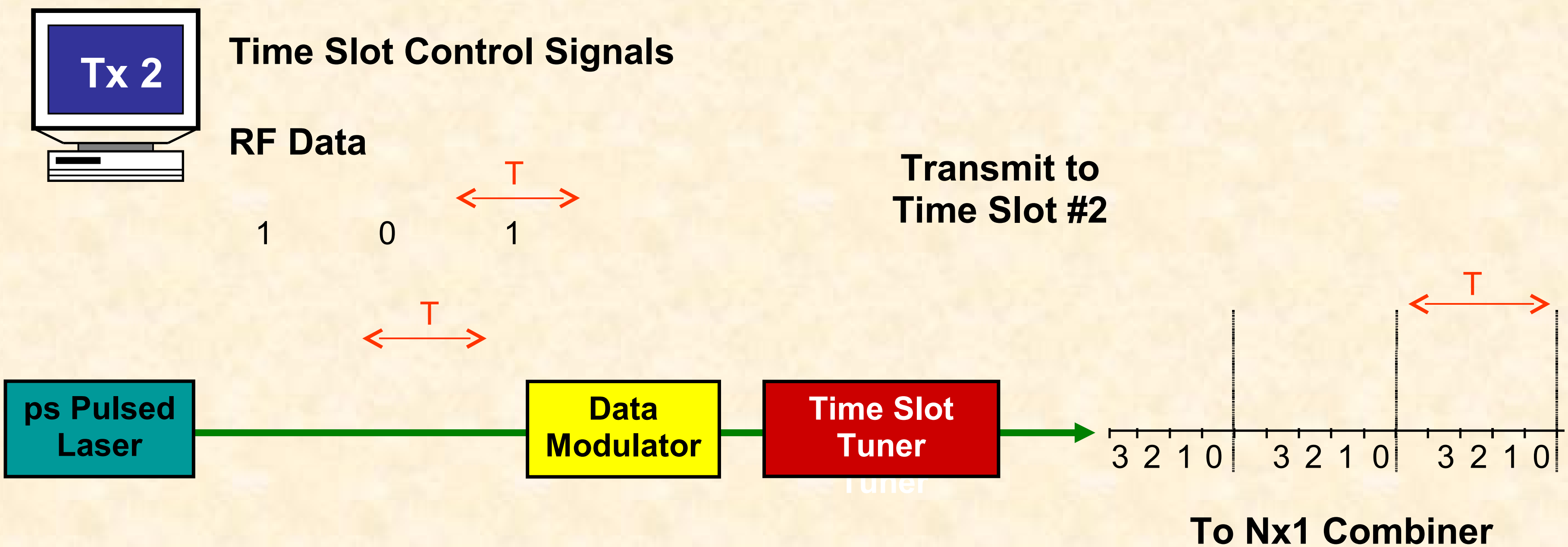
Transmitting to Channel 2



OTDM; Transmitter

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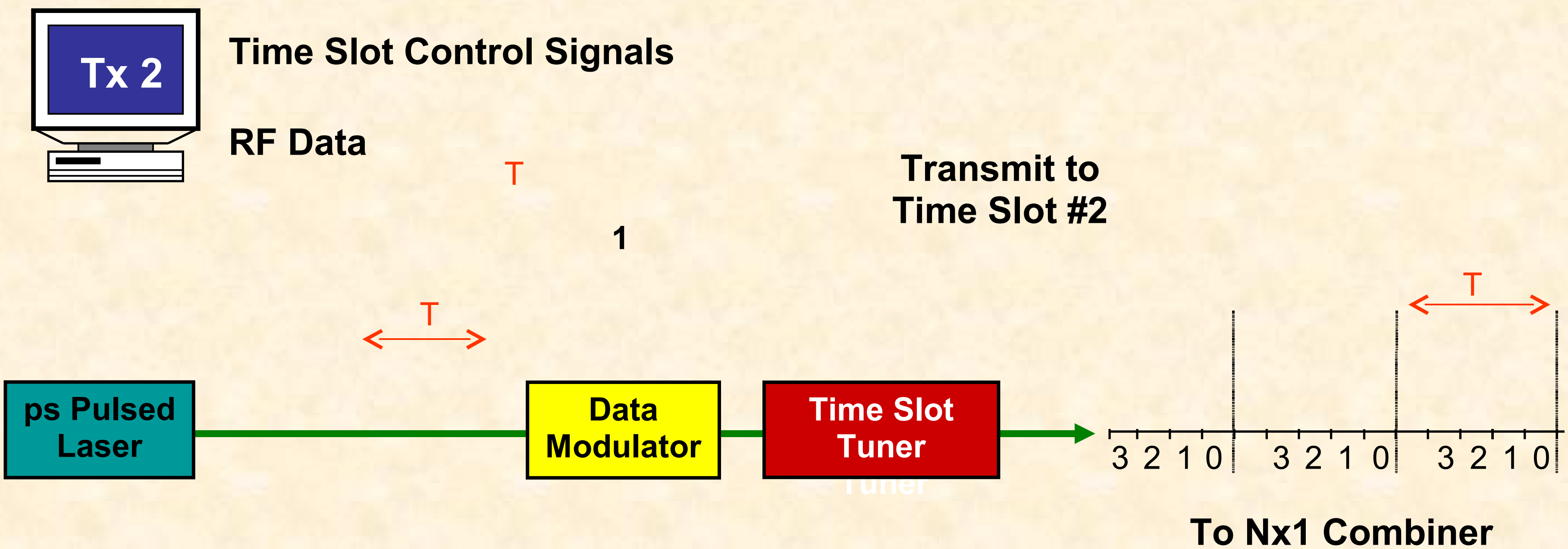

OTDM; Transmitter

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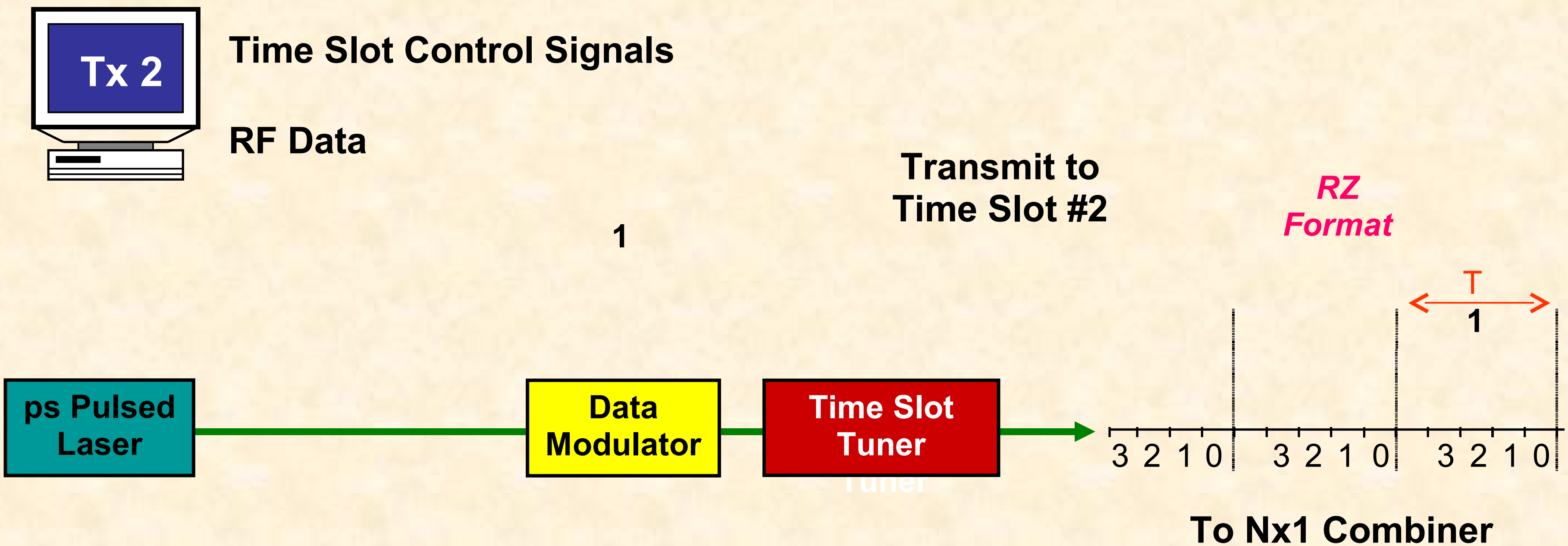

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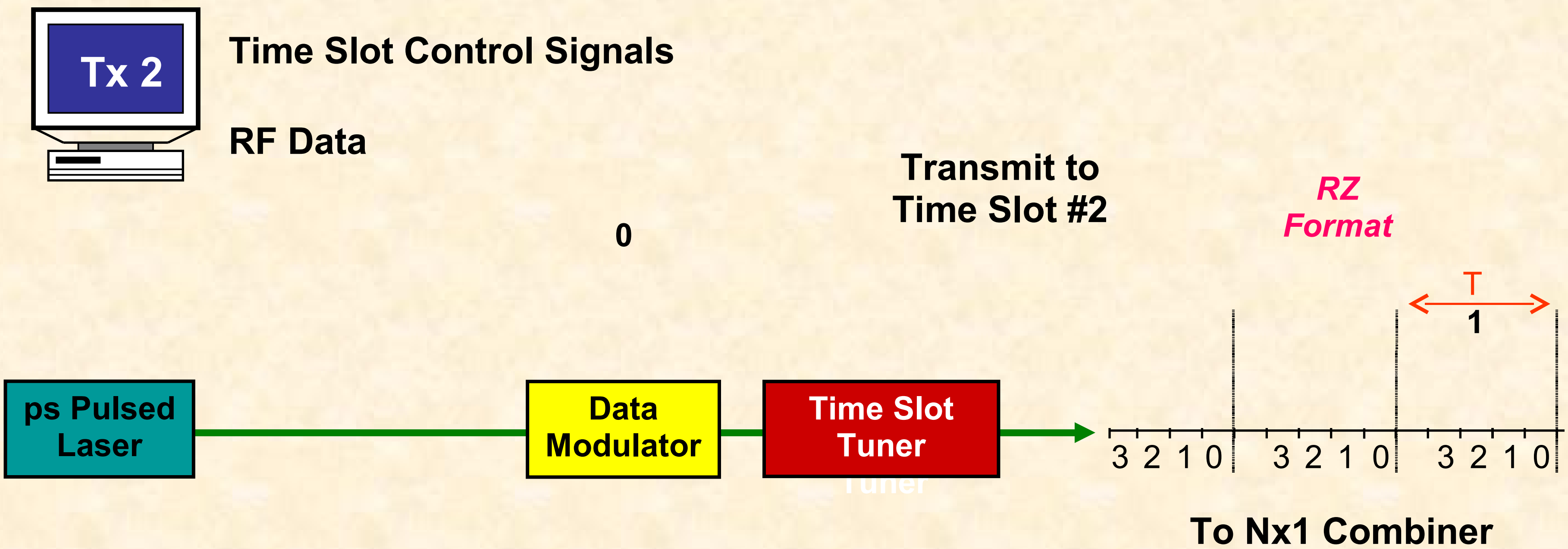

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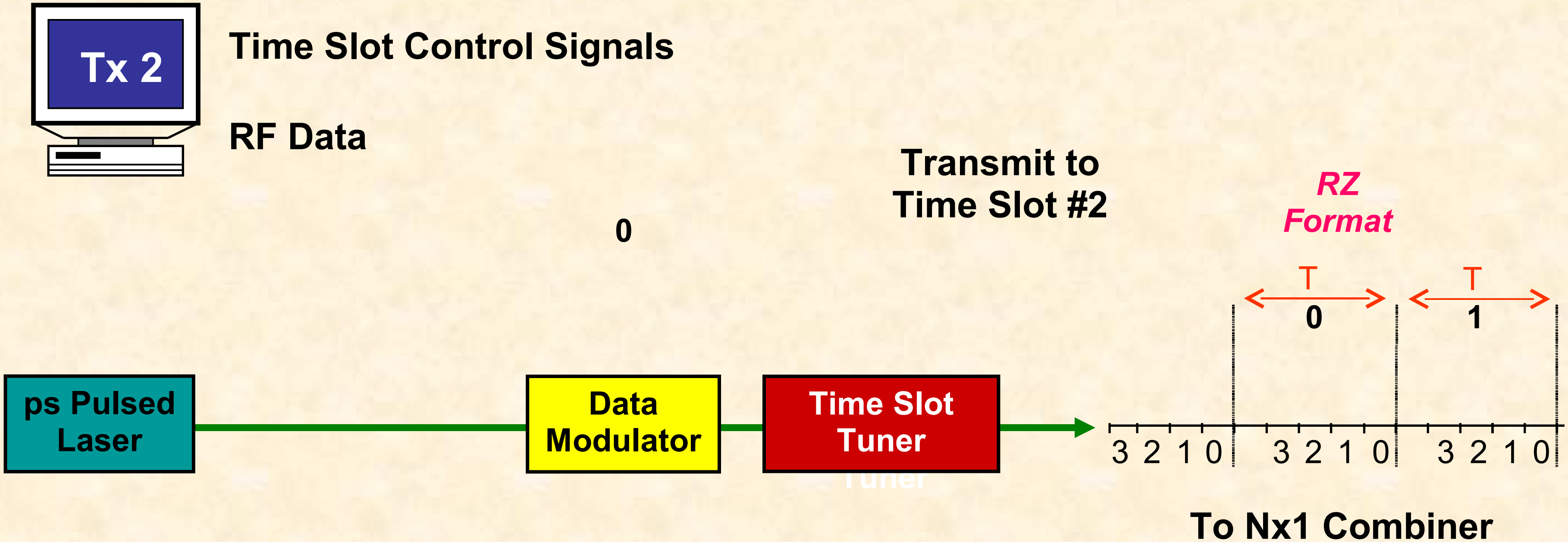

OTDM; Transmitter

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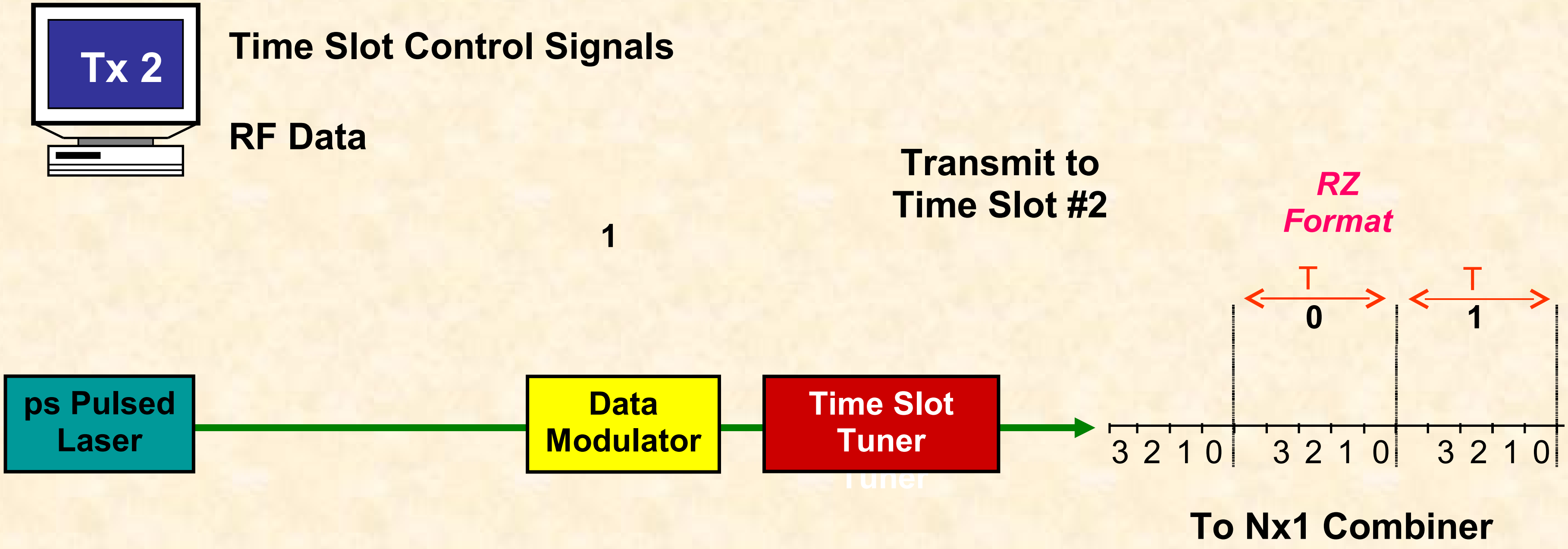
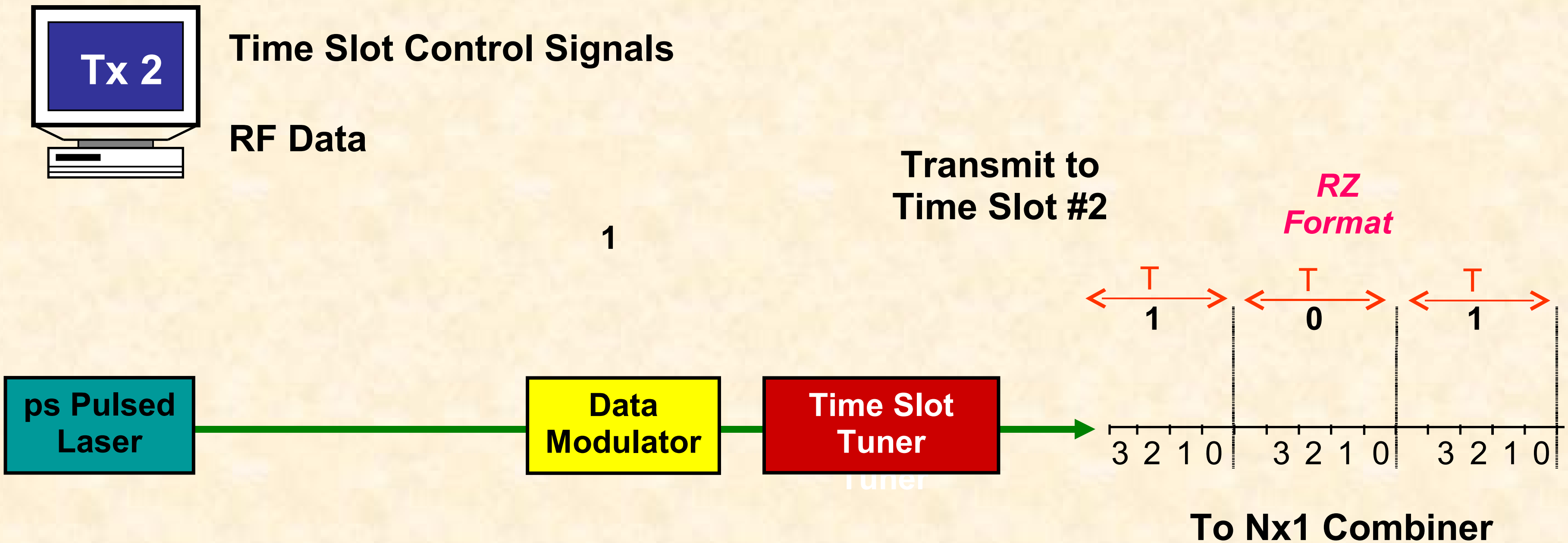


OTDM; Transmitter

Transmitting to Channel 2



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OTDM; Self Clocked Receiver

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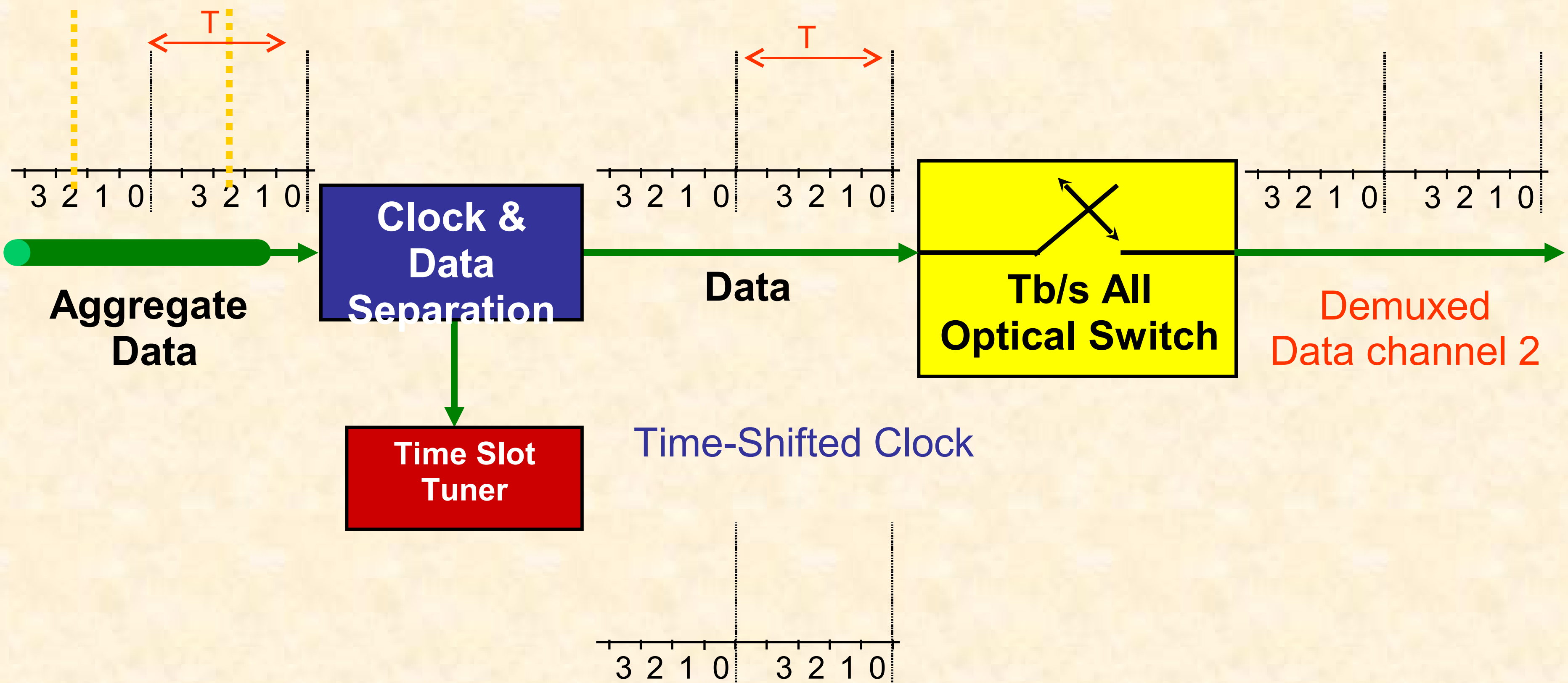
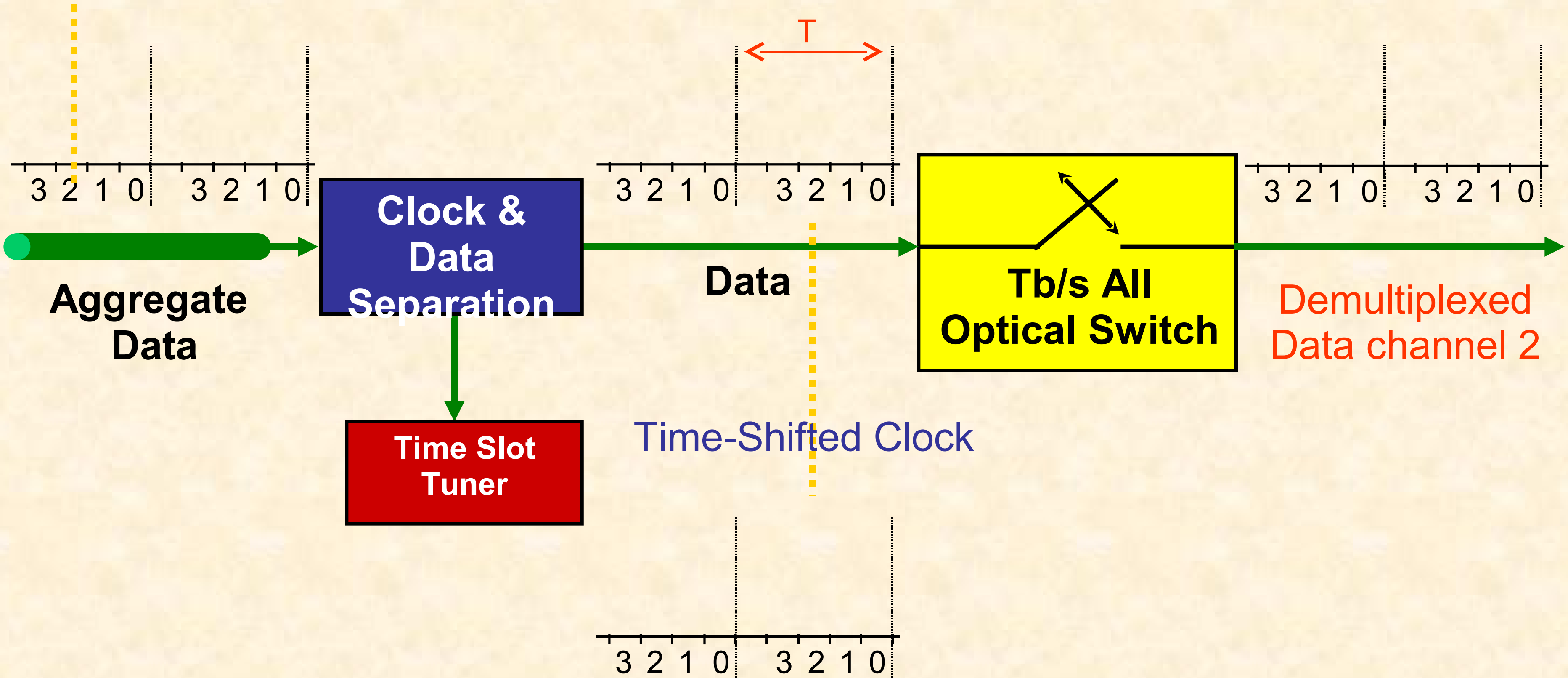
Demultiplexing data from Channel 2



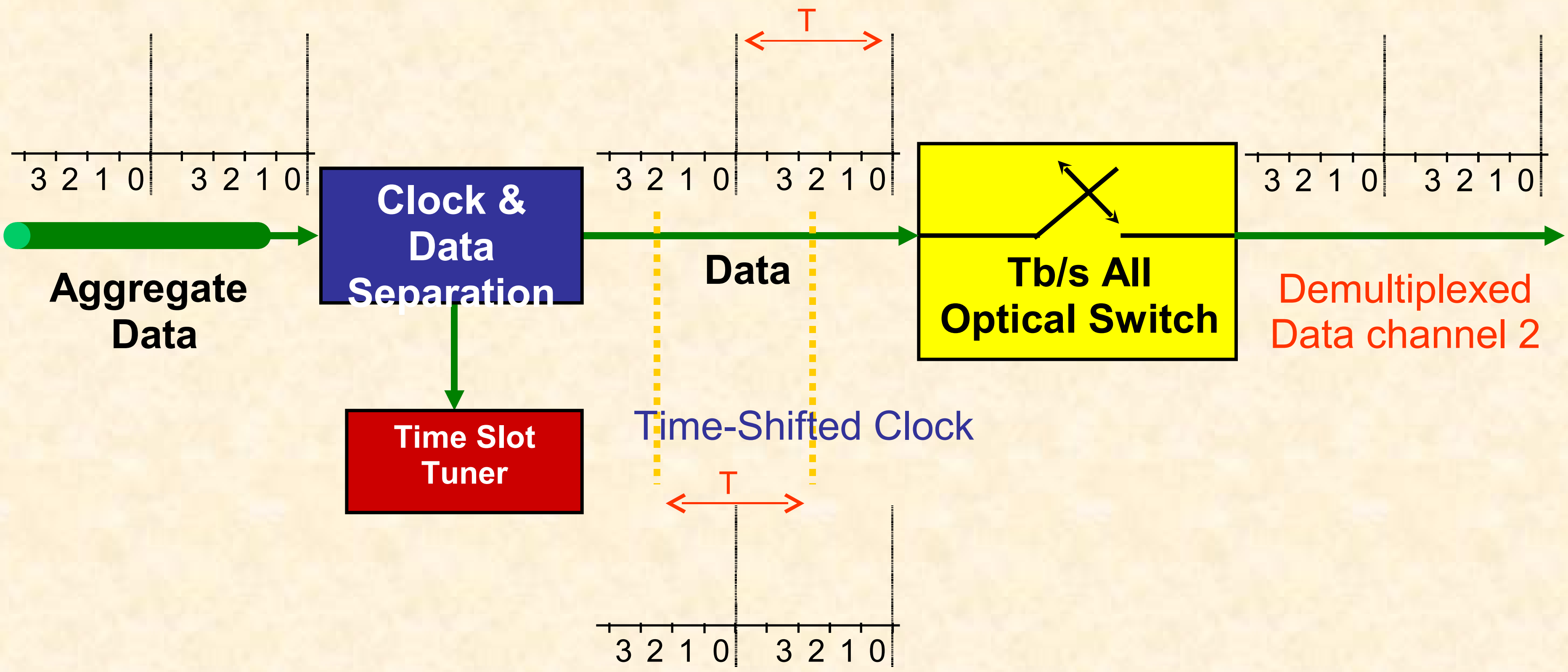
OTDM; Self Clocked Receiver

Demultiplexing data from Channel 2



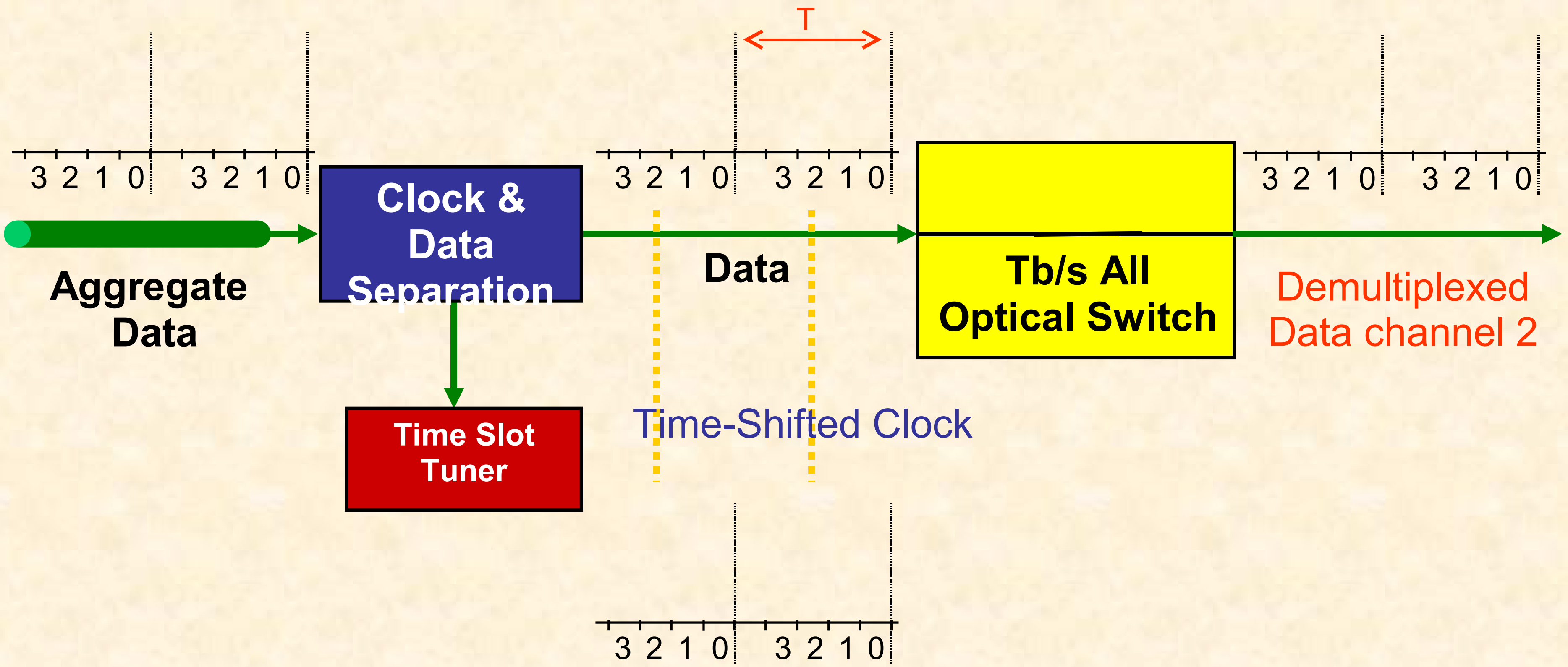
OTDM; Self Clocked Receiver

Demultiplexing data from Channel 2



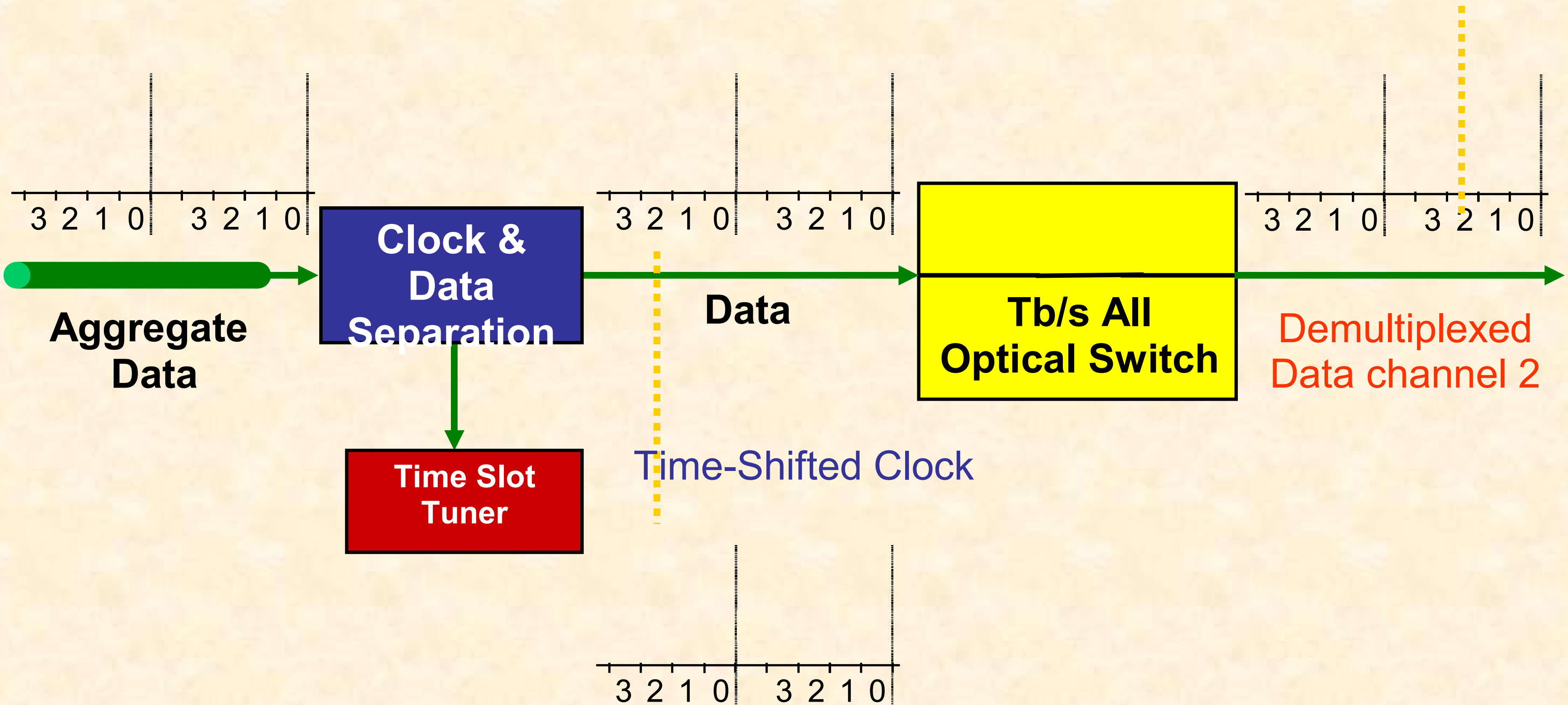
OTDM; Self Clocked Receiver

Demultiplexing data from Channel 2



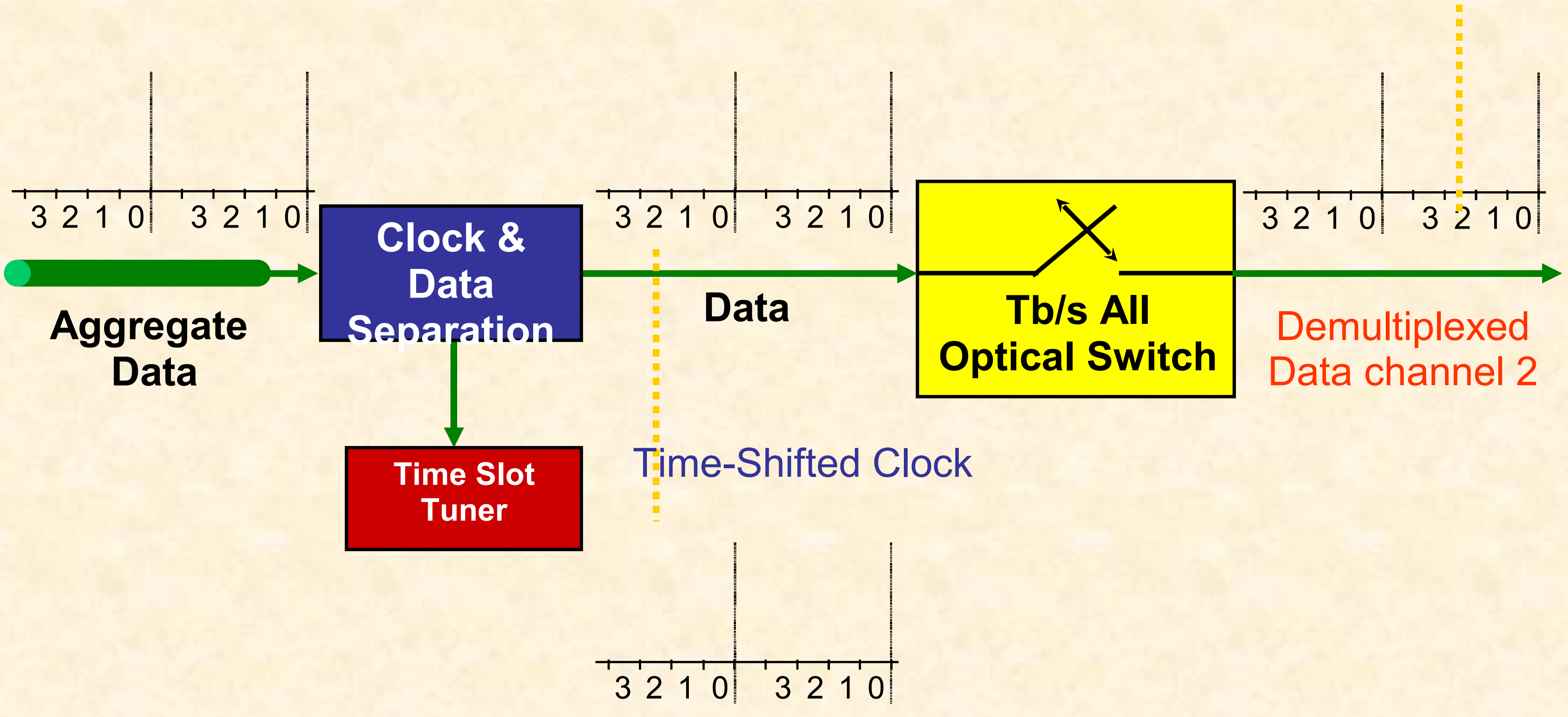
OTDM; Self Clocked Receiver

Demultiplexing data from Channel 2



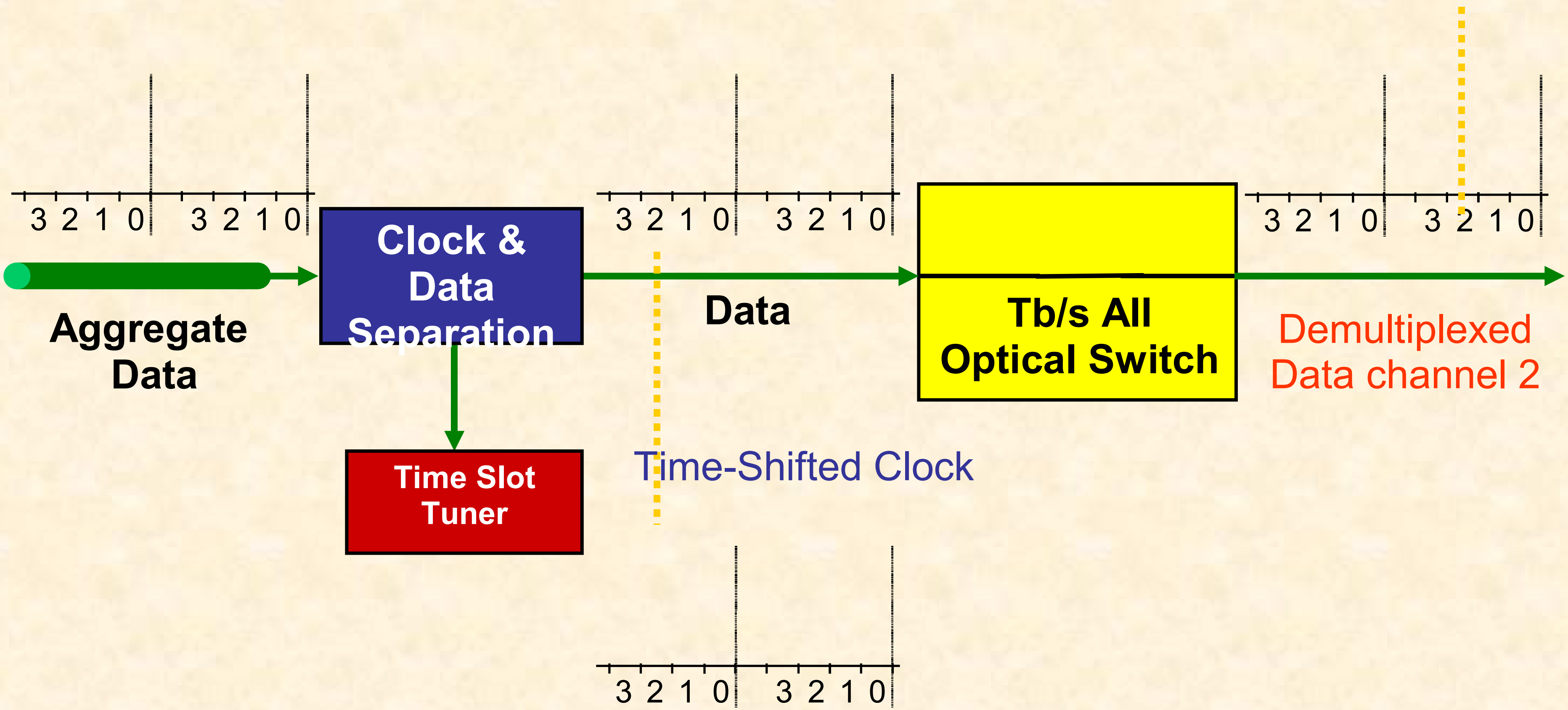
OTDM; Self Clocked Receiver

Demultiplexing data from Channel 2



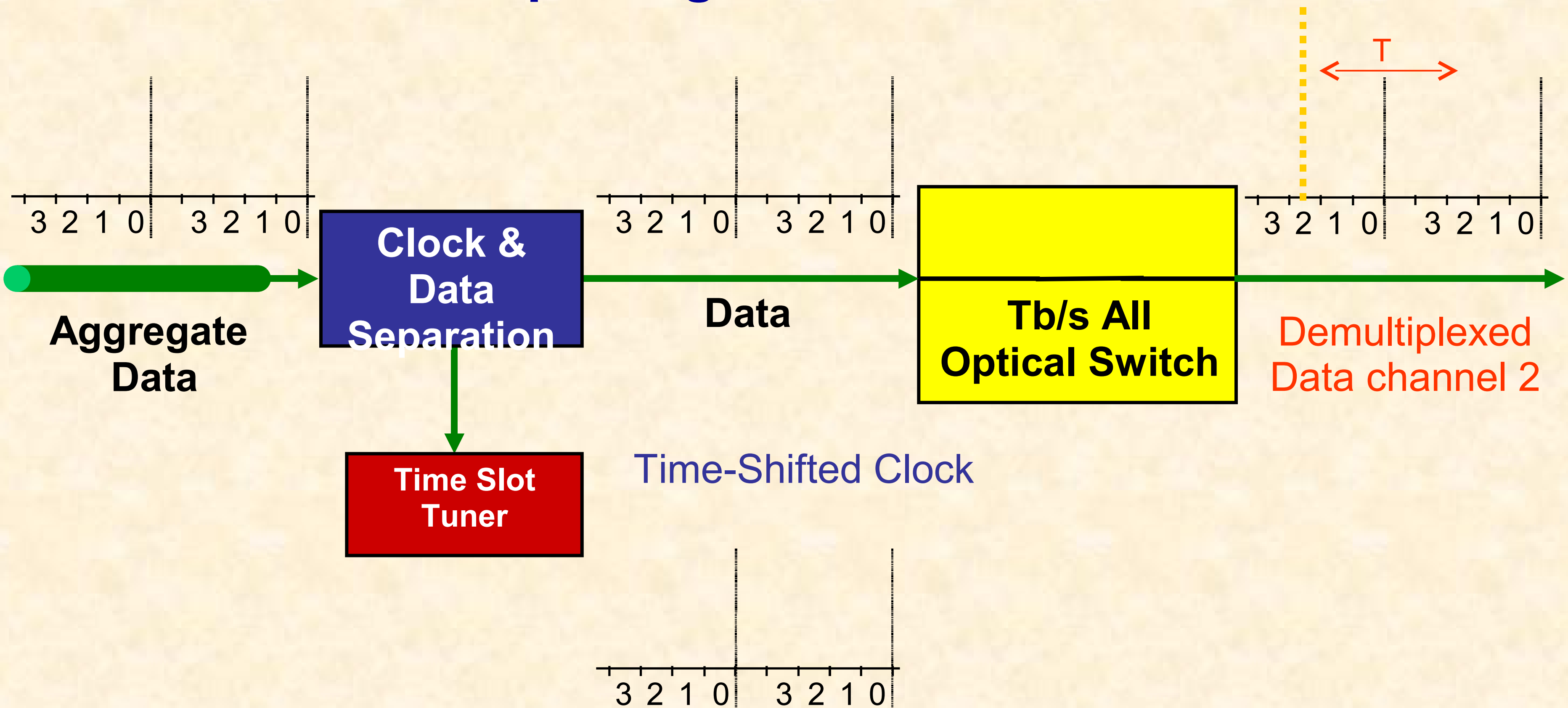
OTDM; Self Clocked Receiver

Demultiplexing data from Channel 2



OTDM; Self Clocked Receiver

Demultiplexing data from Channel 2



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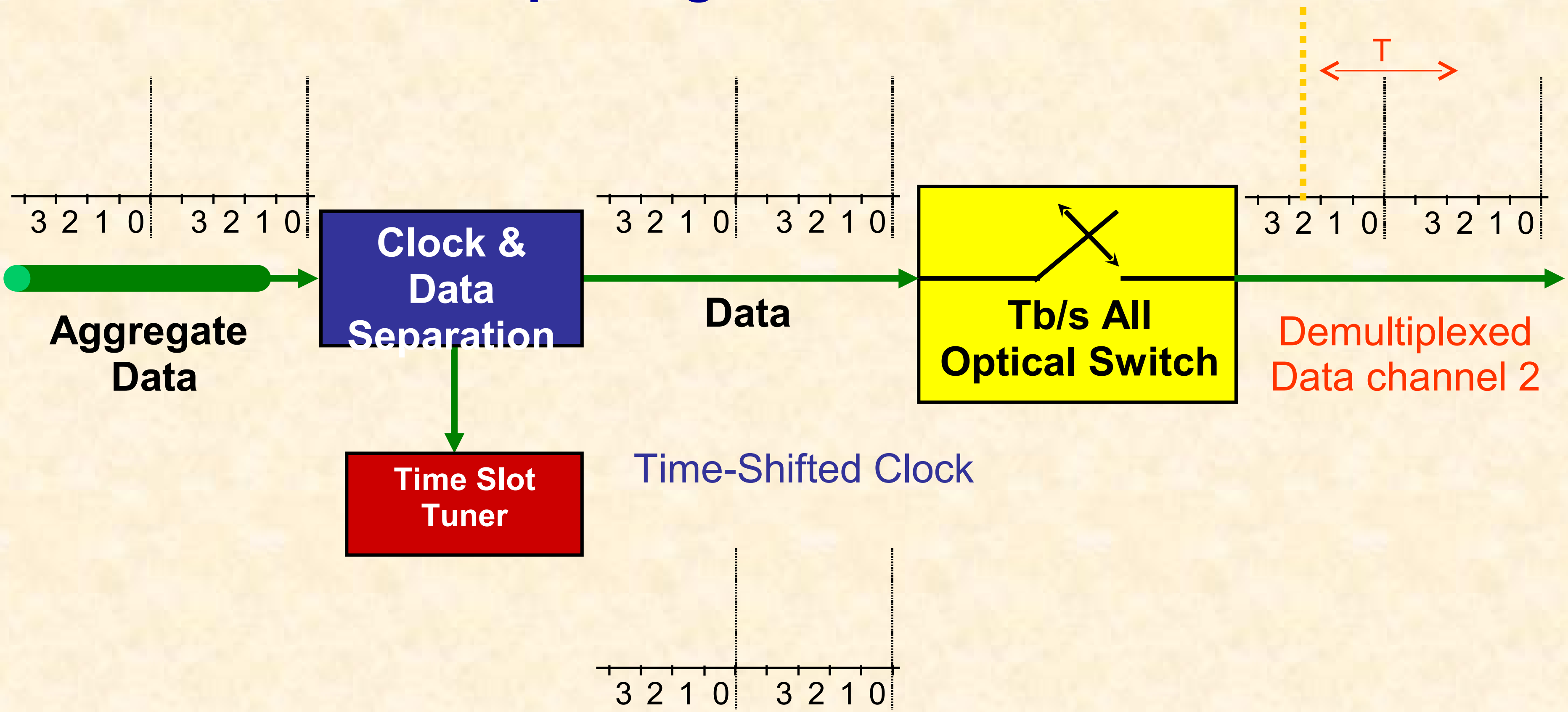
Demultiplexing data from Channel 2



ADAPTNet

ADAPTNet

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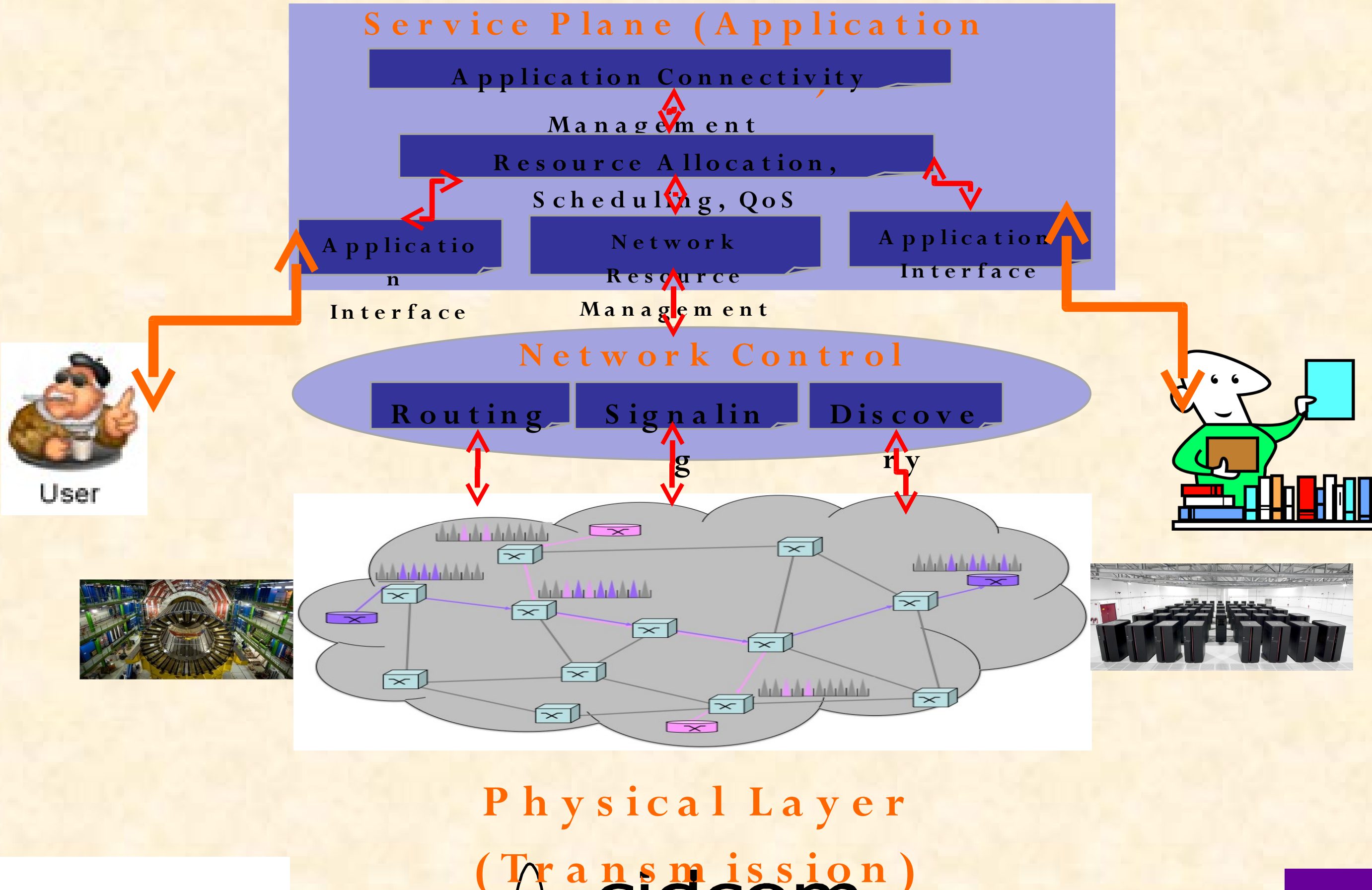

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Solution

- multi and cross-layer solution
  - physical layer
    - >100GBit/s per channel and >1TBit/s per fibre
  - control and management plane
    - understanding of application requirements and on-demand/dynamic
  - application to network interface
    - hide network complexity and connectivity provisioning process

Solution

- Carrier Class Ethernet
  - Ethernet standard for data rates higher than 10Gbit/s is already the subject of intensive development
  - 40Gbit/s and 100Gbit/s Ethernet Task Force (ETF)
  - pre-standards equipment being available commercially in 2009

- 100Gbit/s Ethernet will provide an off-the-shelf solution in the future
  - consumer based i.e. HDTV,SHDTV

- Other applications require higher data rates and support demanding quality of service (QoS) levels
  - E-science e.g. radio astronomy, UHD multimedia
  - research is already under way on Ethernet operating at 640Gbit/s which will doubtless become the focus of future standardization activities

- Ethernet is inherently packet-based, while high performance applications

OTDM

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- circuit-switched OTDM approach can adapt naturally to high-end application requirements for flexible capacity and QoS
- OTDM can offer an extra dimension to capacity upgrades
  - utilising the time dimension in the optical domain for capacity upgrades reduces the transponder complexity
  - proven ability to scale to ever higher single-channel data rates for serial ultrahigh capacity transport
- main drivers for migrating to higher single channel rates are
  - better utilization of the optical fibre
  - conservation of router ports and lowering of the network management overhead
  - factors will continue to drive the bit rate per channel higher to many 100's of Gbit/s

Service Provisioning

- applications to set up their own virtual network in an on-demand manner
- efficient and on-demand bandwidth provisioning mechanism
- network resource virtualization mechanism that decouples service delivery from bandwidth and protocol engineering
- protocols for point-to-point, point-to-multipoint and multipoint-to-point operation

New Networking Paradigm

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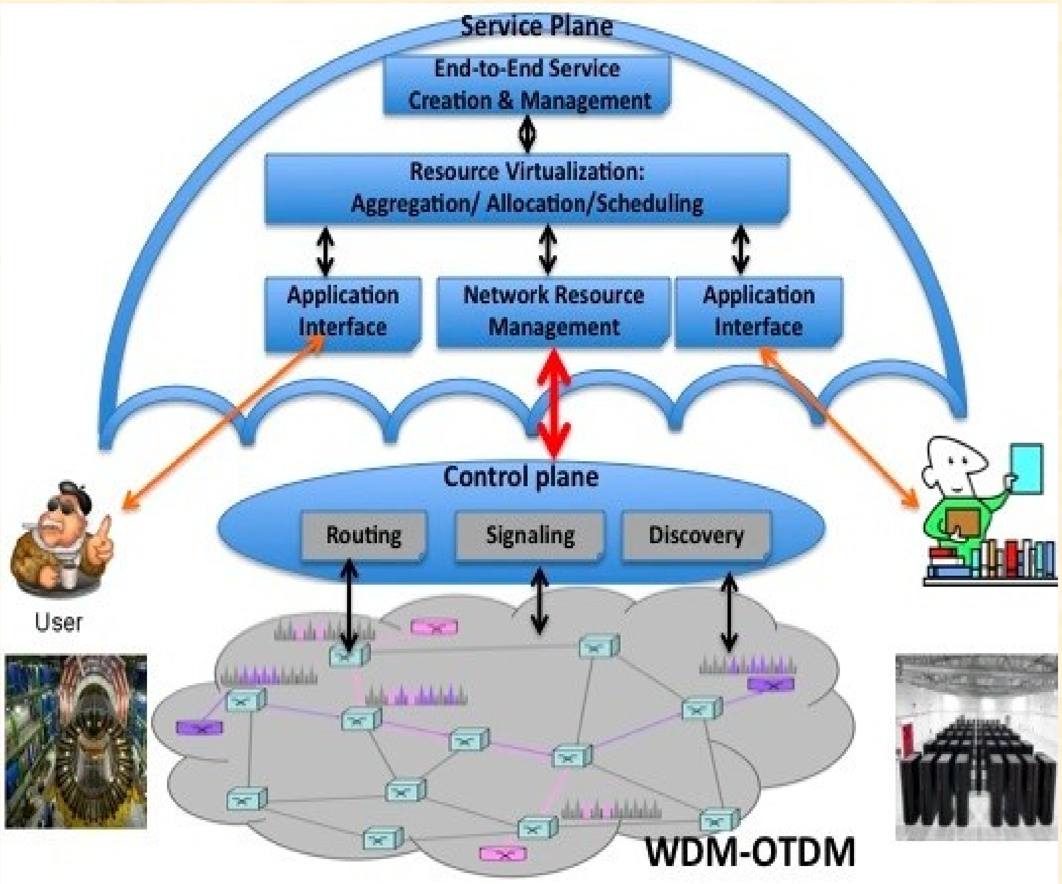

· Application requirements
· End-user requirements
· S

Service Plane

Control Plane

Network Elements

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Conclusions; Network Requirements

- a dynamic ultra high-speed platform that serves different types of bandwidth intensive application seamlessly
- **scalability;** a solution beyond the current or emerging Ethernet and other optical transport developments
- supports the **granularity** requirements of individual applications
- supports **end-to-end quality of service performance** requirements for different types of applications
- offers **application perceived network dynamics** without necessarily requiring a fully dynamic optical layer; this function will be provided by the service plane
- maintains **compatibility** with other mainstream solutions e.g. Ethernet
- capable of **deploying new applications** quickly and efficiently, presenting minimal complexity to the user