EC2402 Optical Fiber Communication and Networks

UNIT V

Optical Networks

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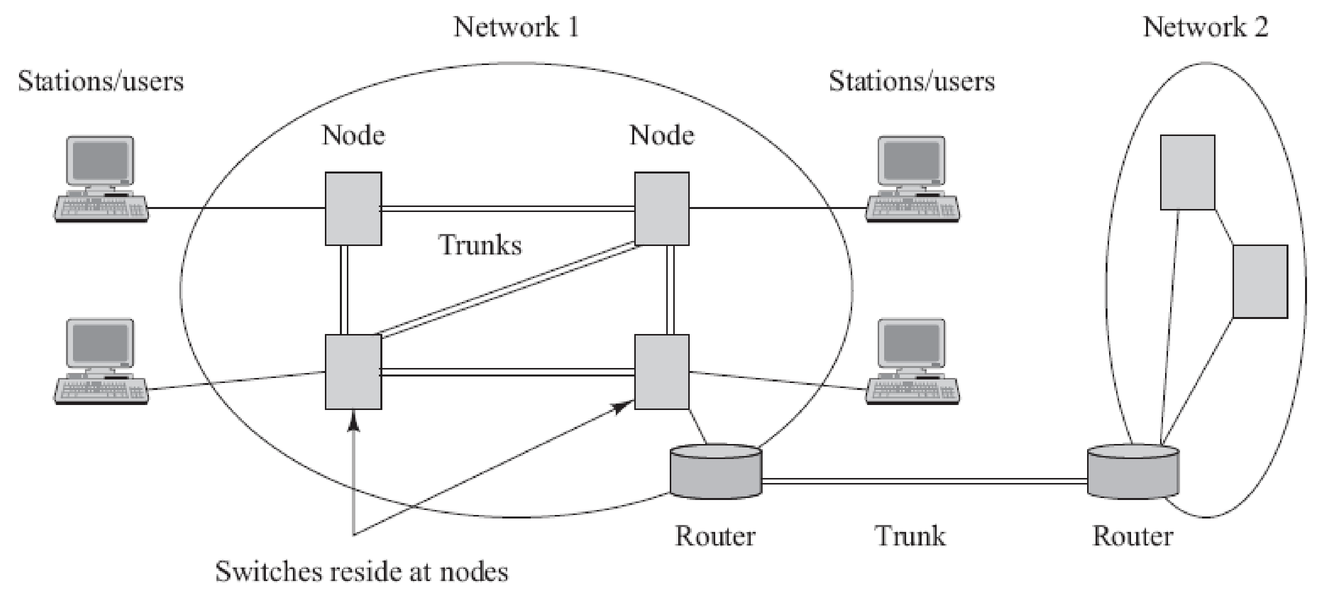
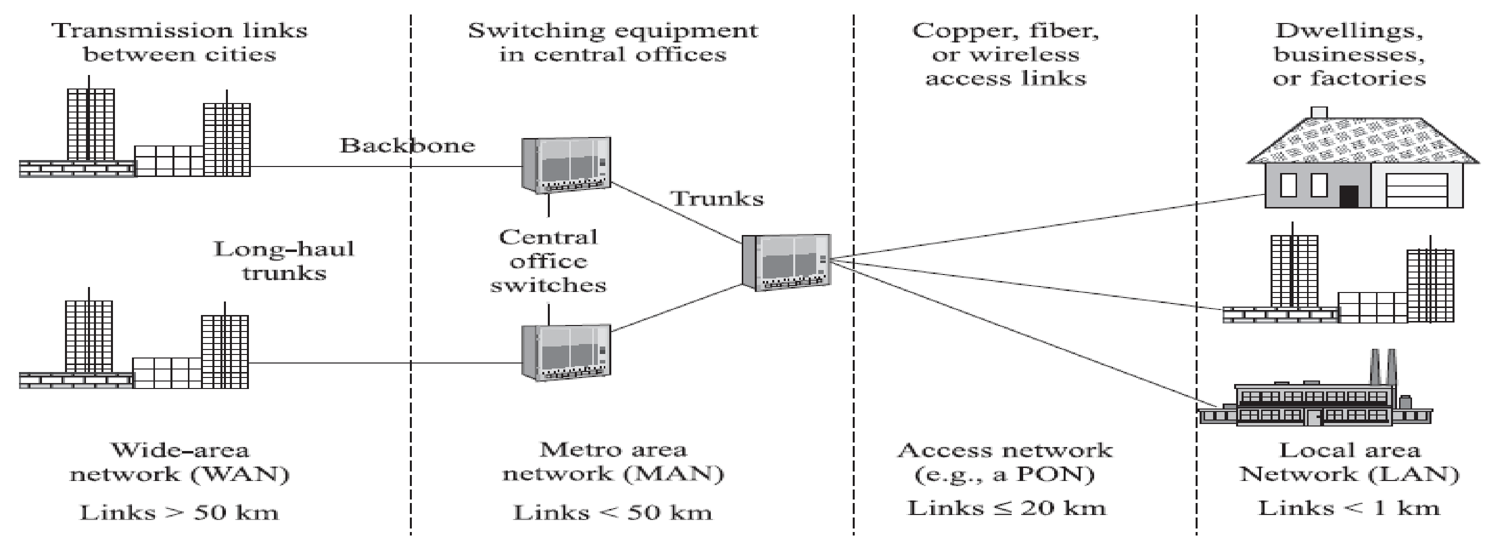
Network Terminology

- *Stations* are devices that network subscribers use to communicate.
- A *network* is a collection of interconnected stations.
- A *node* is a point where one or more communication lines terminate.
- A *trunk* is a transmission line that supports large traffic loads.
- The *topology* is the logical manner in which nodes are linked together by information transmitting channels to form a network.



Segments of a Public Network

- A *local area network* interconnects users in a large room or work area, a department, a home, a building, an office or factory complex, or a group of buildings.
- A *campus network* interconnects a several LANs in a localized area.
- A *metro network* interconnects facilities ranging from buildings located in several city blocks to an entire city and the metropolitan area surrounding it.
- An *access network* encompasses connections that extend from a centralized switching facility to individual businesses, organizations, and homes.



Network Categories

Optical Networks are categorized in multiple ways:

- All Optical (or Passive Optical) Networks Vs Optical/Electrical/Optical Networks
- Based on service area
  - Long haul, metropolitan and access network
  - Wide area (WAN), metropolitan area (MAN) or local area network (LAN)
- Depending on the Protocol
  - SONET, Ethernet, ATM, IP
- Number of wavelengths
  - single wavelength, CWDM or DWDM

Passive Optical Networks

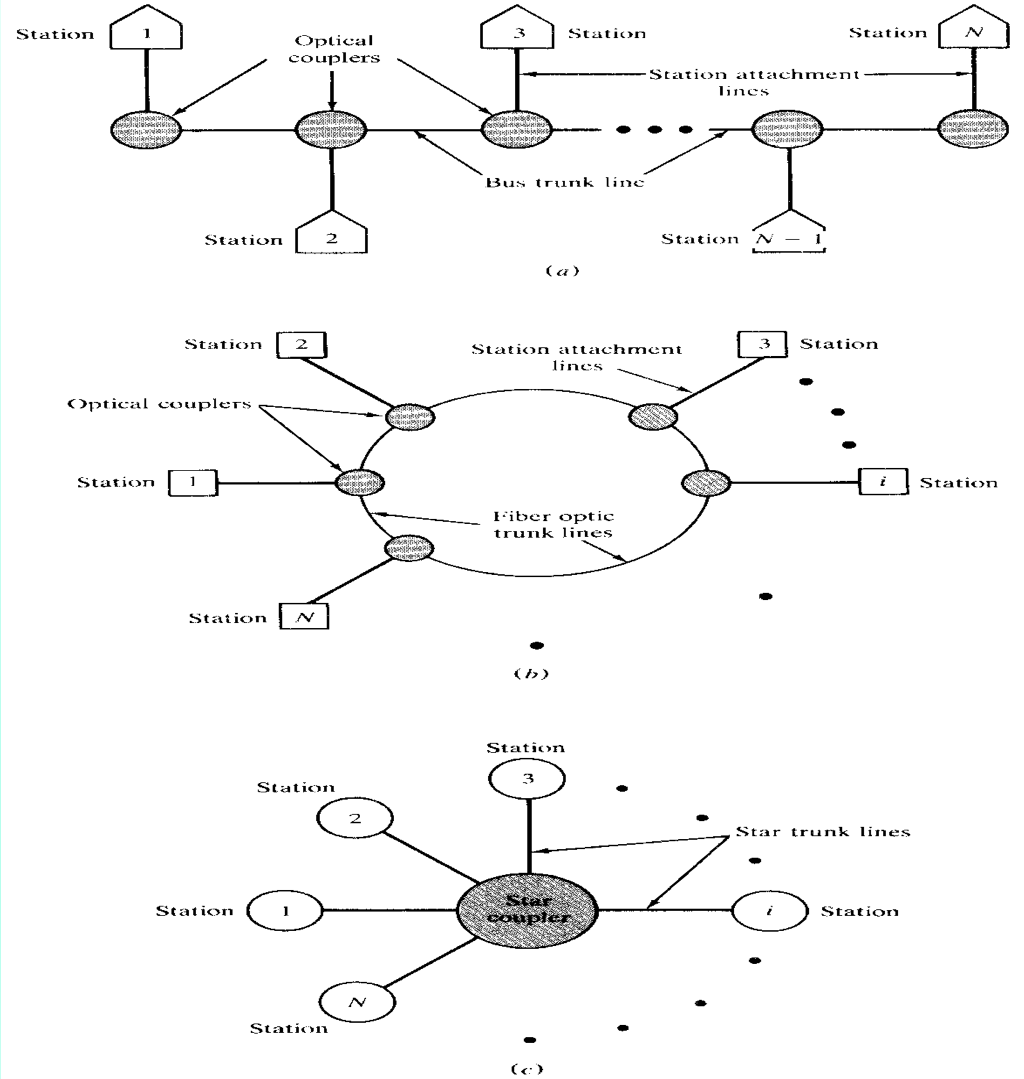
- There is no O/E conversion in between the transmitter and the receiver (one continuous light path)
- Power budget and rise time calculations has to be done from end-to-end depending on which Tx/Rx pair communicates
- Star, bus, ring, mesh, tree topologies
- PON Access Networks are deployed widely.

The PON will still need higher layer protocols (Ethernet/IP etc.) to complete the service

Star, Tree & Bus Networks

- Tree networks are widely deployed in the access front
- Tree couplers are similar to star couplers (expansion in only one direction; no splitting in the uplink)
- Bus networks are widely used in LANs
- Ring networks (folded buses with protection) are widely used in MAN
- Designing ring & bus networks is similar

Passive Optical Network (PON) Topologies



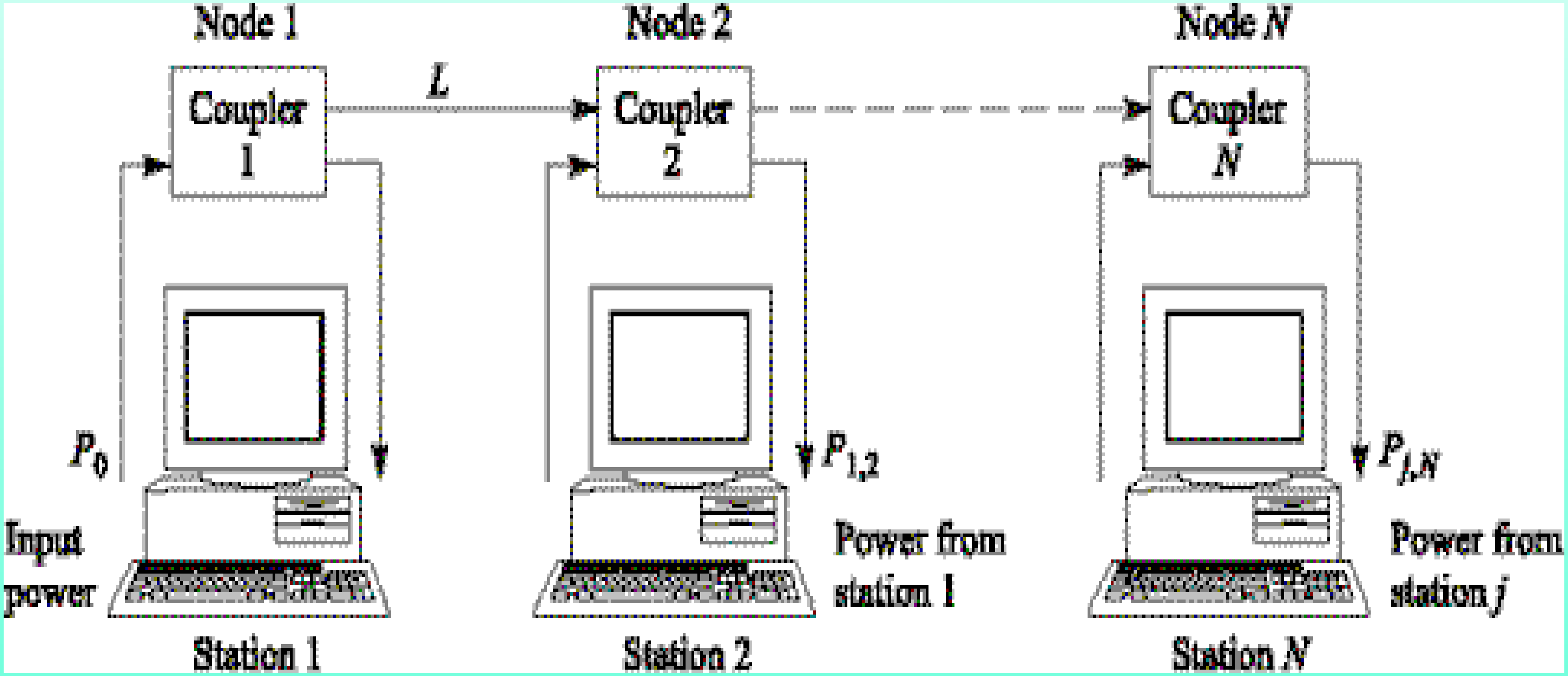
BUS

RING

STAR

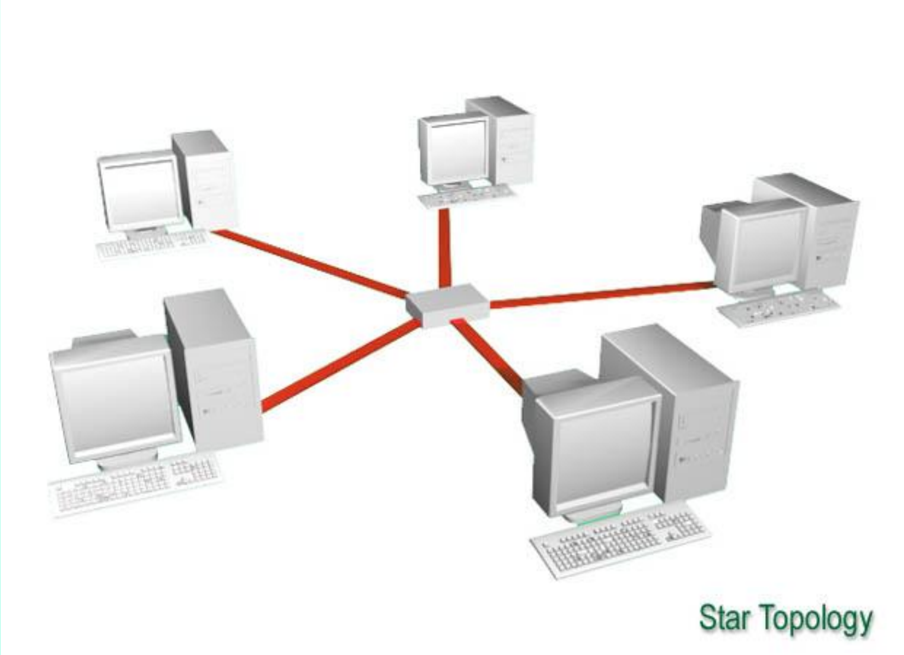
Linear bus topology

Ex. 12.1



$$10\log\left(\frac{P_o}{P_{L,N}}\right)=(N-1)\alpha L+2NL_C+(N-2)L_{thru}+2L_{TAP}+NL_i$$

Star Network



Power Budget:

$$P_s - P_r = 2l_c + \alpha(L_1 + L_2) + \text{Excess Loss} + 10\ \text{Log}\ N + \text{System Margin}$$

Worst case power budget need to be satisfied

Network Layering Concept

- *Network architecture:* The general physical arrangement and operational characteristics of communicating equipment together with a common set of communication protocols
- *Protocol:* A set of rules and conventions that governs the *generation, formatting, control, exchange, and interpretation of information* sent through a telecommunication network or that is stored in a database
- *Protocol stack*: Subdivides a protocol into a number of individual layers of manageable and comprehensible size
  - The lower layers govern the *communication facilities.*
  - The upper layers support *user applications* by structuring and organizing data for the needs of the user.

Synchronous Optical Networks

- SONET is the TDM optical network standard for North America
- SONET is called Synchronous Digital Hierarchy (SDH) in the rest of the world
- SONET is the basic phycal layer standard
- Other data types such as ATM and IP can be transmitted over SONET
- OC-1 consists of 810 bytes over 125 us; OC-*n* consists of 810*n* bytes over 125 us
- Linear multiplexing and de-multiplexing is possible with Add-Drop-Multiplexers

Brief History

- Early (copper) digital networks were asynchronous with individual clocks resulting in high bit errors and non-scalable multiplexing
- Fiber technology made highly Synchronous Optical Networks (SONET) possible.
- SONET standardized line rates, coding schemes, bit-rate hierarchies and maintenance functionality

Synchronous Optical Networks

- SONET is the TDM optical network standard for North America (It is called SDH in the rest of the world)
- We focus on the physical layer
- STS-1, Synchronous Transport Signal consists of 810 bytes over 125 us
- 27 bytes carry overhead information
- Remaining 783 bytes: Synchronous Payload Envelope-user data,payment and charges

SONET/SDH Bit Rates

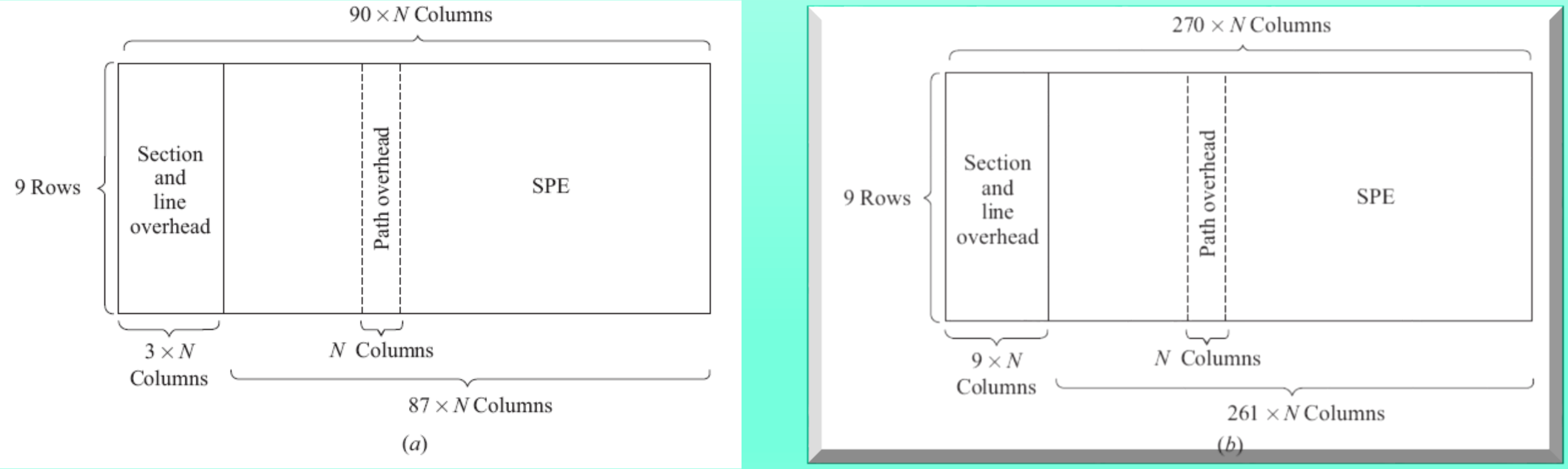
SONET	Bit Rate (Mbps)	SDH
OC-1	**51.84**	**-**
OC-3	**155.52**	**STM-1**
OC-12	**622.08**	**STM-4**
OC-24	**1244.16**	**STM-8**
OC-48	**2488.32**	**STM-16**
OC-96	**4976.64**	**STM-32**
OC-192	**9953.28**	**STM-64**

SONET/SDH

- The SONET/SDH standards enable the interconnection of fiber optic transmission equipment from various vendors through multiple-owner trunk networks.
- The basic transmission bit rate of the basic SONET signal is

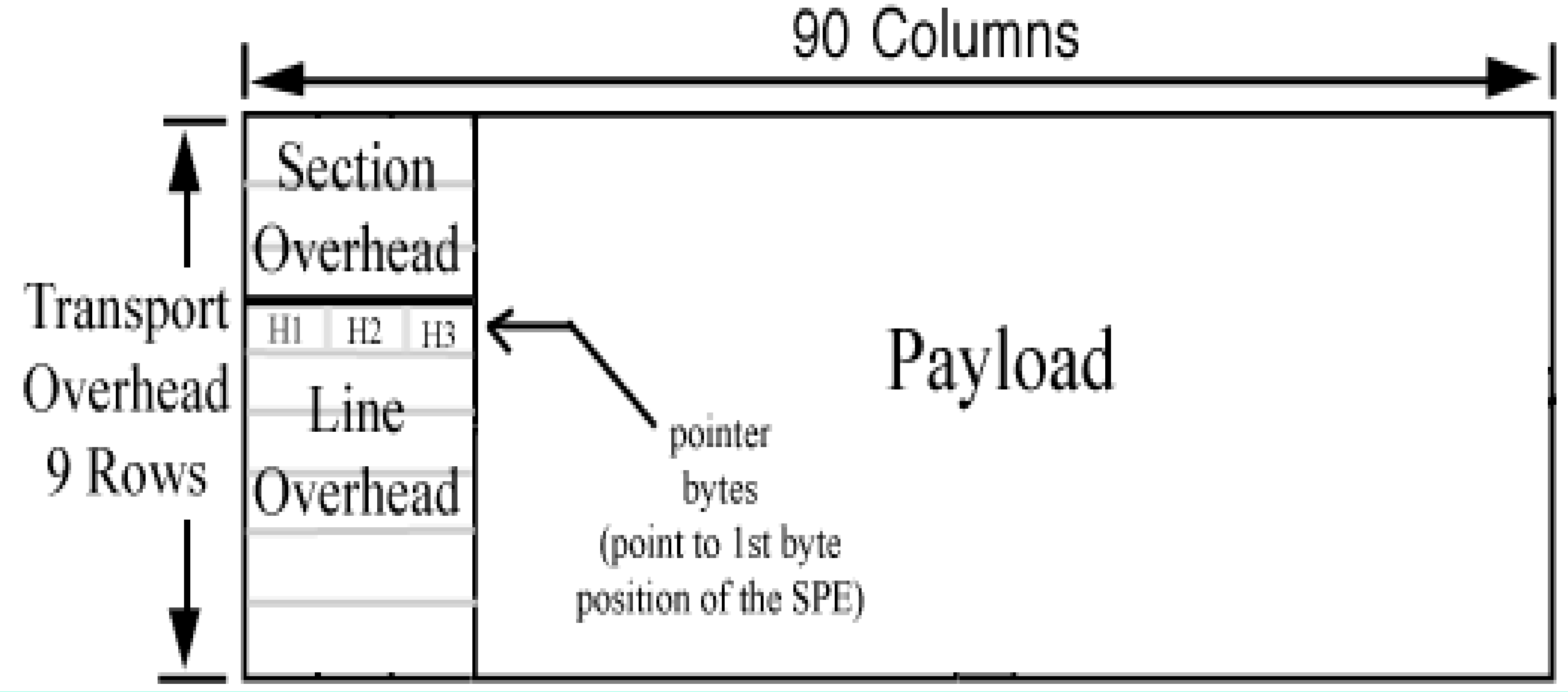
$$\text{STS-1} = (90\ \text{bytes/row})(9\ \text{rows/frame})(8\ \text{bits/byte})/(125\ \mu\text{s/frame}) = 51.84\ \text{Mb/s}$$

- In SDH the basic rate is 155.52 Mb/s.

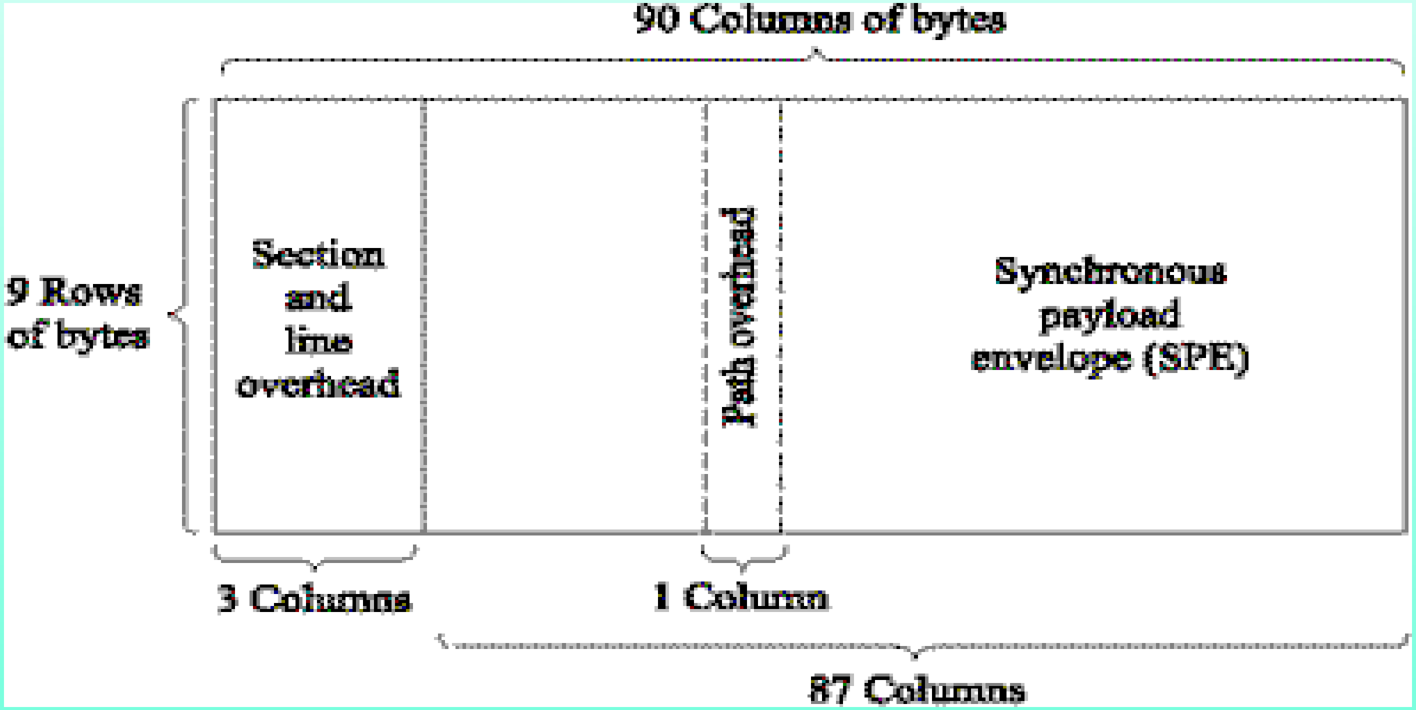


Basic formats of (a) an STS-N SONET frame and (b) an STM-N SDH frame

Basic STS-1 SONET frame

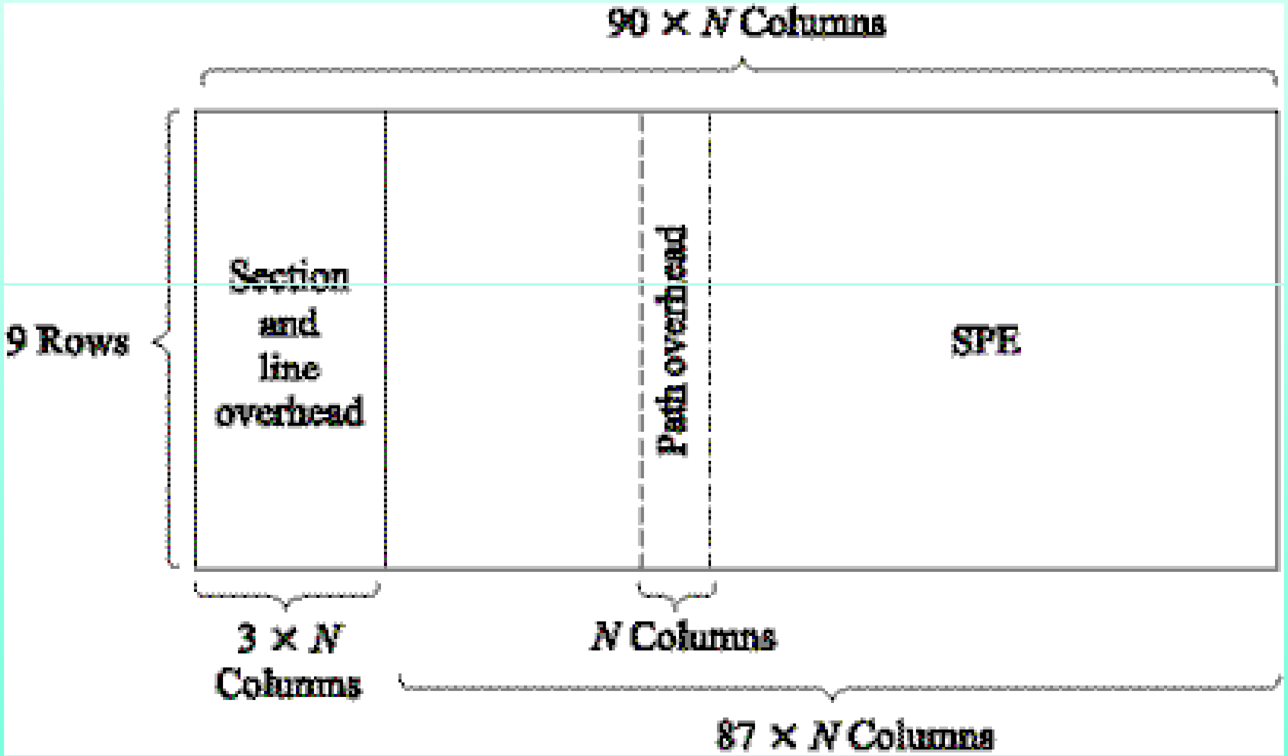


Basic STS-1 SONET frame



$$\text{STS-1}=(90{*}8\text{bits/row})(9\text{rows/frame}){*}125\mu s/\text{frame}=51.84\ \text{Mb/s}$$

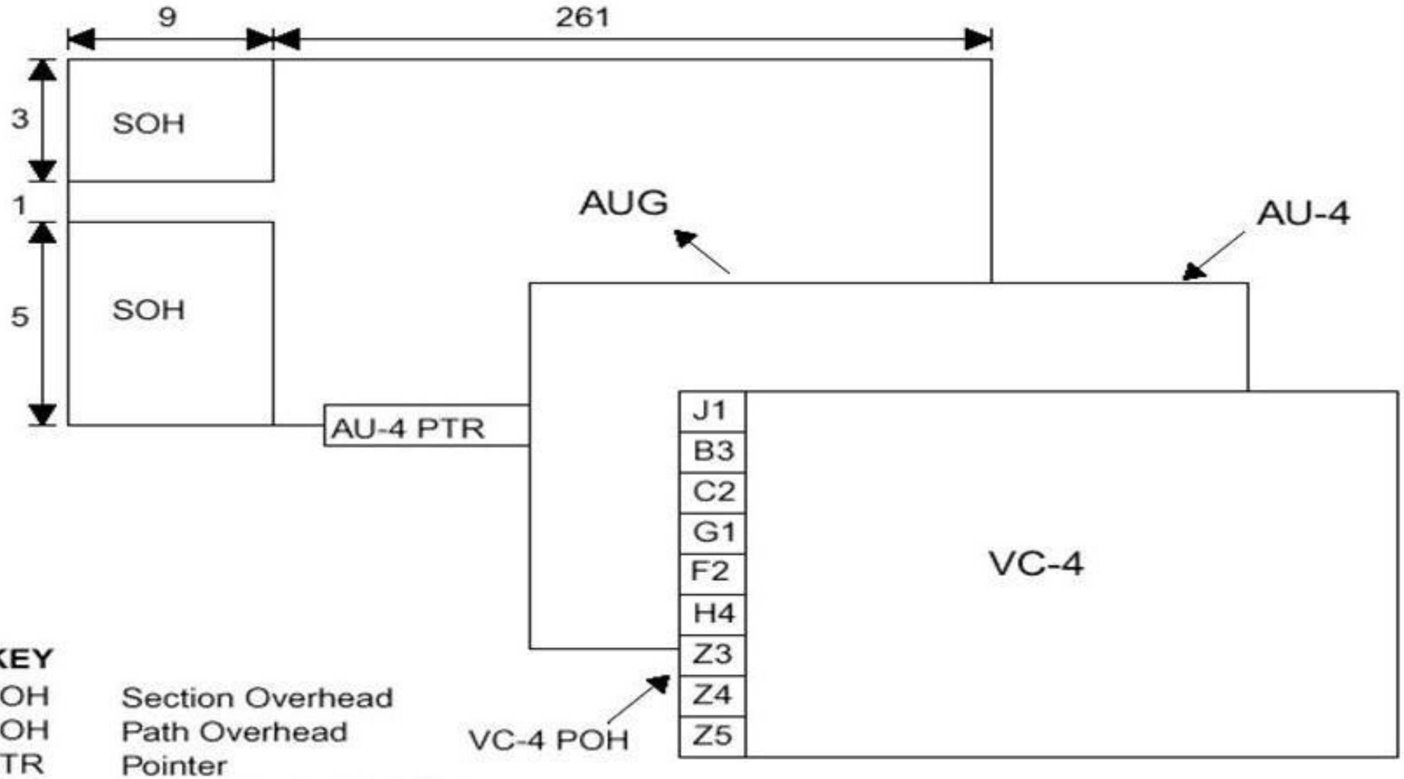
Basic STS-N SONET frame



STS-*N* signal has a bit rate equal to *N* times 51.84 Mb/s

Ex: STS-3 → 155.52 Mb/s

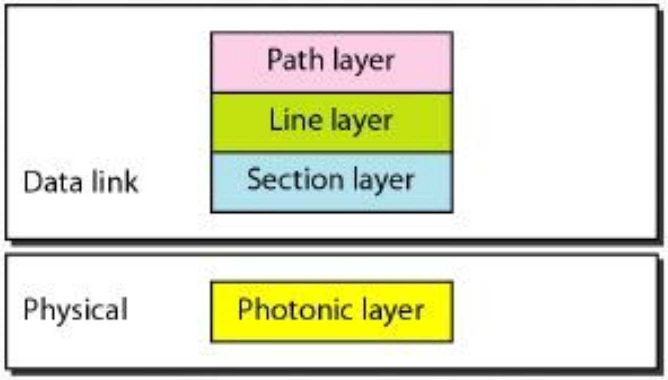
STM-1 frame structure



KEY

SOH	Section Overhead
POH	Path Overhead
PTR	Pointer
AUG	Administrative Unit Group
AU	Administrative Unit
VC	Virtual Container

SONET LAYERS



SONET defines four layers: path, line, section, and photonic

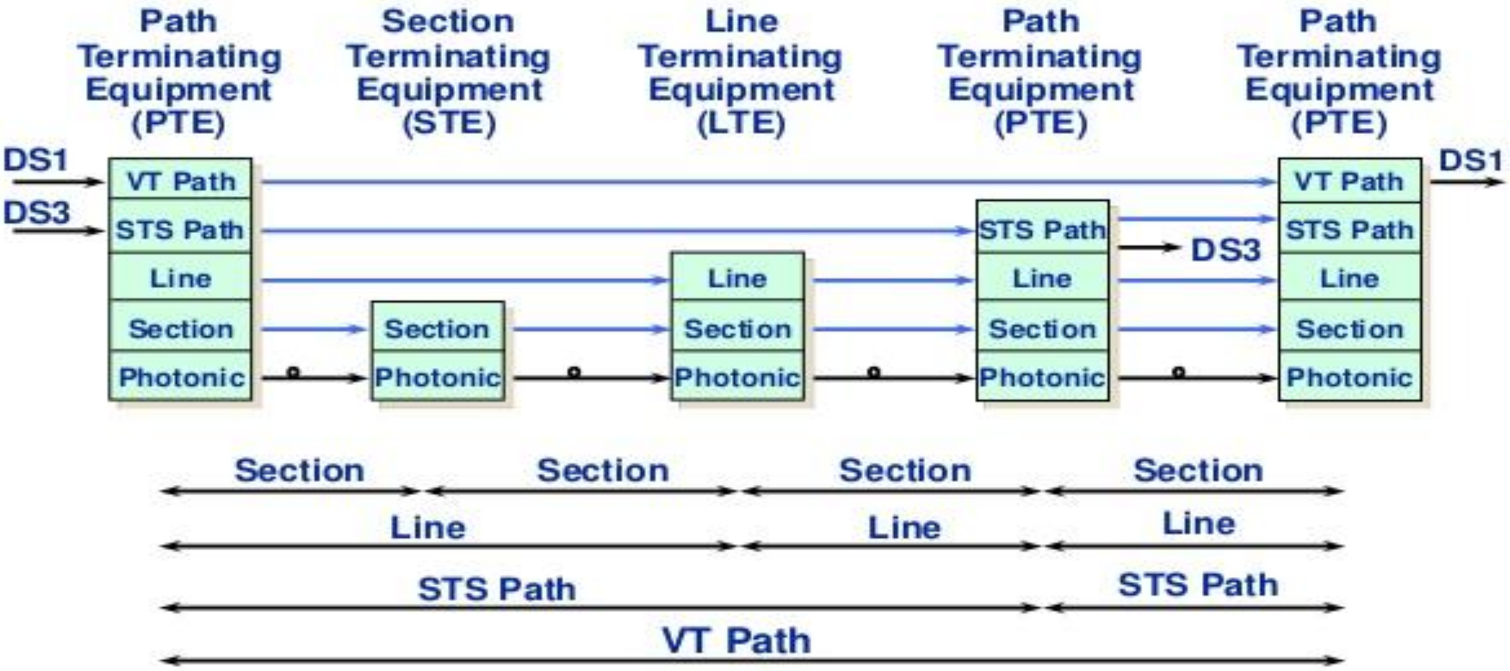
- Path layer is responsible for the movement of a signal from its optical source to its optical destination

- Line layers is for the movement of a signal across a physical line

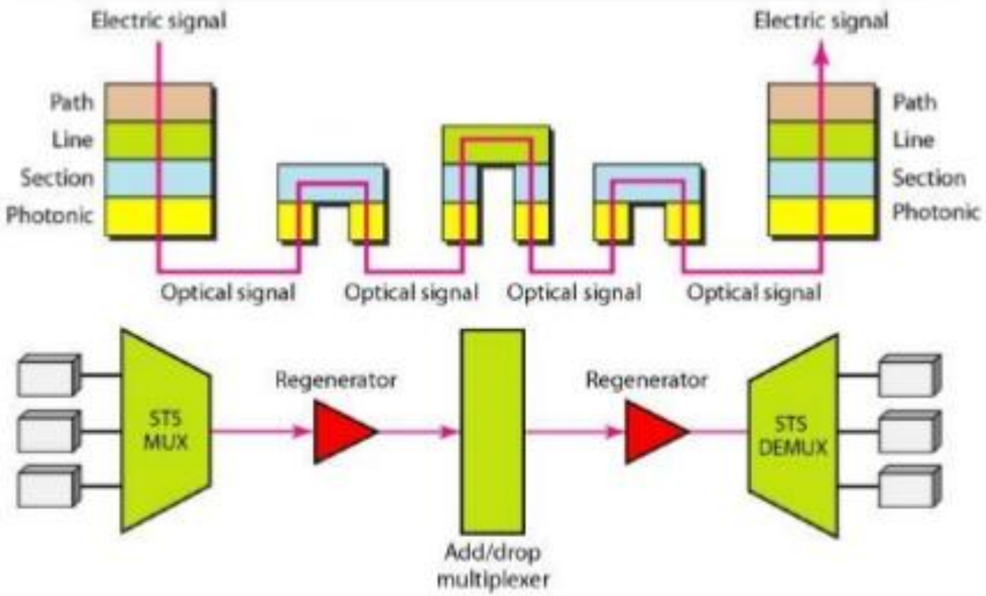
- Section layer is for the movement of a signal across a physical section, handling framing, scrambling, and error control

- Photonic layer corresponds to the physical layer of OSI model

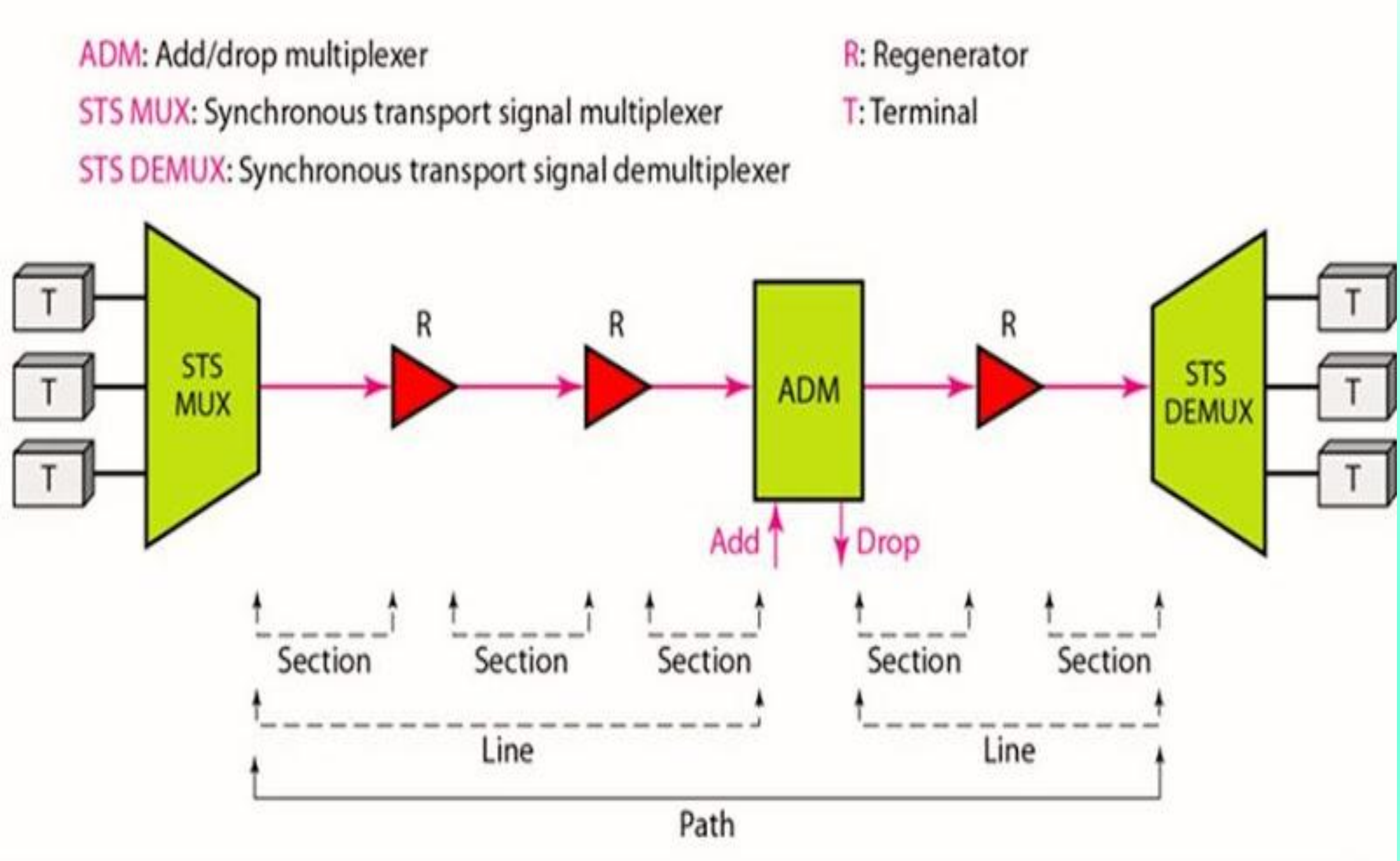
SONET Layers



SONET LAYERs



Physical Configuration


ADM: Add/drop multiplexer

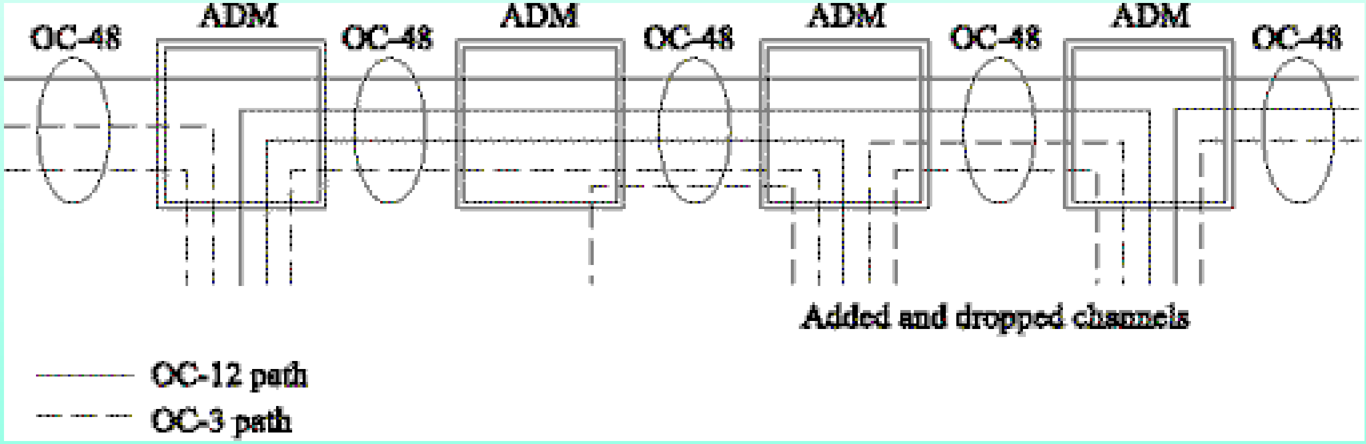
STS MUX: Synchronous transport signal multiplexer

STS DEMUX: Synchronous transport signal demultiplexer

R: Regenerator

T: Terminal

SONET Add Drop Multiplexers

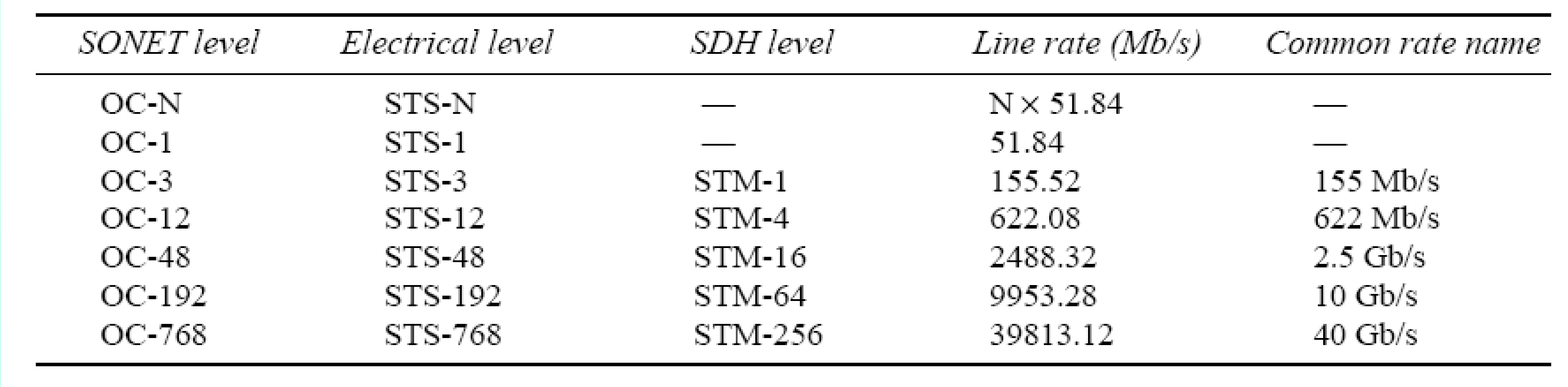


ADM is a fully synchronous, byte oriented device, that can be used add/drop OC sub-channels within an OC-*N* signal

Ex: OC-3 and OC-12 signals can be individually added/dropped from an OC-48 carrier

Common values of OC-N and STM-N

- OC stands for *optical carrier*. It has become common to refer to SONET links as OC-*N links.*
- The basic SDH rate is 155.52 Mb/s and is called the *synchronous transport module—level 1 (STM-1).*



SONET level	*Electrical level*	*SDH level*	*Line rate (Mb/s)*	*Common rate name*
OC-N	STS-N	—	N × 51.84	—
OC-1	STS-1	—	51.84	—
OC-3	STS-3	STM-1	155.52	155 Mb/s
OC-12	STS-12	STM-4	622.08	622 Mb/s
OC-48	STS-48	STM-16	2488.32	2.5 Gb/s
OC-192	STS-192	STM-64	9953.28	10 Gb/s
OC-768	STS-768	STM-256	39813.12	40 Gb/s

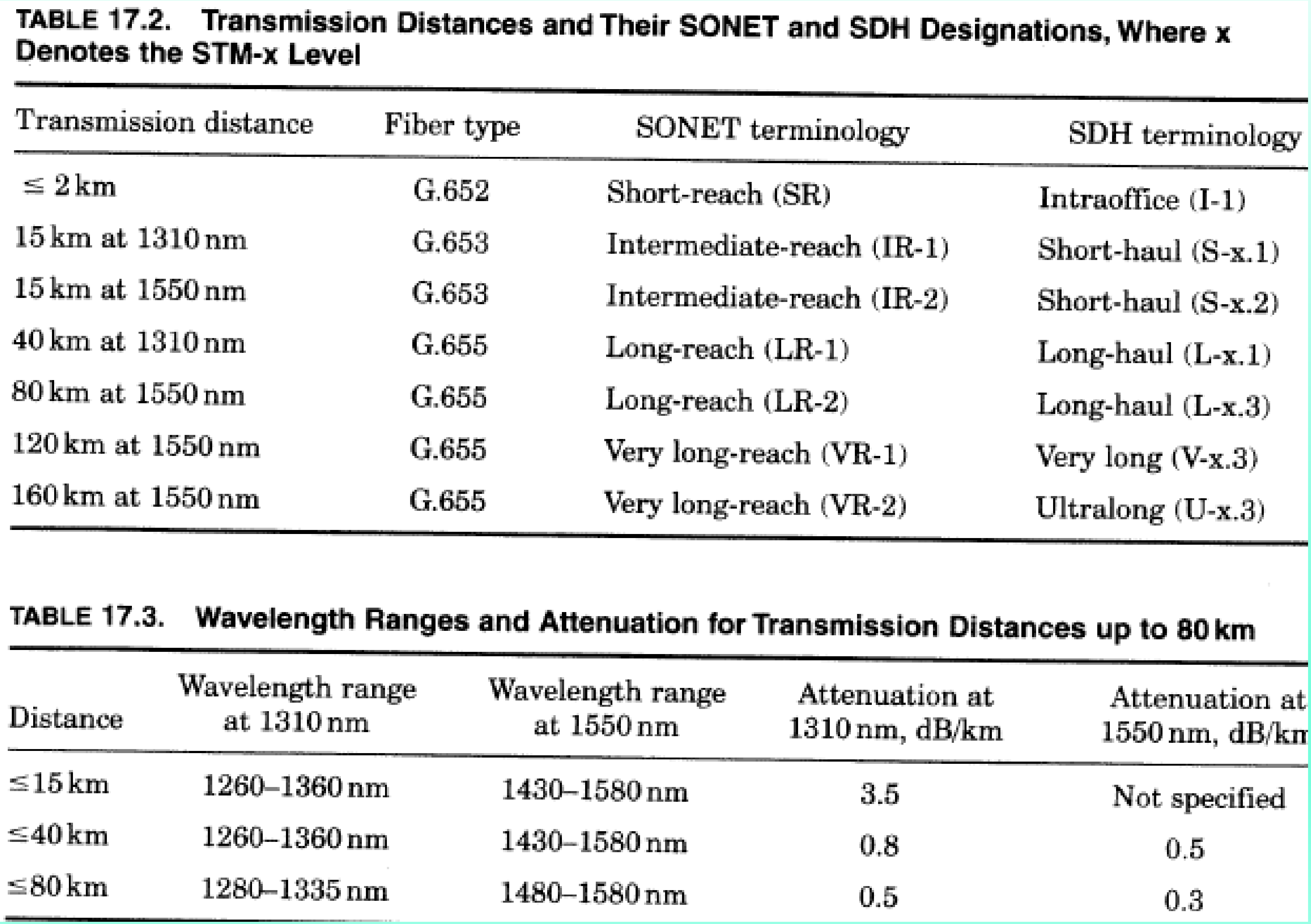


TABLE 17.2. Transmission Distances and Their SONET and SDH Designations, Where x Denotes the STM-x Level

Transmission distance	Fiber type	SONET terminology	SDH terminology
≤ 2 km	G.652	Short-reach (SR)	Intraoffice (I-1)
15 km at 1310 nm	G.653	Intermediate-reach (IR-1)	Short-haul (S-x.1)
15 km at 1550 nm	G.653	Intermediate-reach (IR-2)	Short-haul (S-x.2)
40 km at 1310 nm	G.655	Long-reach (LR-1)	Long-haul (L-x.1)
80 km at 1550 nm	G.655	Long-reach (LR-2)	Long-haul (L-x.3)
120 km at 1550 nm	G.655	Very long-reach (VR-1)	Very long (V-x.3)
160 km at 1550 nm	G.655	Very long-reach (VR-2)	Ultralong (U-x.3)

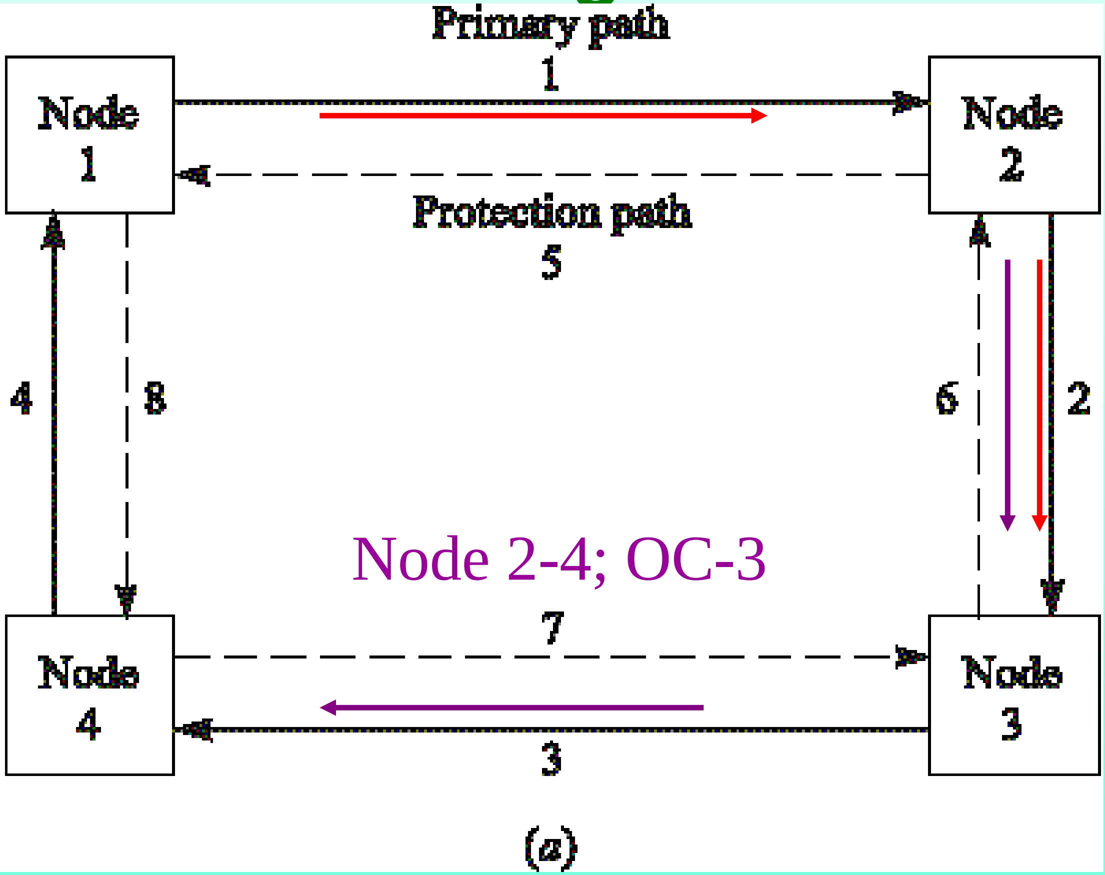
TABLE 17.3. Wavelength Ranges and Attenuation for Transmission Distances up to 80 km

Distance	Wavelength range at 1310 nm	Wavelength range at 1550 nm	Attenuation at 1310 nm, dB/km	Attenuation at 1550 nm, dB/km
≤15 km	1260–1360 nm	1430–1580 nm	3.5	Not specified
≤40 km	1260–1360 nm	1430–1580 nm	0.8	0.5
≤80 km	1280–1335 nm	1480–1580 nm	0.5	0.3

SONET/SDH Rings

- SONET/SDH are usually configured in ring architecture to create loop diversity by self healing
- 2 or 4 fiber between nodes
- Unidirectional/bidirectional traffic flow
- Protection via line switching (entire OC-N channel is moved) or path switching (sub channel is moved)

2-Fiber Unidirectional Path Switched Ring



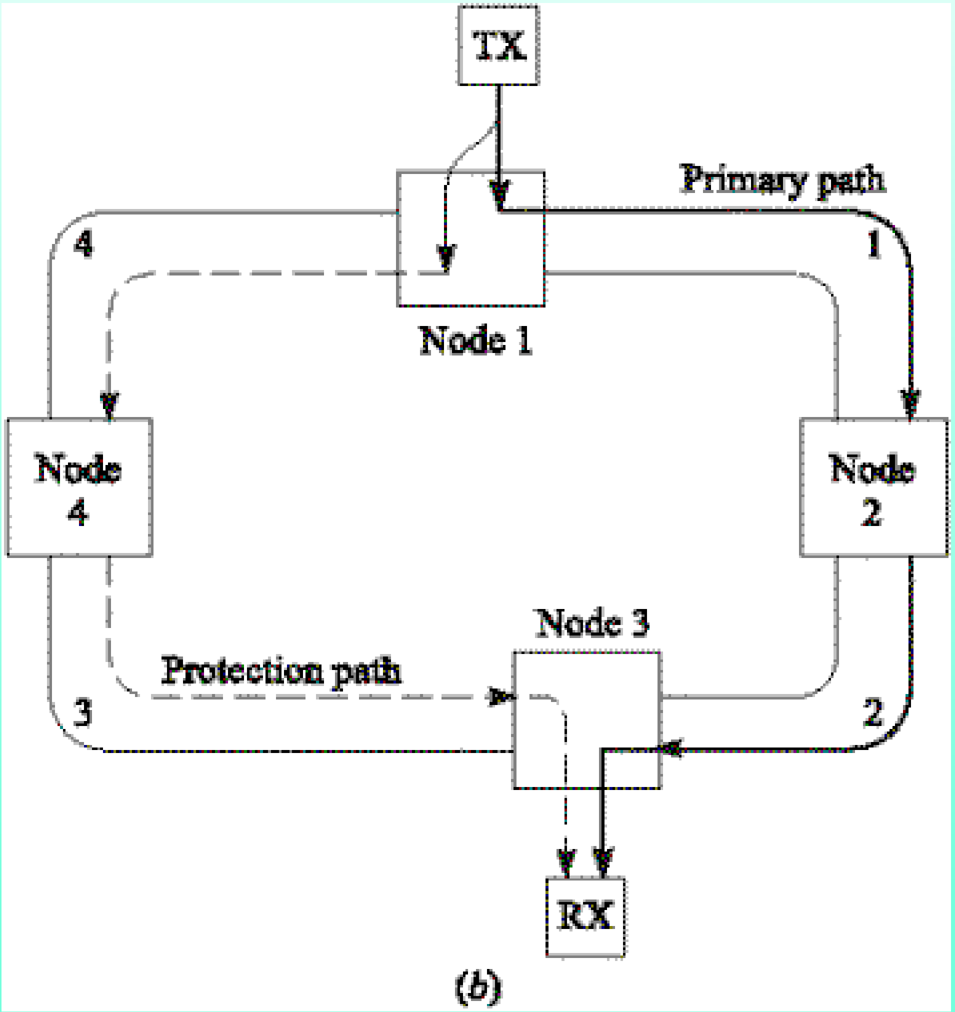
Node 1-2
OC-3

Node 2-4; OC-3

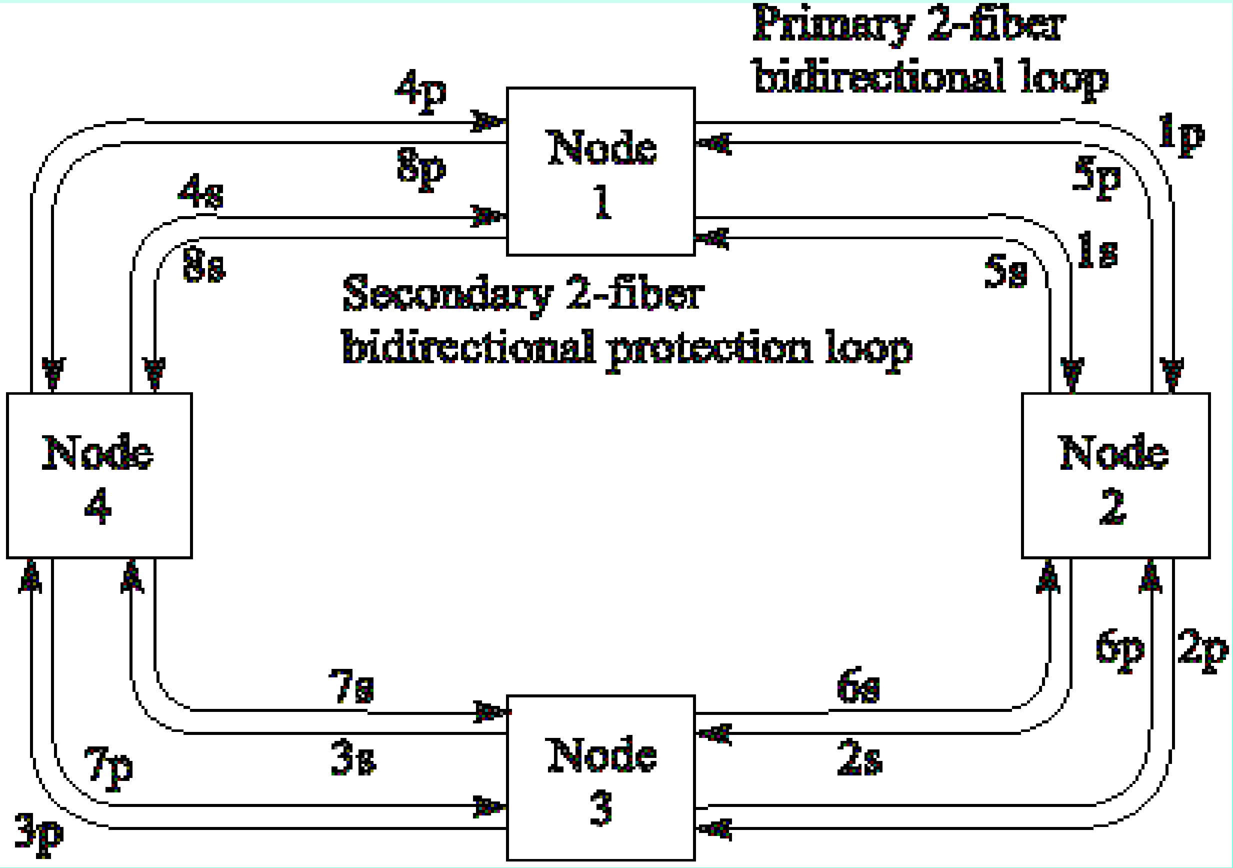
Ex: Total capacity OC-12 may be divided to four OC-3 streams

2-Fiber UPSR

- Rx compares the signals received via the primary and protection paths and picks the best one
- Constant protection and automatic switching



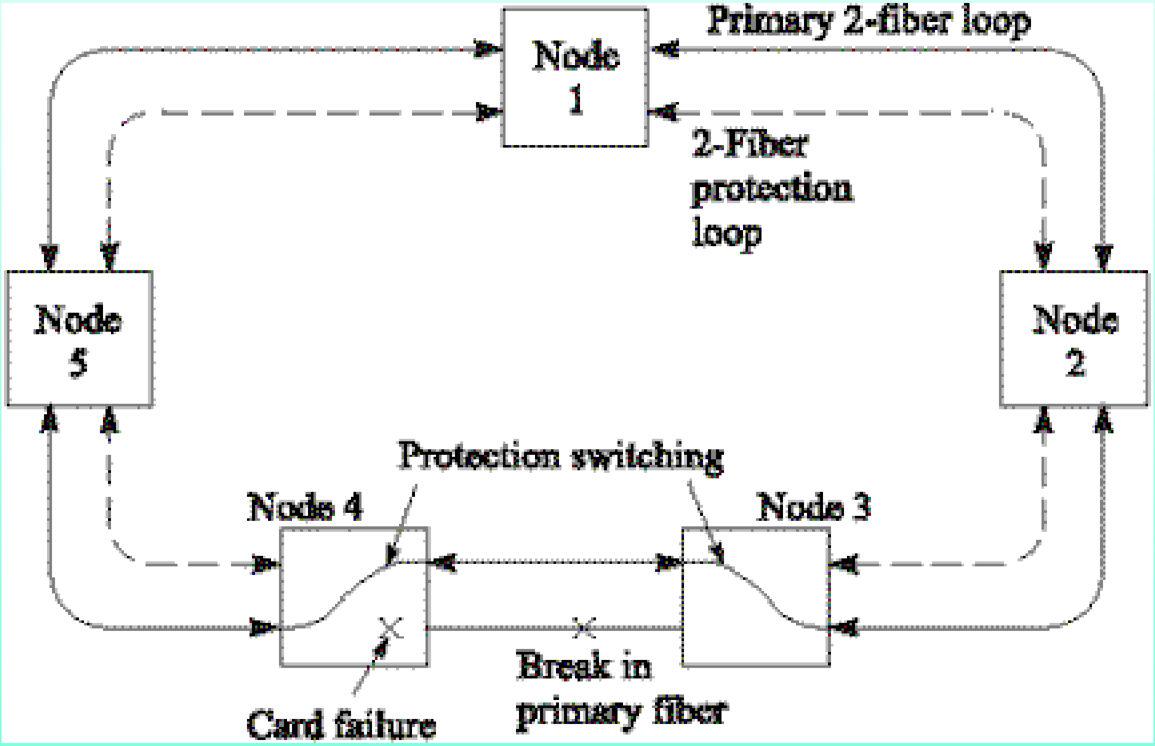
4-Fiber Bi-directional Line Switched Ring (BLSR)



All secondary fiber left for protection

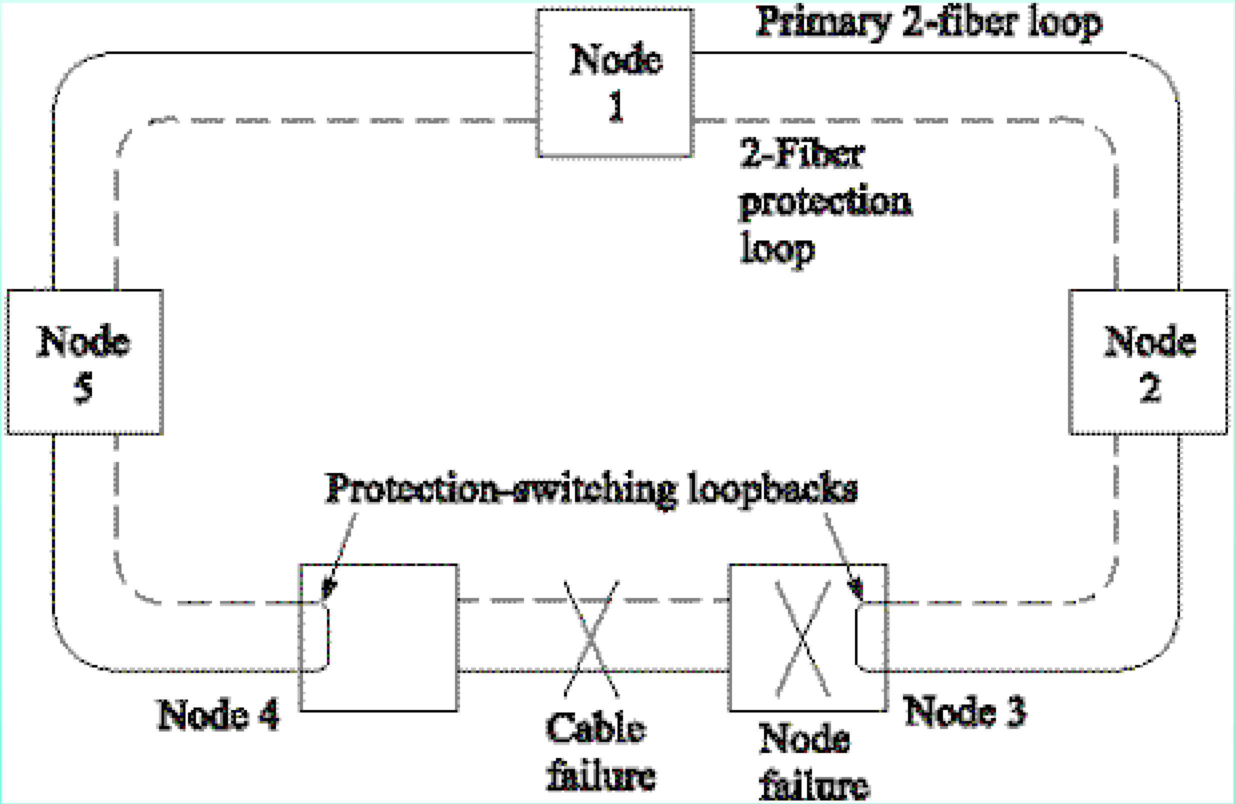
Node 1→3; 1p, 2p　　3→1; 7p, 8p

BLSR Fiber Fault Reconfiguration



In case of failure, the secondary fibers between only the affected nodes (3 & 4) are used, the other links remain unaffected

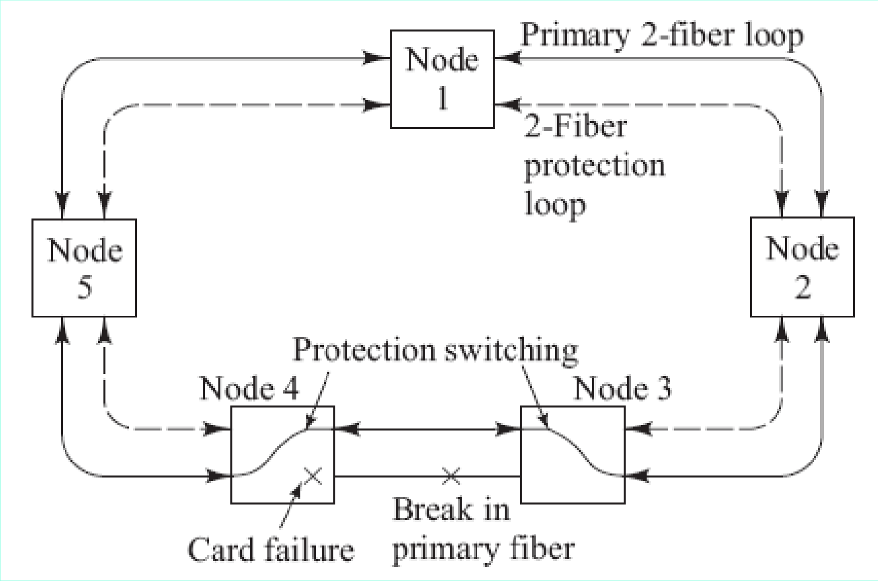
BLSR Node Fault Reconfiguration

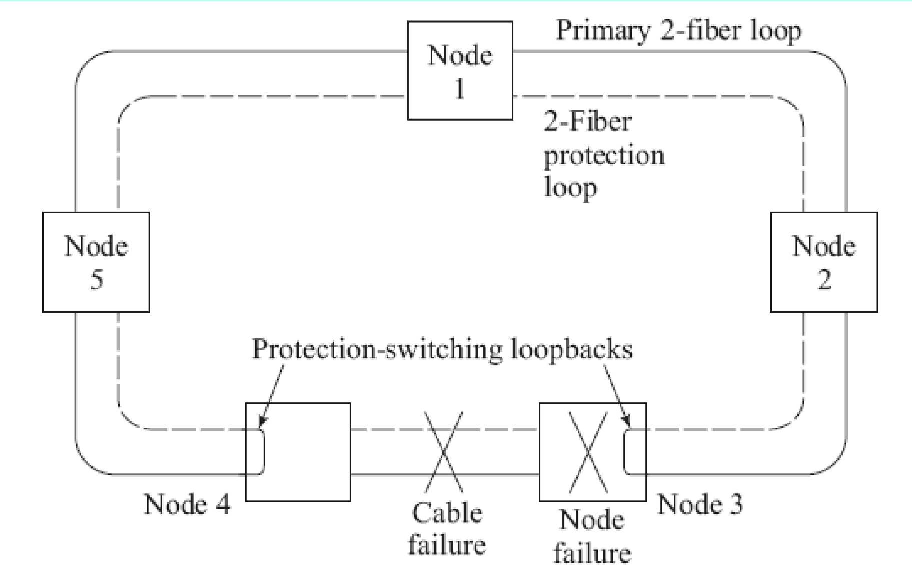


If both primary and secondary are cut, still the connection is not lost, but both the primary and secondary fibers of the entire ring is occupied

BLSR Recovery from Failure Modes

- If a primary-ring device fails in either node 3 or 4, the affected nodes detect a loss-of-signal condition and switch both primary fibers connecting these nodes to the secondary protection pair
- If an entire node fails or both the primary and protection fibers in a given span are severed, the adjacent nodes switch the primary-path connections to the protection fibers, in order to loop traffic back to the previous node.



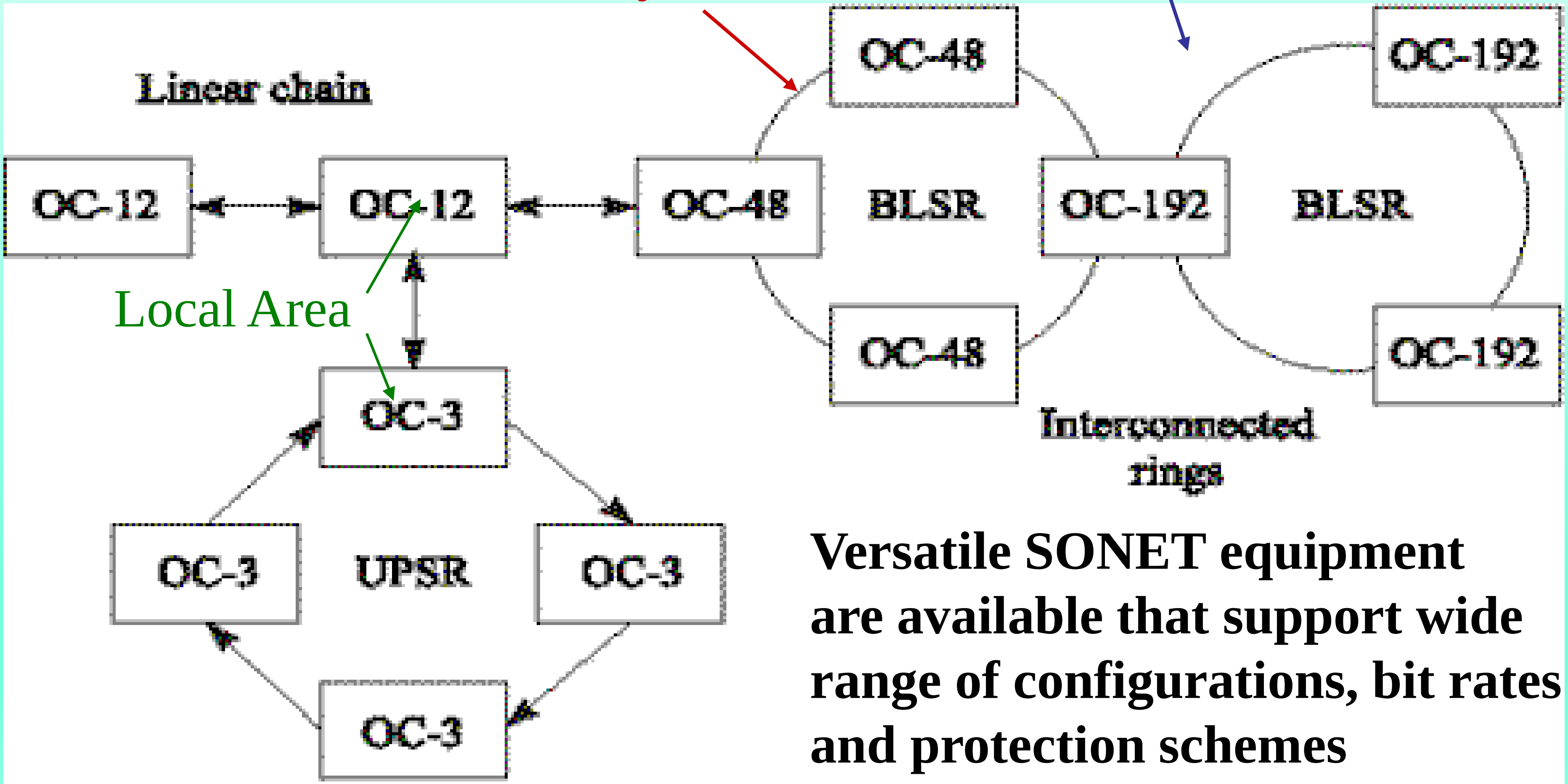


Generic SONET network

Large National Backbone

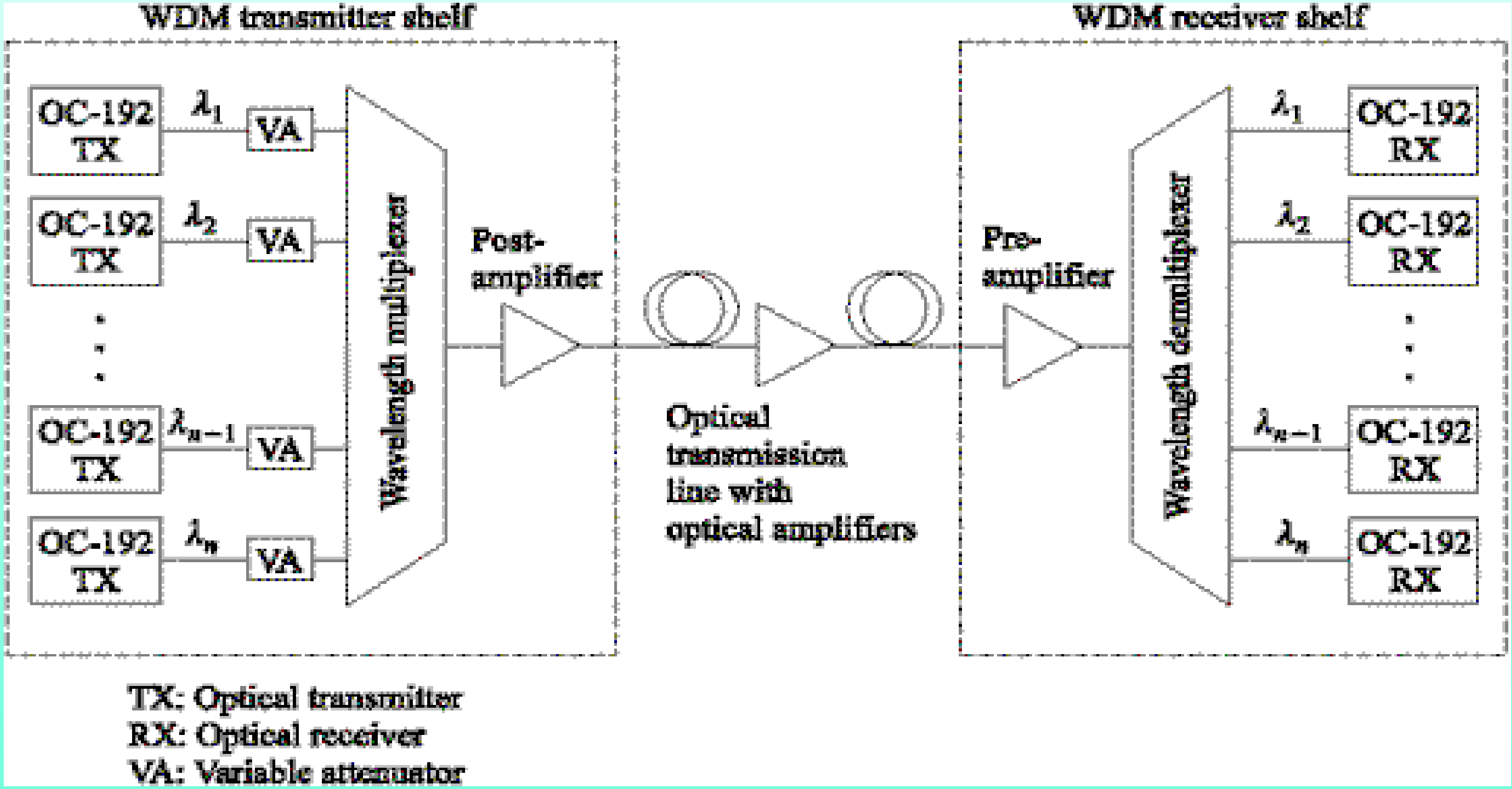
City-wide

Local Area



Versatile SONET equipment are available that support wide range of configurations, bit rates and protection schemes

WDM P-P Link



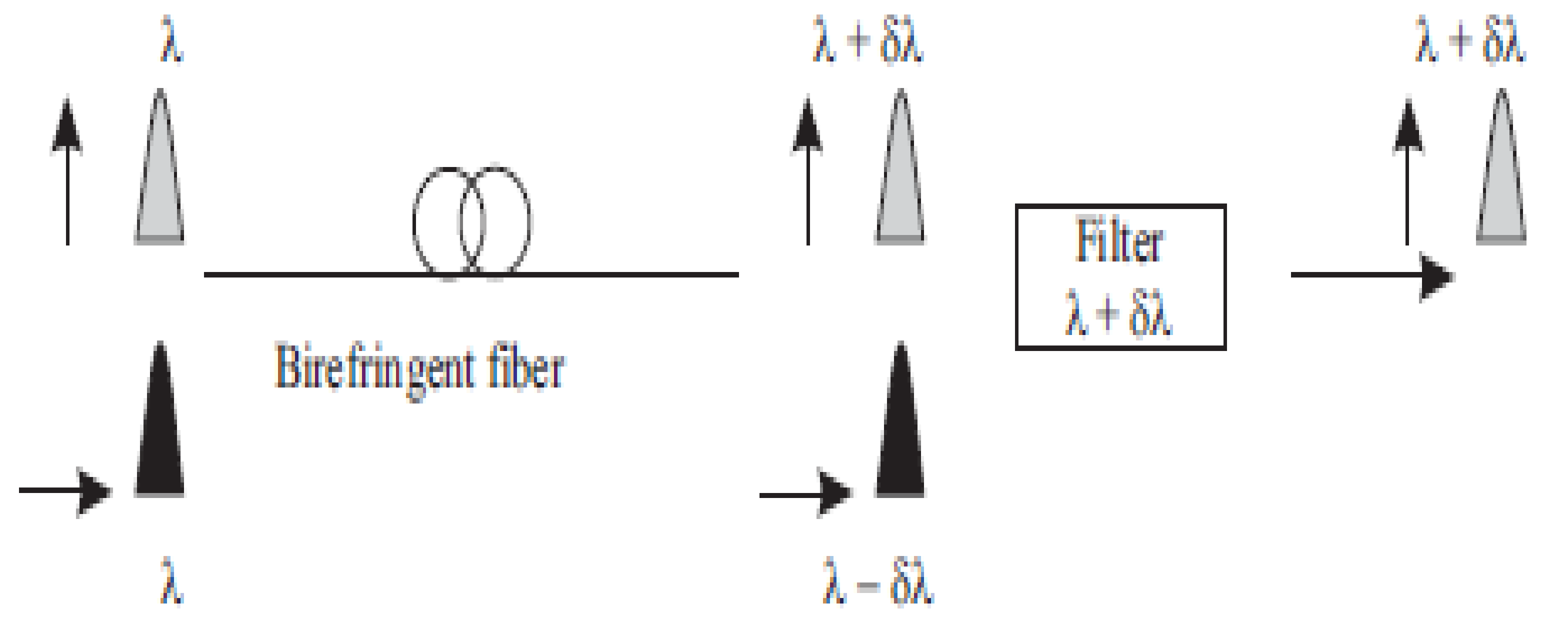
Several OC-192 signals can be carried, each by one wavelength

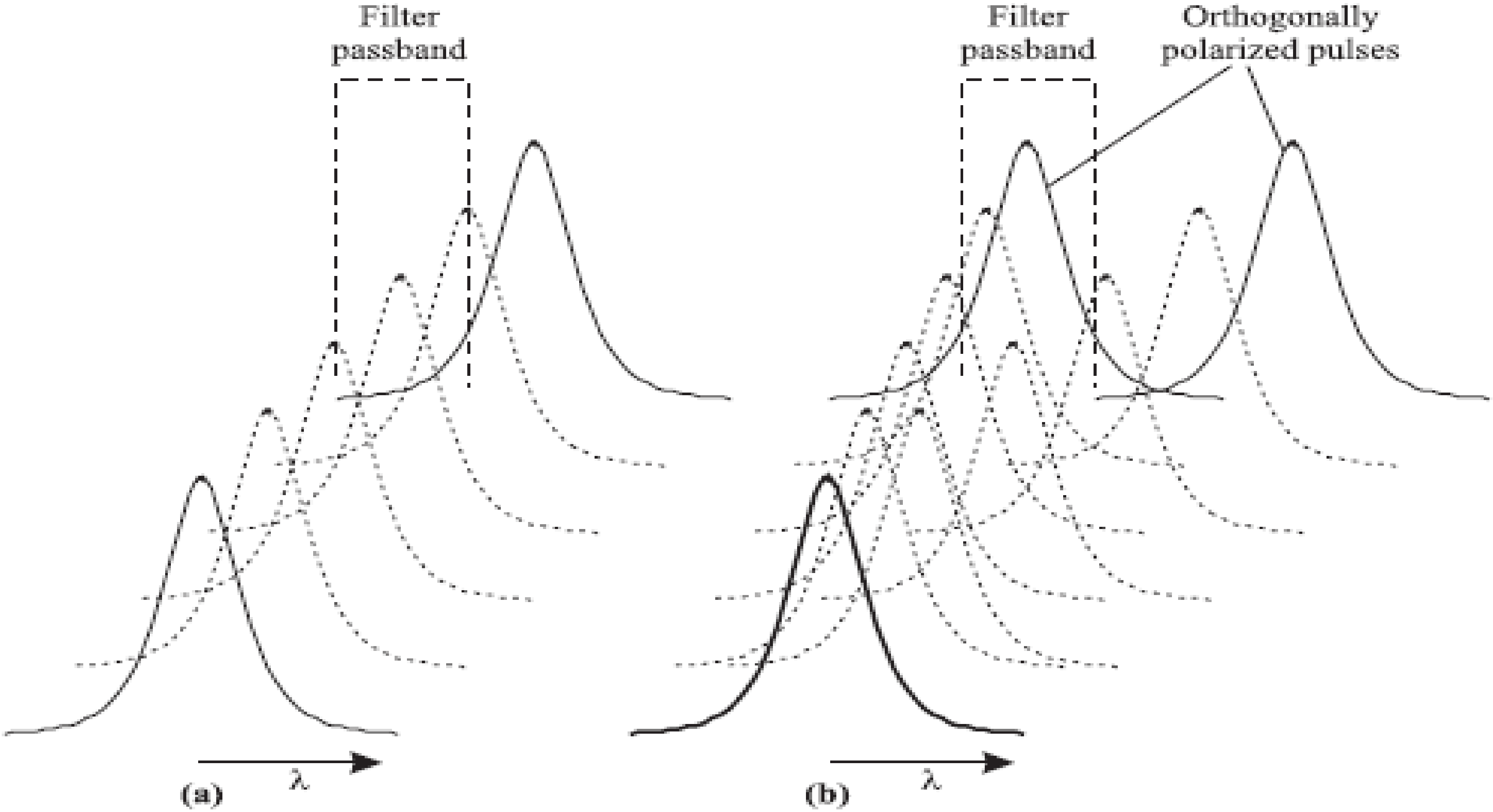
What Are Solitons, Why Are They Interesting And How Do They Occur in Optics?

The phase velocity of a beam (finite width in space or time) must depend on the field amplitude of the wave!

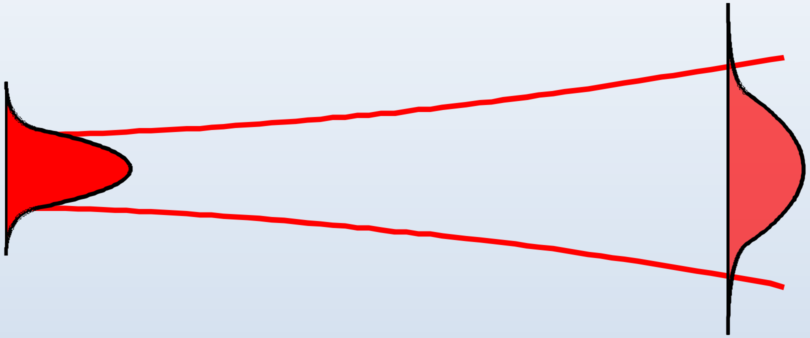
SOLITON

- Two pulses under go wavelength shifts in opposite direction so that the group velocity difference due to the wavelength shift exactly compensate group velocity difference due to birefringence.



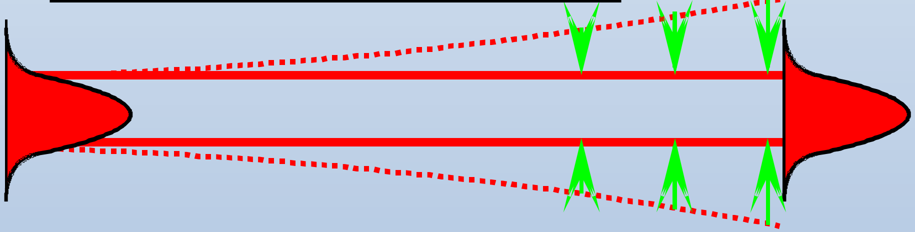

Filter passband
Filter passband
Orthogonally polarized pulses
λ
(a)
λ
(b)

All Wave Phenomena: A Beam Spreads in Time and Space on Propagation



Space: Broadening by Diffraction
Time: Broadening by Group Velocity Dispersion

Spatial/Temporal Soliton



Broadening +
Narrowing Via **a Nonlinear** Effect
= Soliton (Self-Trapped beam)

1. An *optical* soliton is a shape invariant self-trapped beam of light or a *self-induced waveguide*

2. Solitons occur frequently in nature in all nonlinear wave phenomena

3. Contribution of Optics: ***Controlled Experiments***

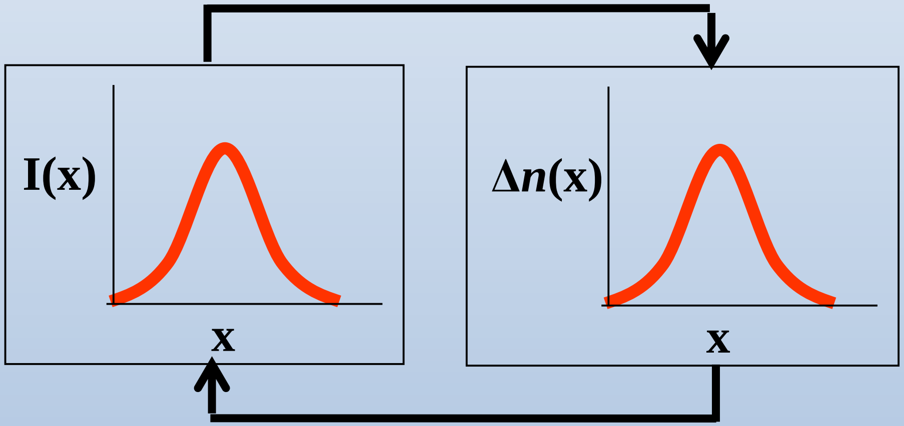
Solitons Summary

exhibit both **wave-like** and **particle-like** properties

- solitons are *common* in nature and science
- any *nonlinear* mechanism leading to beam narrowing will give bright solitons, beams whose shape repeats after1 soliton period!
- solitons are the **modes** of nonlinear (high intensity) optics
- **robustness** (stay localized through small perturbations)
- **unique collision and interaction properties**
  - Kerr media
    - no energy loss to radiation fields
    - number of solitons conserved
  - Saturating nonlinearities
    - small energy loss to radiation fields
    - depending on geometry, number of solitons can be either conserved or not conserved.

Self-consistency Condition

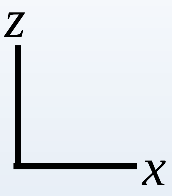
$I(x) \rightarrow \Delta n(x) = n_2 I(x)$



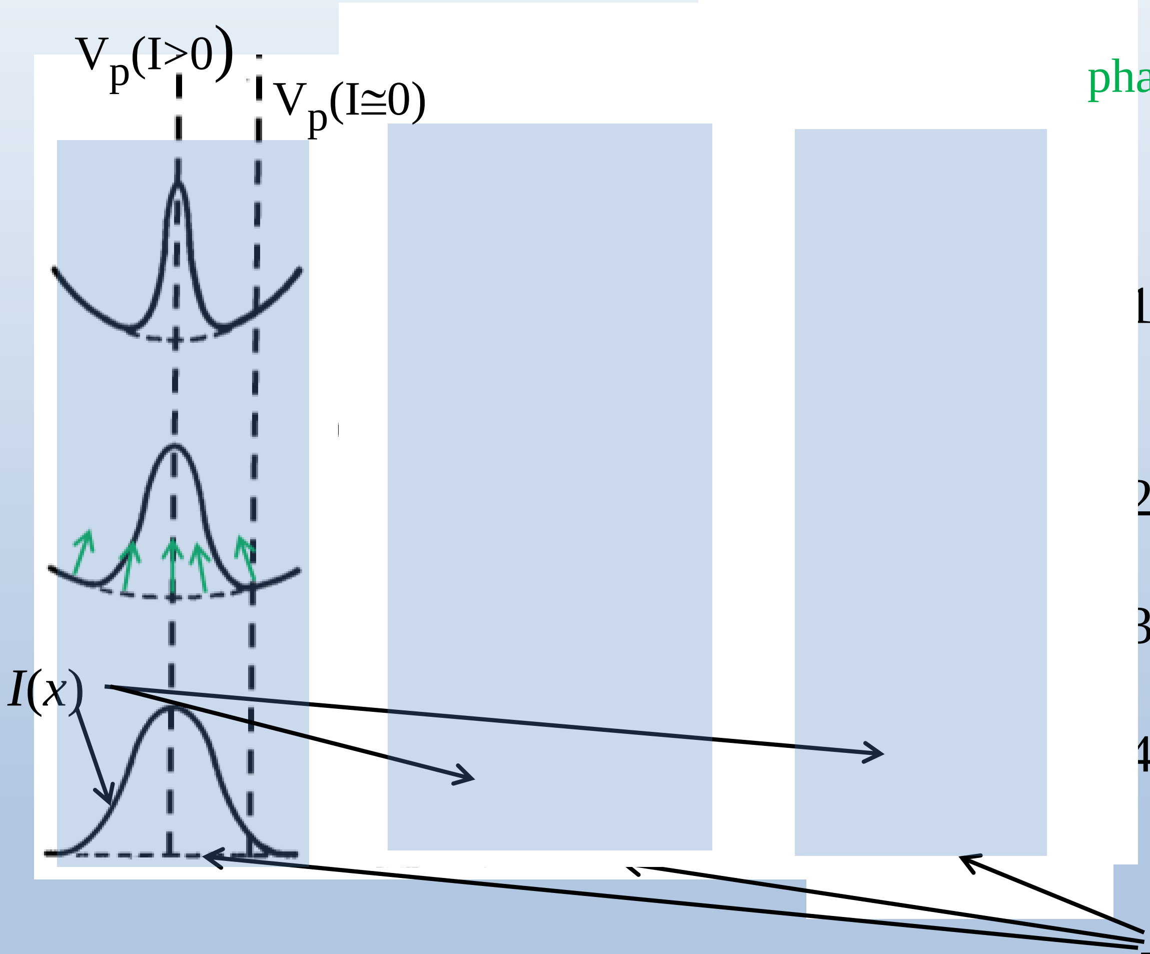
$\Delta n(x)$ traps beam

1D Bright Spatial Soliton

Diffraction in 1D only!



Optical Kerr Effect → Self-Focusing: $\boldsymbol{n(\mathrm{I})=n_0+n_2\mathrm{I},\ \ n_2>0}$



phase velocity: $\mathrm{V_p}(\mathrm{I}) = \dfrac{c}{n} = \dfrac{c}{n_0 + n_2\mathrm{I}}$

Soliton Properties

1. No change in shape on propagation
2. $\mathrm{V_p}$(soliton) < $\mathrm{V_p(I\cong0)}$
3. Flat (plane wave) phase front
4. Nonlinear phase shift ∝ z (not obvious)

Self-focusing

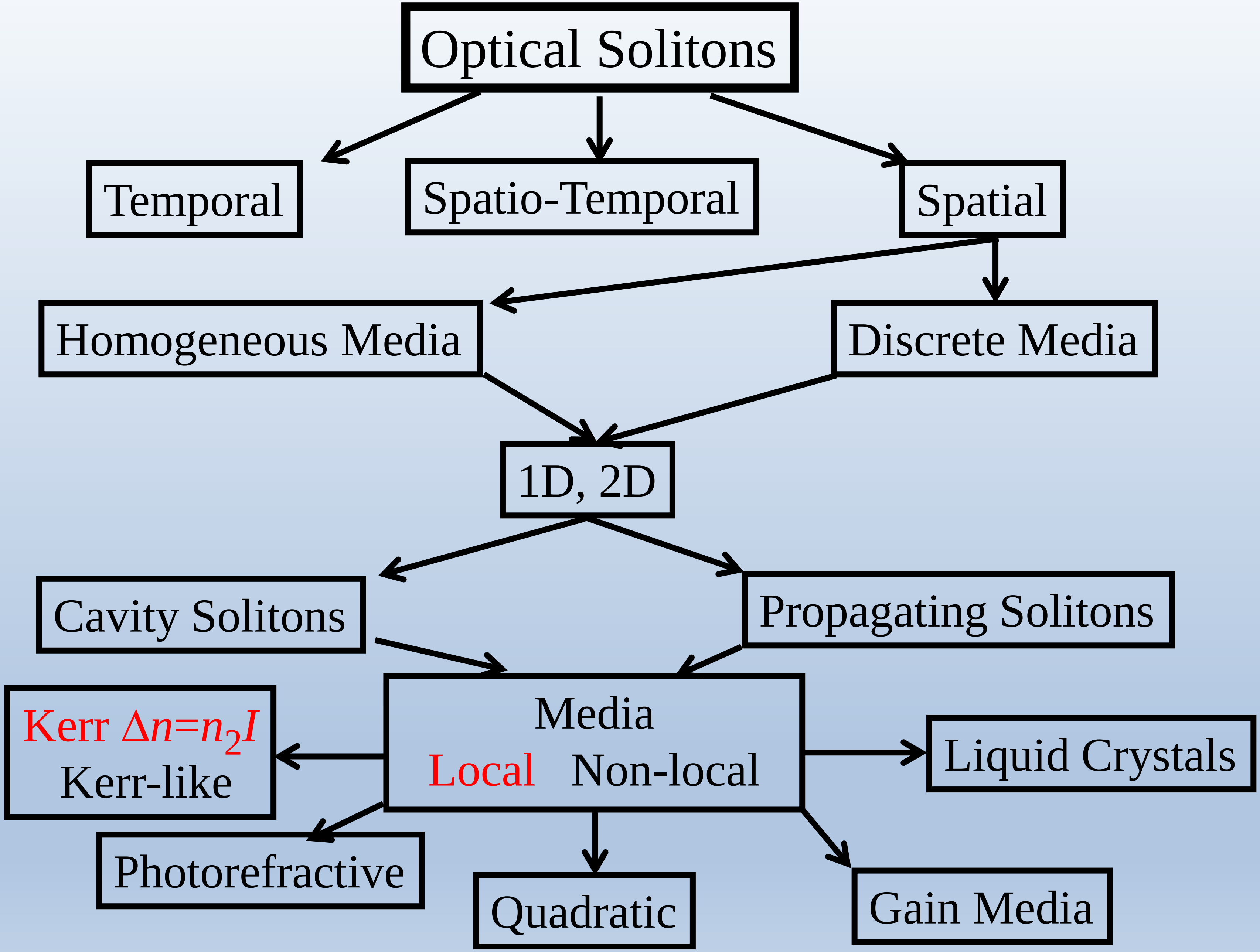
$\boldsymbol{n_2>0}$

$\mathrm{V_p(I\cong0)>V_p(I>0)}$

Diffraction in space

Soliton!

Phase front



Optical Solitons

Temporal

Spatio-Temporal

Spatial

Homogeneous Media

Discrete Media

1D, 2D

Cavity Solitons

Propagating Solitons

Media

Local Non-local

Kerr $\Delta n=n_2 I$

Kerr-like

Liquid Crystals

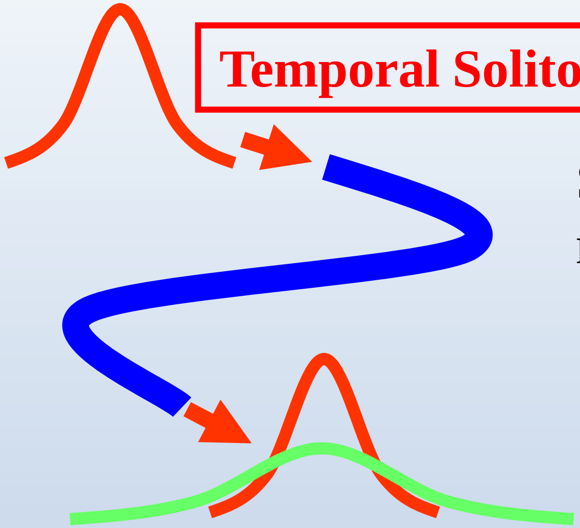
Photorefractive

Quadratic

Gain Media

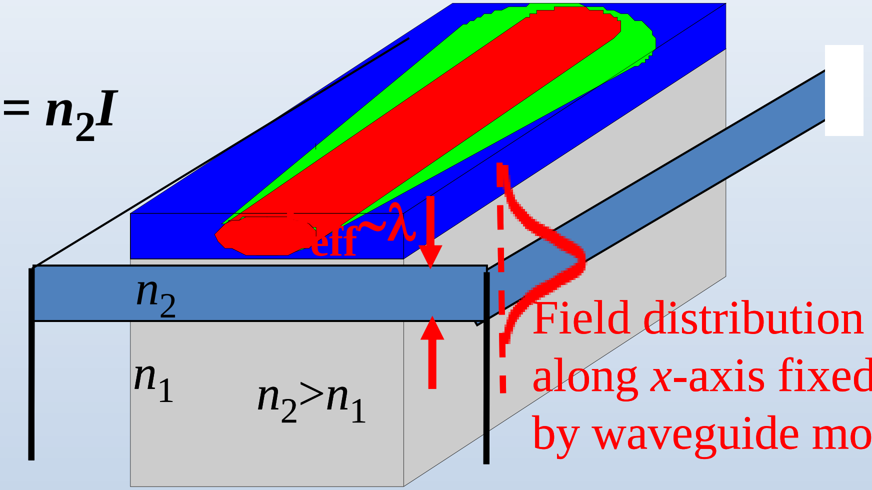
Optical Solitons

Temporal Solitons in Fibers



Supported by Kerr nonlinearity $\Delta n^{NL} = n_2 I$

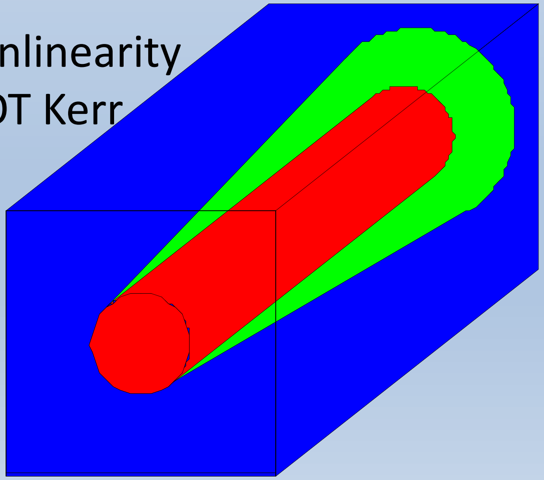
Spatial Solitons 1D



Field distribution along *x*-axis fixed by waveguide mod

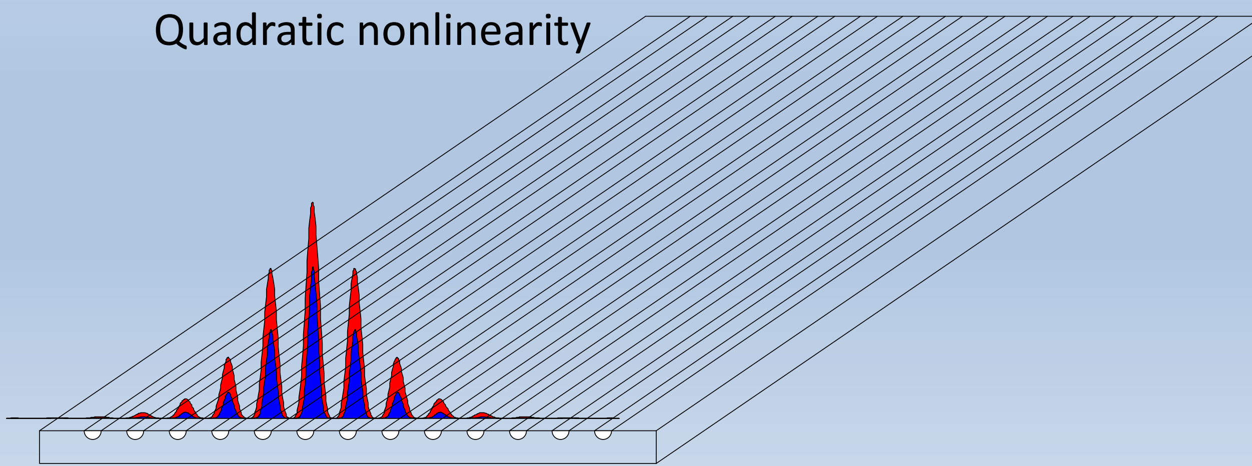
Spatial Solitons 2D

nonlinearity NOT Kerr



Discrete Spatial Solitons 1D

Two color solitons
Quadratic nonlinearity



Nonlinear Wave Equation

$$\nabla^2\vec{E} - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\vec{E} = \mu_0\frac{\partial^2}{\partial t^2}\{\vec{P}^L + \vec{P}^{NL}\}$$

$\vec{\vec{\chi}}^{(3)}_{Kerr} \vdots EEE$

$\varepsilon_0\vec{\vec{\chi}}^{(1)}\cdot\vec{E}$

depends on nonlinear mechanism

$$E(\vec{r}) \propto \vec{A}(x,y)\exp[i\{kz-\omega t\}] \;\longrightarrow\; \nabla^2\vec{E} + \frac{n_0^2}{c^2}\omega^2\vec{E} = -\omega^2\mu_0\vec{P}^{NL}$$

Slowly varying phase and amplitude approximation (SVEA, 1st order perturbation theory)

$$\xrightarrow{\textit{spatial}} -2ik\frac{\partial}{\partial z}\vec{E} + \underbrace{\nabla_\perp^2\vec{E}}_{\text{diffraction}} = \underbrace{-\omega^2\mu_0\vec{P}^{NL}}_{\text{nonlinearity}}$$

$$\xrightarrow{\textit{temporal}} -2ik\frac{\partial}{\partial z}\vec{E} + kk_2\frac{\partial^2}{\partial T^2}\vec{E} = -\omega^2\mu_0\vec{P}^{NL}$$

Group velocity dispersion

Plane Wave Solution?

→ Unstable mode
→ Filamentation

Shape invariance

$$\boxed{\frac{\partial}{\partial z}|E| = 0}$$

$+$

Zero diffraction and/or dispersion

$$\boxed{\nabla_\perp^2 E = 0 \text{ or } k_2 = 0}$$

$$\frac{\partial}{\partial z}|E| = 0 \longrightarrow$$

Nonlinear Mode
Spatial soliton

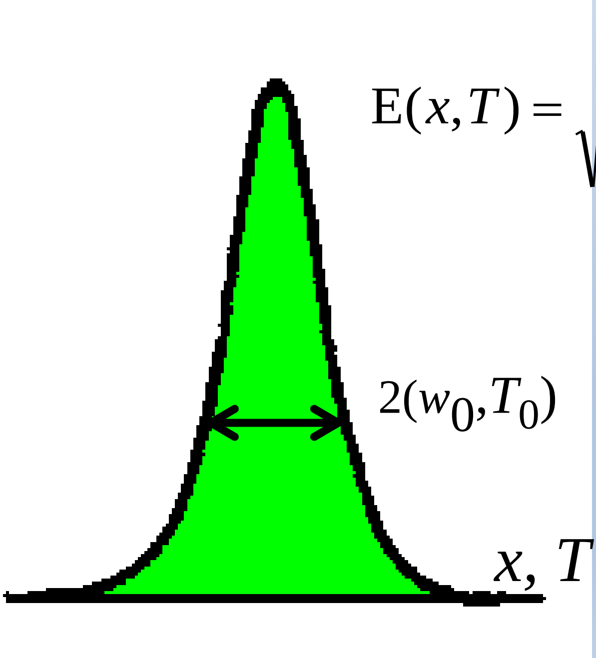
1D **Kerr** Solitons: $\Delta n^{\mathrm{NL}} = n_2 I = n_{2,E}|E|^2$

Kerr Effect : $P^{NL} = 2\varepsilon_0 n_0 n_{2,E} \,|\, E\,|^2$

<u>"Nonlinear Schrödinger Equation" "NLSE"</u>

$$\text{Space} \rightarrow -2ik\frac{\partial}{\partial z}E + \underbrace{\frac{\partial^2}{\partial x^2}E}_{\text{diffraction}} = \underbrace{-2k^2\Delta n^{\mathrm{NL}} n_0 E}_{\text{nonlinearity}} \qquad \text{Time} \rightarrow -2ik\frac{\partial}{\partial z}E + \underbrace{\frac{\partial^2}{\partial T^2}E}_{\text{dispersion}} = \underbrace{-2k^2\Delta n^{\mathrm{NL}} n_0 E}_{\text{nonlinearity}}$$

Bright Soliton, $n_2 > 0$



Invariant shape on propagation

Nonlinear phase shift

$$\mathrm{E}(x,T) = \sqrt{\frac{n_0}{n_{2,E}}\,\frac{1}{n_0 k_{vac}(w_0,T_0)}}\,\mathrm{sech}\{\frac{(x,T)}{(w_0,T_0)}\}\exp[-i\frac{z}{2n_0 k_{vac}(w_0^2,T_0^2)}]$$

$$P_{sol} = \frac{h_{eff}c\varepsilon_0}{w_0 k_{\mathrm{vac}}^2(\omega) n'_{2||,\mathrm{E}}(-\omega;\omega)} \rightarrow \frac{dP_{sol}}{dw_0} = -\frac{h_{eff}c\varepsilon_0}{w_0^2 k_{\mathrm{vac}}^2(\omega) n'_{2||,\mathrm{E}}(-\omega;\omega)} < 0$$

Remarkable stability comes from $\frac{dP_{sol}}{dw_0} < 0$,

i.e. if $P_{sol} \uparrow \Rightarrow w_0 \downarrow$ and vice-versa!

All other nonlinearities do NOT lead to analytical solutions and must be found numerically!

Nonlinear Schrödinger Equation

$$\frac{\partial A}{\partial z} + \beta_1 \frac{\partial A}{\partial t} + \frac{i}{2}\beta_2 \frac{\partial^2 A}{\partial t^2} + \frac{\alpha}{2} A = i\gamma |A|^2 A$$

Nonlinear Schrödinger Equation

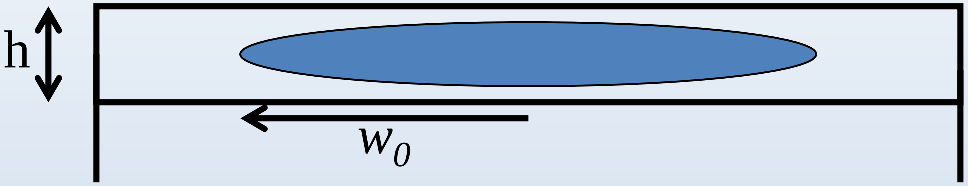
$$T = t - \beta_1 z \qquad \alpha = 0$$

$$\boxed{i\frac{\partial A}{\partial z} - \frac{1}{2}\beta_2 \frac{\partial^2 A}{\partial T^2} + \gamma |A|^2 A = 0}$$

Balance between dispersion and nonlinearity

Stability of *Kerr* Self-Trapped Beams in 2D?

1 D Waveguide Case

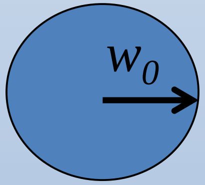


Diffraction length $L_D = \dfrac{\pi w_0^2 n_0}{\lambda_{vac}}$ Nonlinear length (π/2) $L_{NL} = \dfrac{\lambda_{vac} \pi w_0 h}{2 n_2 P}$

$$\frac{L_D}{L_{NL}} = \frac{2 n_2 n_0}{\lambda_{vac}^2 h} w_0 P = \text{constant} \quad \Rightarrow \quad \frac{dP}{dw_0} < 0$$

Stable, i.e. *robust*!

2 D Bulk Medium Case



$$L_D = \frac{\pi w_0^2 n_0}{\lambda_{vac}} \qquad L_{NL} = \frac{\lambda_{vac} \pi w_0^2}{2 n_2 P}$$

$$\frac{L_D}{L_{NL}} = \frac{2 n_2 n_0}{\lambda_{vac}^2} P = \text{constant} \quad \Rightarrow \quad \frac{dP}{dw_0} = 0$$

Unstable!

Fluctuation in power leads to either diffraction or narrowing dominating

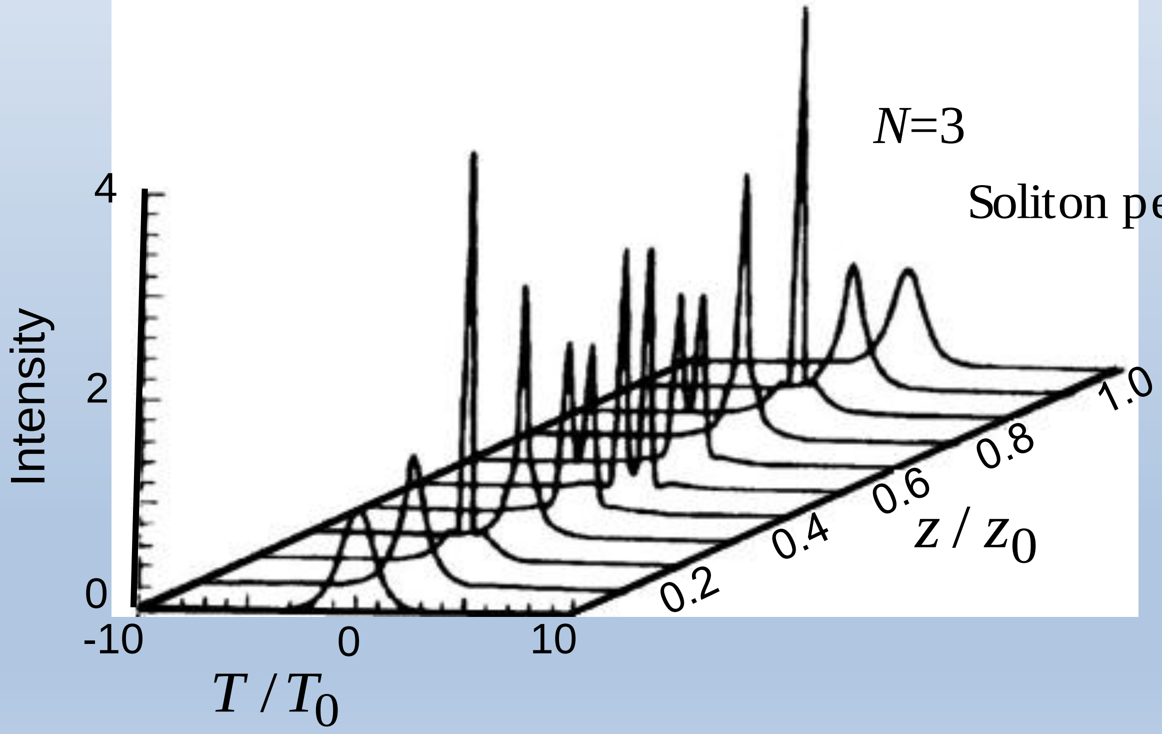
No Kerr solitons in 2D! **BUT,2D solitons stable in other forms of nonlinearity**

Higher Order Solitons

- Previously discussed solitons were *N*=1 solitons where $N^2 L_{\mathrm{NL}} = L_{\mathrm{D}}$

- Higher Order solitons obtained from Inverse Scattering or Darboux transforms

$$N = 2 \quad u(\xi,\tau) = \frac{4[\cosh(3\tau) + 3e^{4i\xi}\cosh(\tau)]e^{i\xi/2)}}{[\cosh(4\tau) + 4\cosh(2\tau) + 3\cos(4\xi)]} \qquad \xi = \frac{z}{L_{\mathrm{D}}} \qquad \tau = \frac{T}{T_0}$$



Soliton period (same for all N): $z_0 = \pi L_{\mathrm{D}}/2$

Need to refine “consistency condition”.
Soliton shape must reproduce itself every soliton period!

Optical Bullets: Spatio-Temporal Solitons

Electromagnetic pulses that do not spread in time and space

Characteristic Lengths

Temporal Dispersion: $L_\mathrm{D}(T) = T_0^2 / |k_2|$

Spatial Diffraction: $L_\mathrm{D}(\vec{r}_\perp) = k w_0^2 / 2$

Nonlinear Length: $L_\mathrm{NL} = [k_\mathrm{vac} n_2 P_\mathrm{peak} / A_\mathrm{eff}]^{-1}$

Soliton: $L_\mathrm{NL} = L_\mathrm{D}(T) = L_\mathrm{D}(\vec{r}_\perp)$

Soliton period: $z_0 = \pi L_\mathrm{D} / 2$

Require: dispersion length (time) ≅ diffraction length (space) ≅ nonlinear length

Solitons Summary

exhibit both **wave-like** and **particle-like** properties

- solitons are *common* in nature and science
- any *nonlinear* mechanism leading to beam narrowing will give bright solitons, beams whose shape on propagation is either constant or repeats after 1 soliton period!
- they arise due to a balance between diffraction (or dispersion) and nonlinearity in both homogeneous and discrete media. Dissipative solitons also require a balance between gain and loss.
- solitons are the **modes** (not eigenmodes) of nonlinear (high intensity) optics
- an important property is **robustness** (stay localized through small perturbations)
- **unique collision and interaction properties**
  - Kerr media
    - no energy loss to radiation fields
    - number of solitons conserved
  - Saturating nonlinearities
    - small energy loss to radiation fields
    - depending on geometry, number of solitons can be either conserved or not conserved.

- Solitons force you to give up certain ideas which govern linear optics!!

WDM Networks

- Single fiber transmits multiple wavelengths → WDM Networks
- One entire wavelength (with all the data) can be switched/routed
- This adds another dimension; the Optical Layer
- Wavelength converters/cross connectors; all optical networks
- Note protocol independence

Types of WDM

- Unidirectional
- Bidirectional

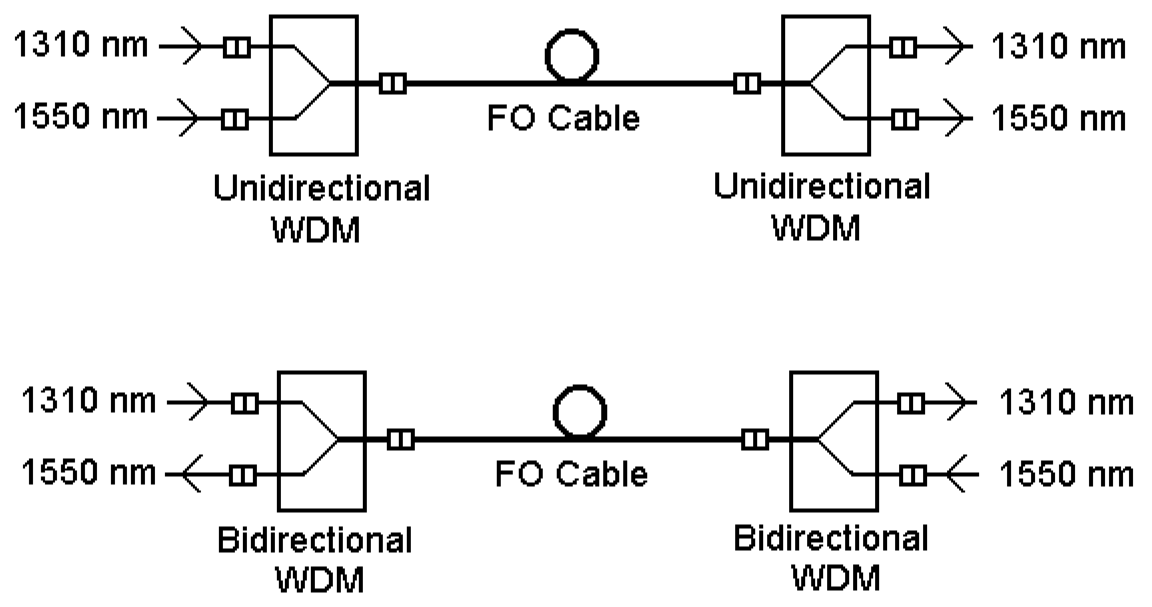
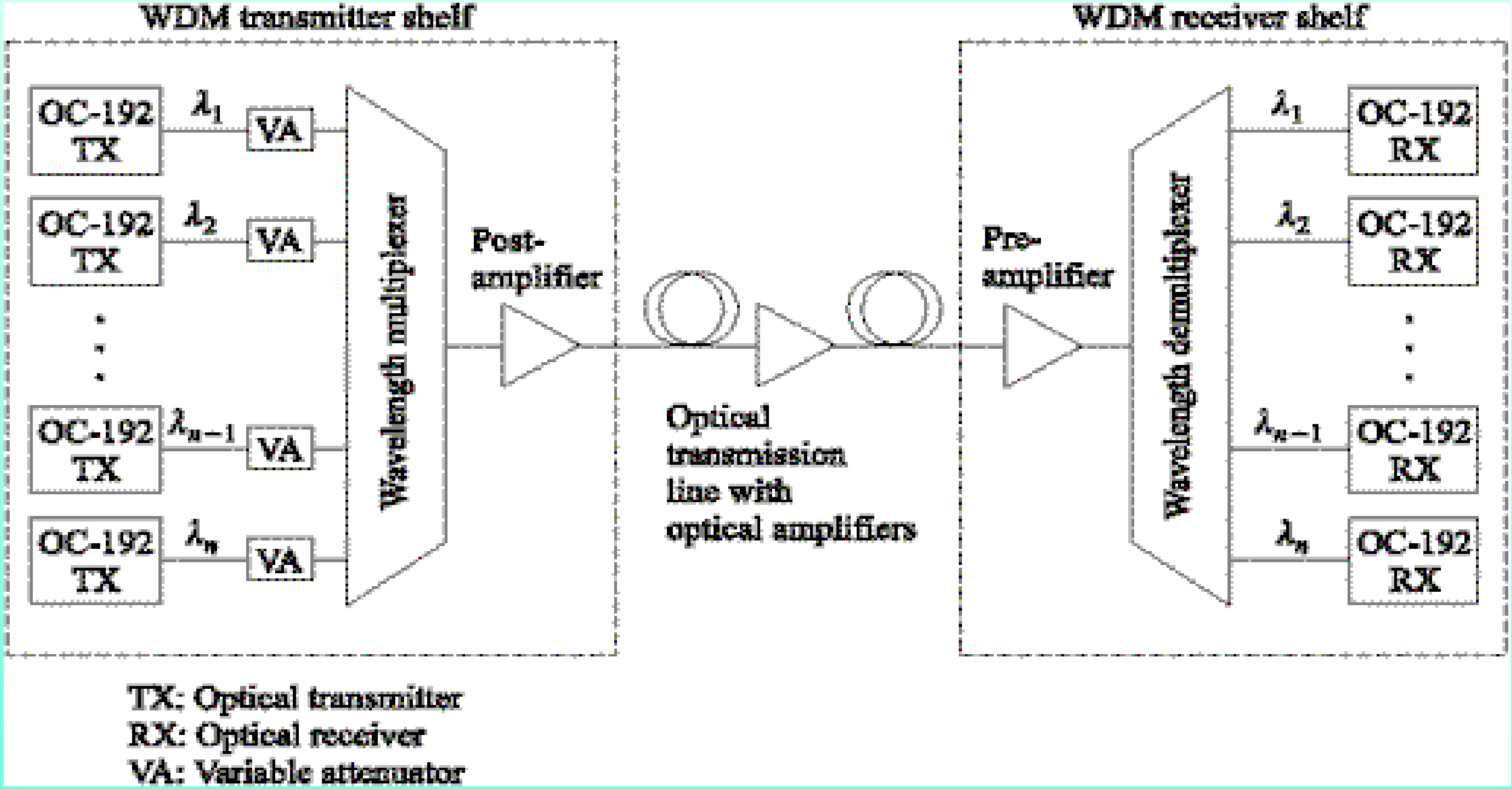


Figure 5: Types of WDM (duplexers)

WDM P-P Link



Several OC-192 signals can be carried, each by one wavelength

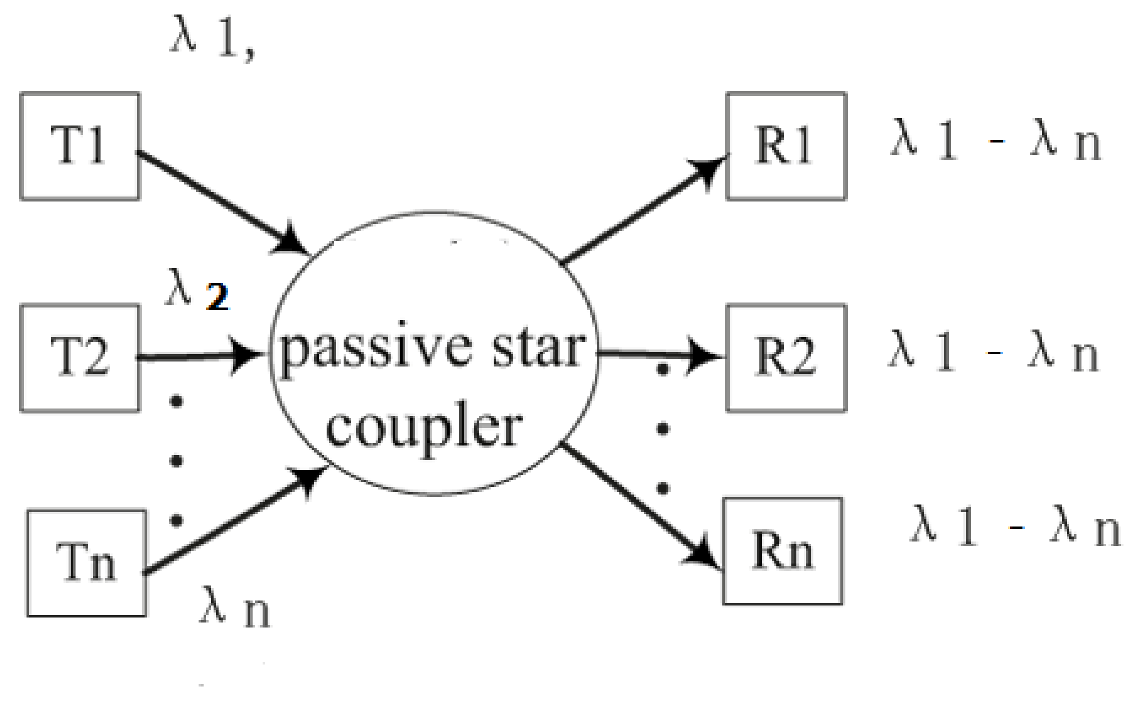
Versions of WDM

- Coarse WDM (CWDM)
  - ✓ 4-16 wavelength per fiber
  - ✓ difficult to amplify
- Dense WDM(DWDM)
  - ✓ 32+wavelength per fiber
  - ✓ Increase density and capacity
- Ultra Dense WDM(UDWDM)
  - ✓ 100+ wavelength per fiber.

WDM Networks

- Broadcast and Select: employs passive optical stars or buses for local networks applications
  - Single hop networks
  - Multi hop networks
- Wavelength Routing: employs advanced wavelength routing techniques
  - Enable wavelength reuse
  - Increases capacity

Broadcast and Select network



Broadcast and Select N/W topologies:

1. Star
2. Bus

Types of broadcast and select N/W

- Single hop networks

  without optical to electrical conversion

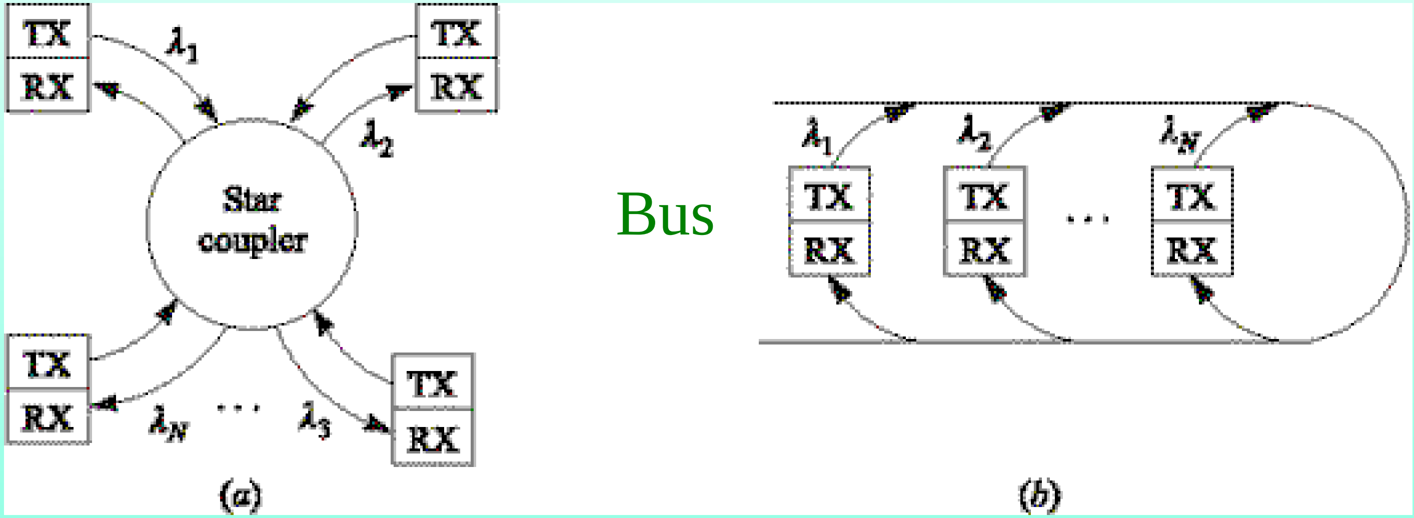
- Multi hop networks

  Electro optical conversion occur

Single hop broadcast and select WDM

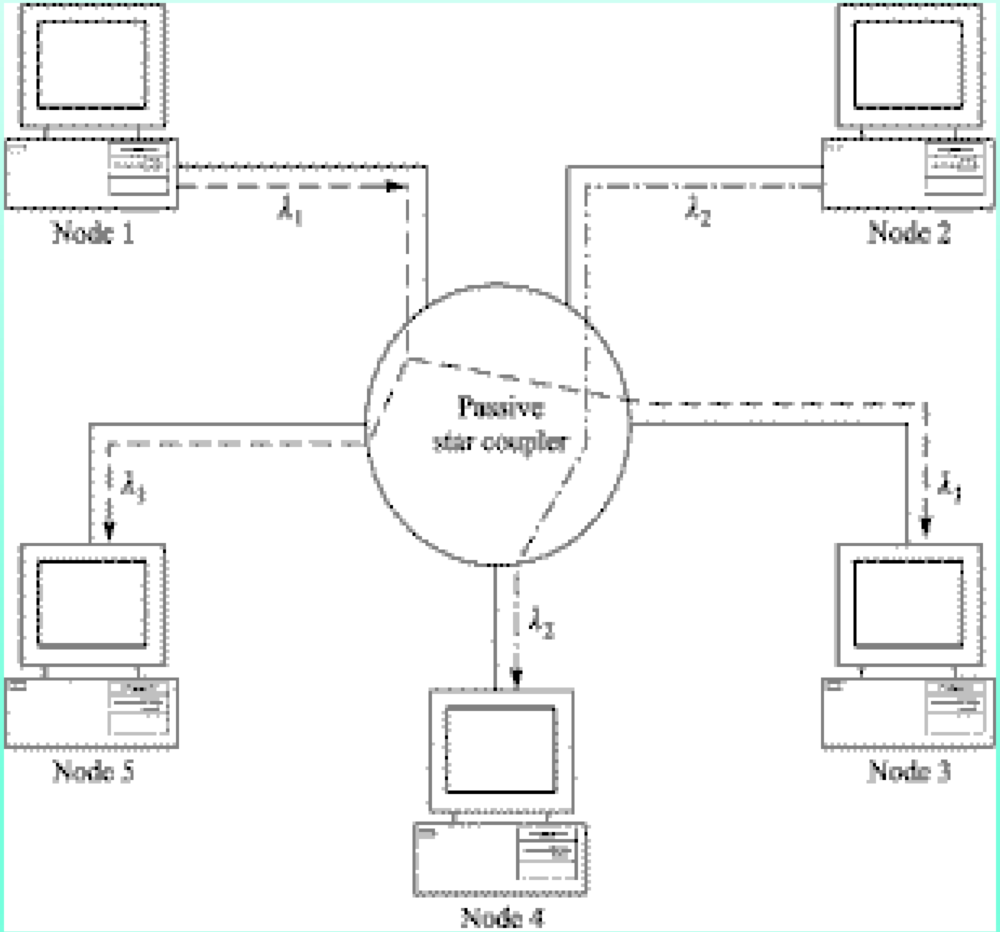
Star

Bus



- Each Tx transmits at a different fixed wavelength
- Each receiver receives all the wavelengths, but selects (decodes) only the desired wavelength
- Multicast or broadcast services are supported
- Dynamic coordination (tunable filters) is required

A Single-hop Multicast WDM Network



It is attractive for
i. lograthamic splitting loss
ii. No tapping and insertion loss

Support multicast or broadcast Networks

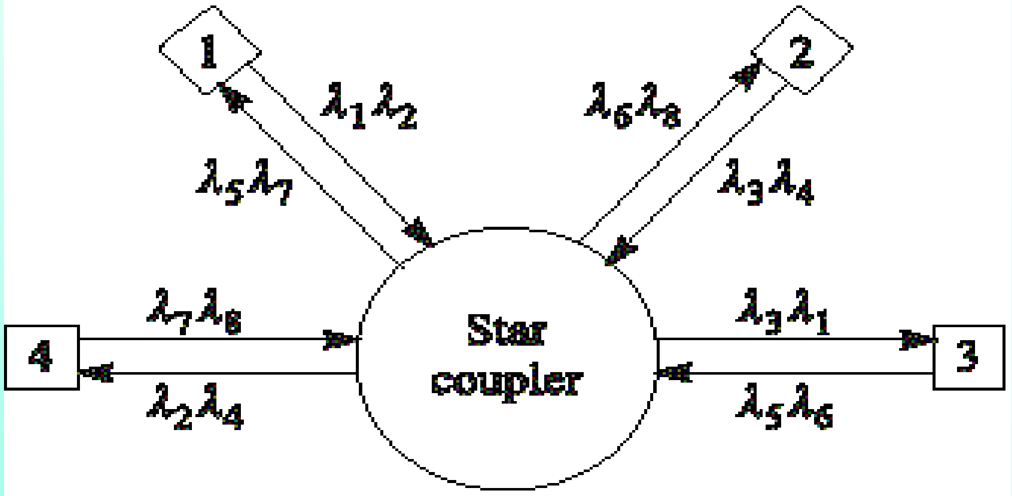
Advantages:

1. Simple architecture
2. Protocol transparent

Disadvantage

Need rapidly tunable lasers and optical filters.

Multi-hop Architecture



Four node broadcast and select multihop network

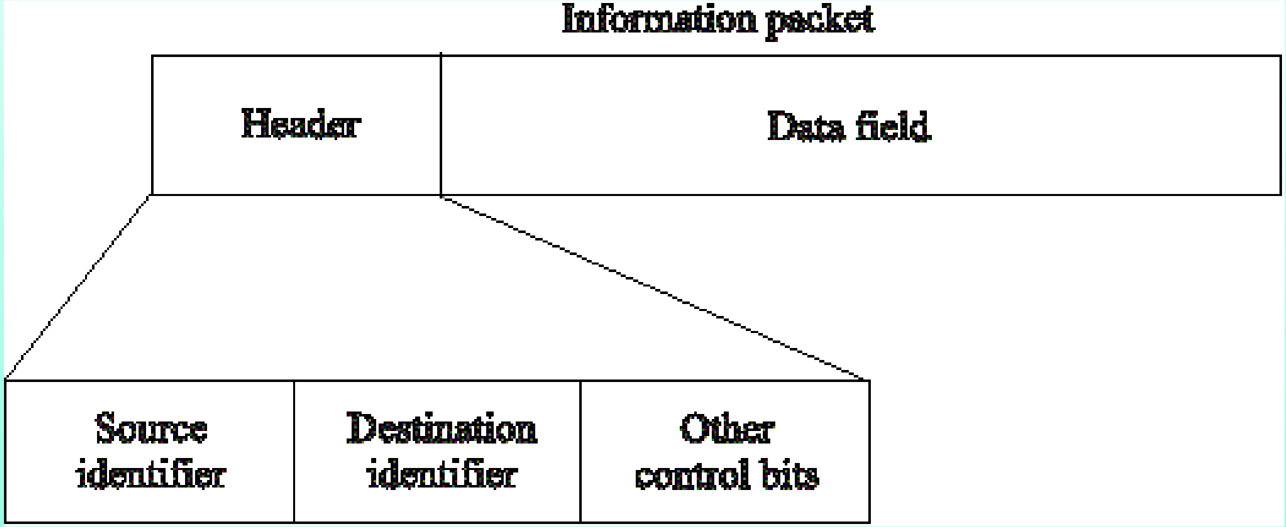
Each node transmits at fixed set of wavelengths and receive fixed set of wavelengths

Multiple hops required depending on destination

Ex. Node1 to Node2: N1→N3 (λ1), N3→N2 (λ6)

No tunable filters required but throughput is less

Fig. 12-17: Data packet

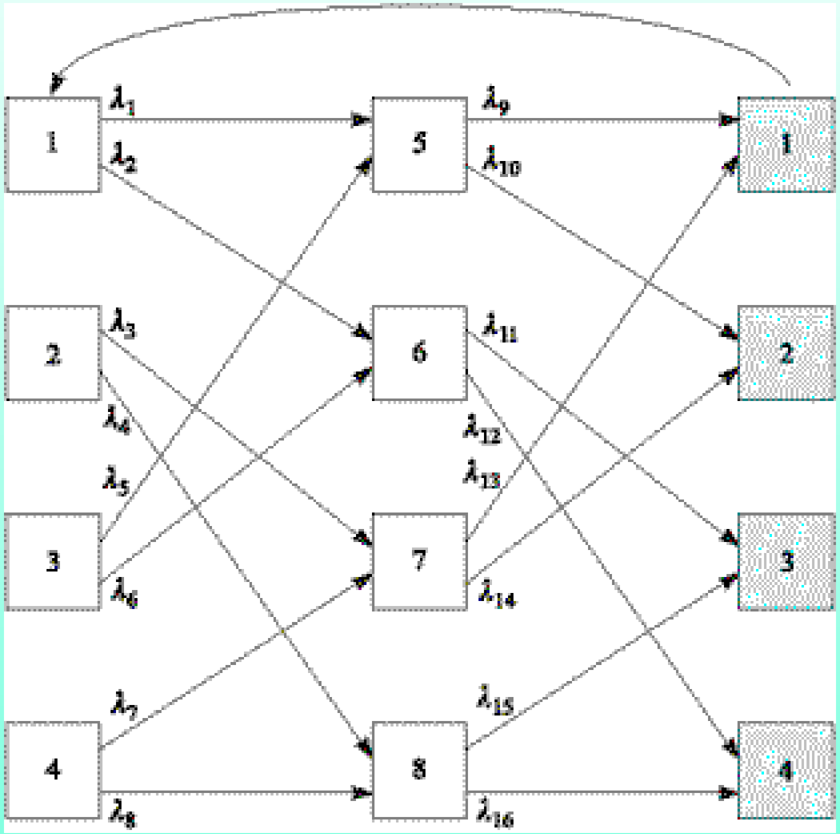


In multihop networks, the source and destination information is embedded in the header

These packets may travel asynchronously (Ex. ATM)

Shuffle Net

- Shuffle Net is one of several possible topologies in multihop networks
- N_λ = (# of nodes) X (λper node)
- Max. # of hops = 2(#of-columns) –1
- (-) Large # of λ's
- (-) High splitting loss

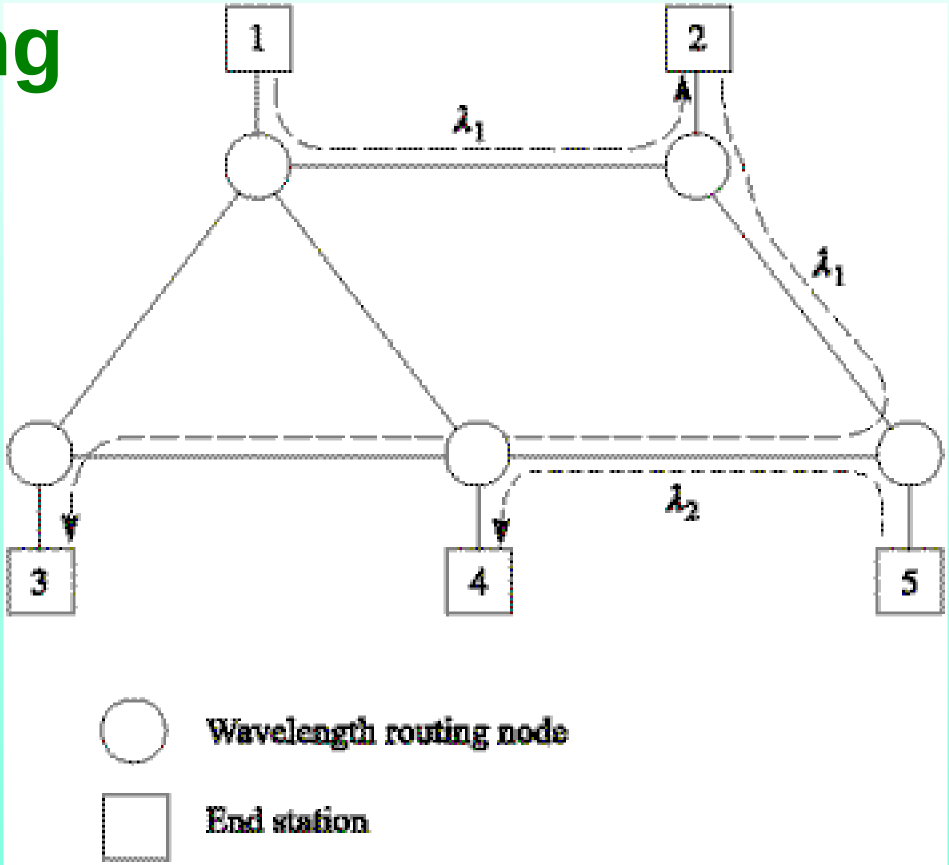


A two column shuffle net

Ex: Max. 2 X 2 - 1= 3 hops

Wavelength Routing

- The limitation is overcome by:
  - λ reuse,
  - λ routing and
  - λ conversion
- As long as the logical paths between nodes do not overlap they can use the same λ



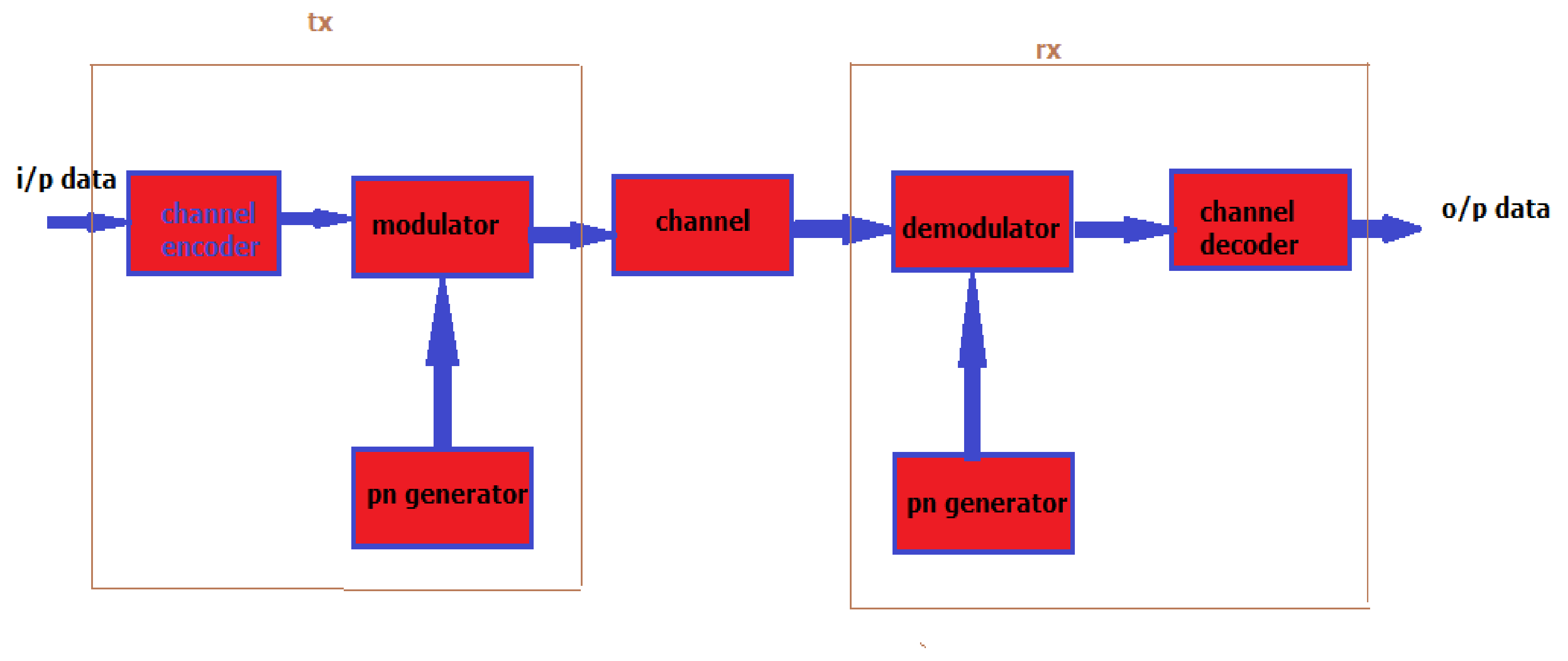
OPTICAL CDMA

- Provide multiple access to a network without using wavelength sensitive component
- Multiple access- 2 or more users use same propagation channel simultaneously.
- CDMA- transforming narrow band signal into wide band signal.

Why Spread spectrum used:

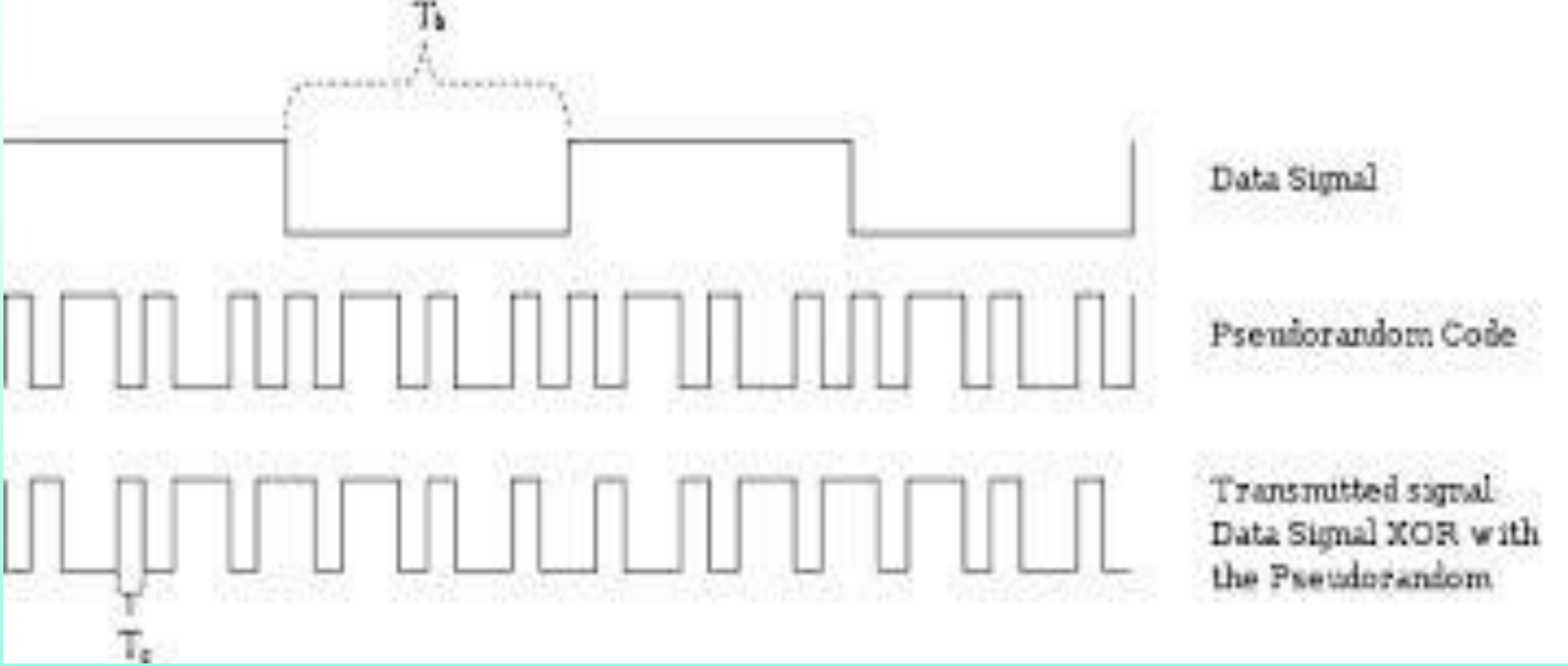
- Security.

Principle of spread spectrum



Pseudo Noise sequence:

- Periodic binary sequence noise like waveform generated by shift registers



Principle of optical CDMA: based on optical spread spectrum.

Optical encoder: map each bit into high rate optical sequences.

Chip: symbol in the spreading code.

1 data bit: Encoded into sequences consisting of N chips.

0 data bit: Not encoded.

Types of optical CDMA

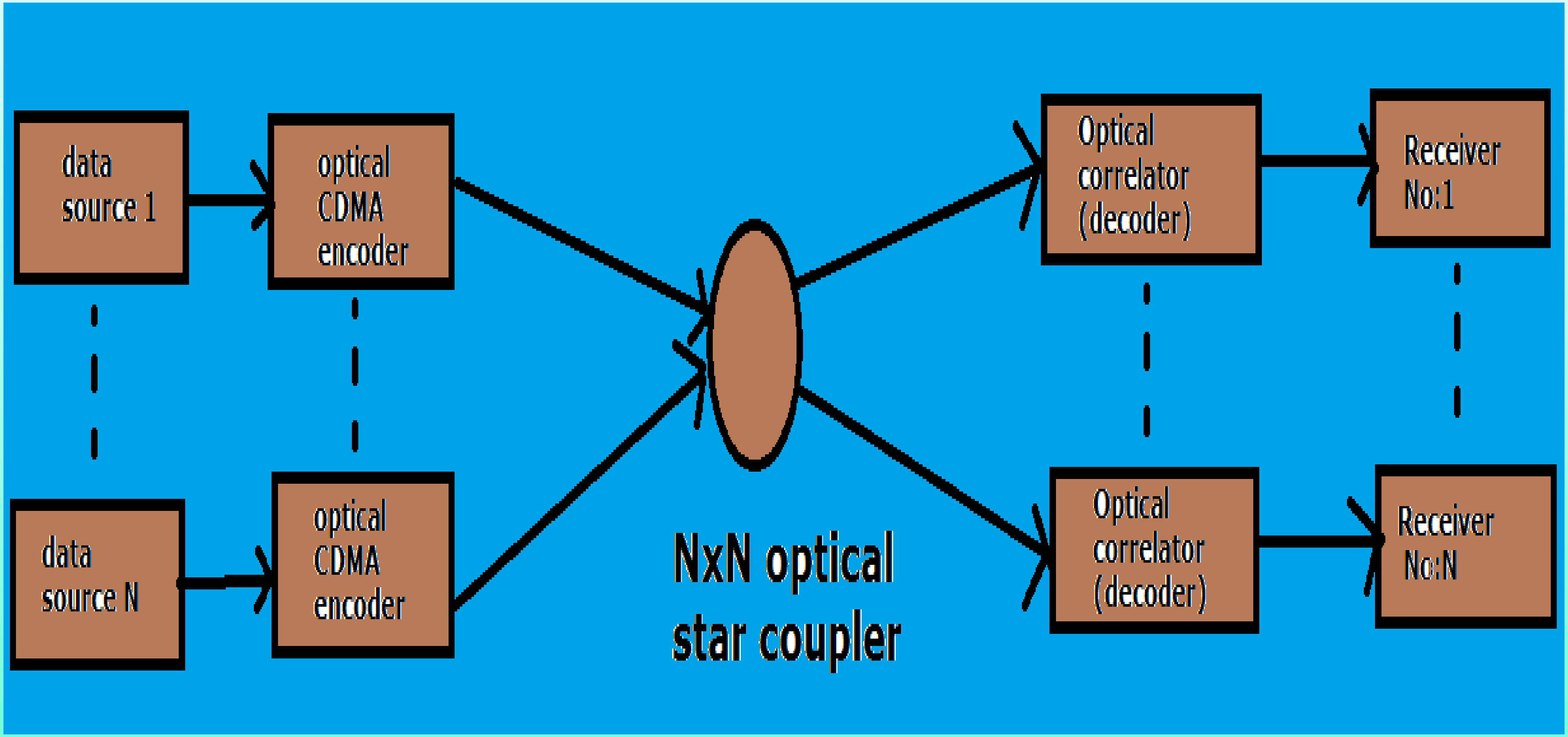
Synchronous optical CDMA:

- ✓ Follow rigorous transmission schedule.
- ✓ More successful transmission.
- ✓ Real time transmission-voice, interactive video.-Efficient

Asynchronous optical CDMA:

- ✓ Access in Random and collision between users can occur.
- ✓ When traffic are bursty in nature and not need real time communication requirements.
- ✓ Data transfer or file transfer and asynchronous scheme.

OPTICAL CDMA NETWORK MODEL


data source 1

optical CDMA encoder

data source N

optical CDMA encoder

NxN optical star coupler

Optical correlator (decoder)

Receiver No:1

Optical correlator (decoder)

Receiver No:N

- Setup consists of N transmitter and N receiver.
- Send data from node i to node k – node k is impressed upon the data by the encoder at node i.
- In receiver differentiates codes by using correlation detection.

- Each receiver correlates with its own address f(n) with received signal.
- $r(n) \ = \sum_{k=0}^{N} s(k) f(k-1)$
- s(n)=f(n) -received signal arrived at correlated destination, auto correlation function.
- s(n)≠ f(n) -received signal reaches at incorrect destination, cross correlation function.
- Receiver maximize auto correlation and minimize cross correlation.

ULTRA HIGH CAPACITY N/Ws

- Major challenge – provide enormous BW atleast 1THZ.
- Using dense WDM- increase capacity for

  long transmission.
- Allow transfer rates 1 Tb/sec on single fiber.
- Attractive in LANs and MANs.

Ultra high capacity WDM systems.

EDFA- Erbium Doped fiber Amplifier 1530 nm to 1560 nm.

EDFA+Raman amplifier – boost the gain at higher wavelengths.

Two popular approaches for increasing capacity.

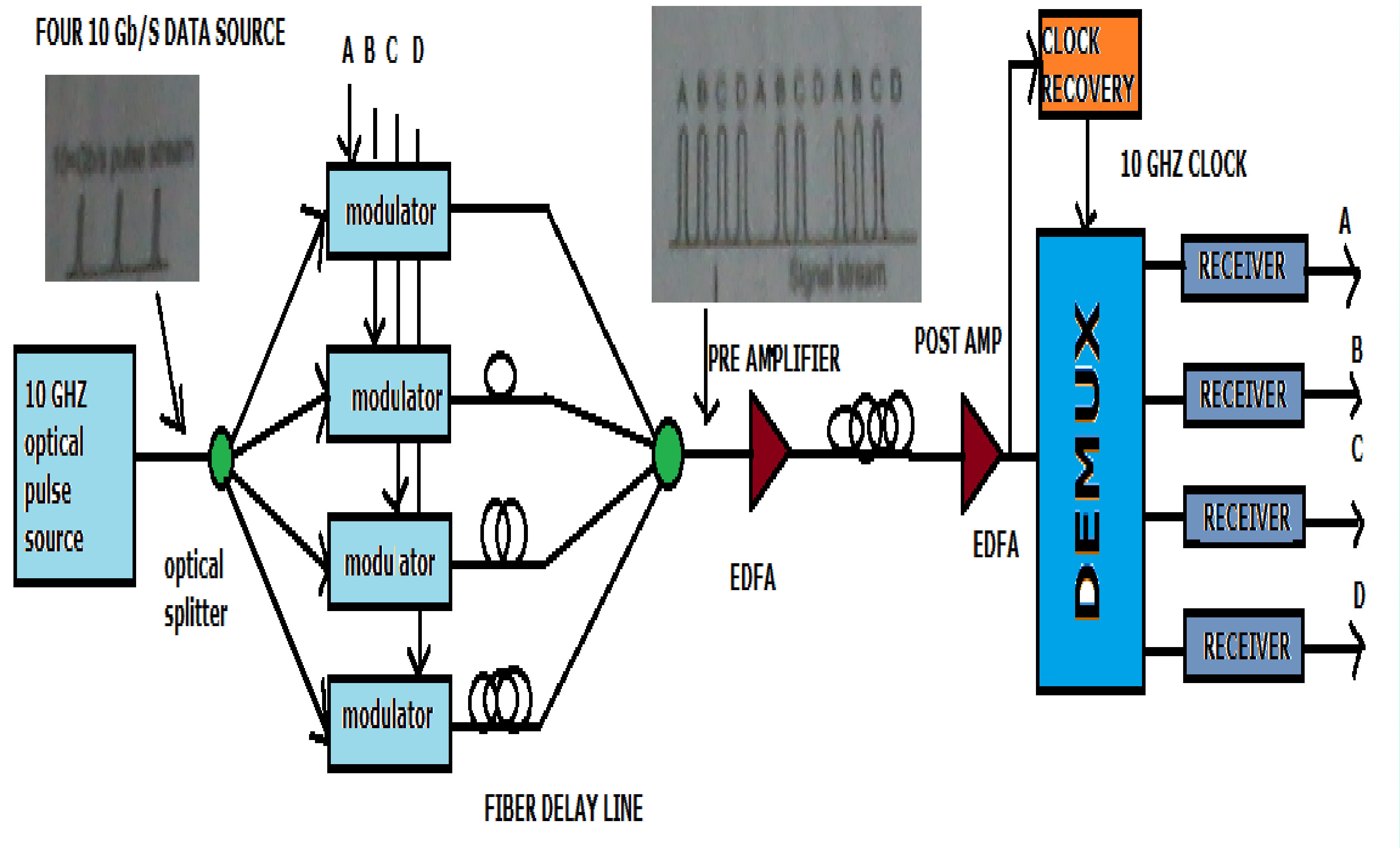
- Widen spectral Bandwidth:

1530-1560 nm → 1530-1610nm using gain boosting with raman amplifier.

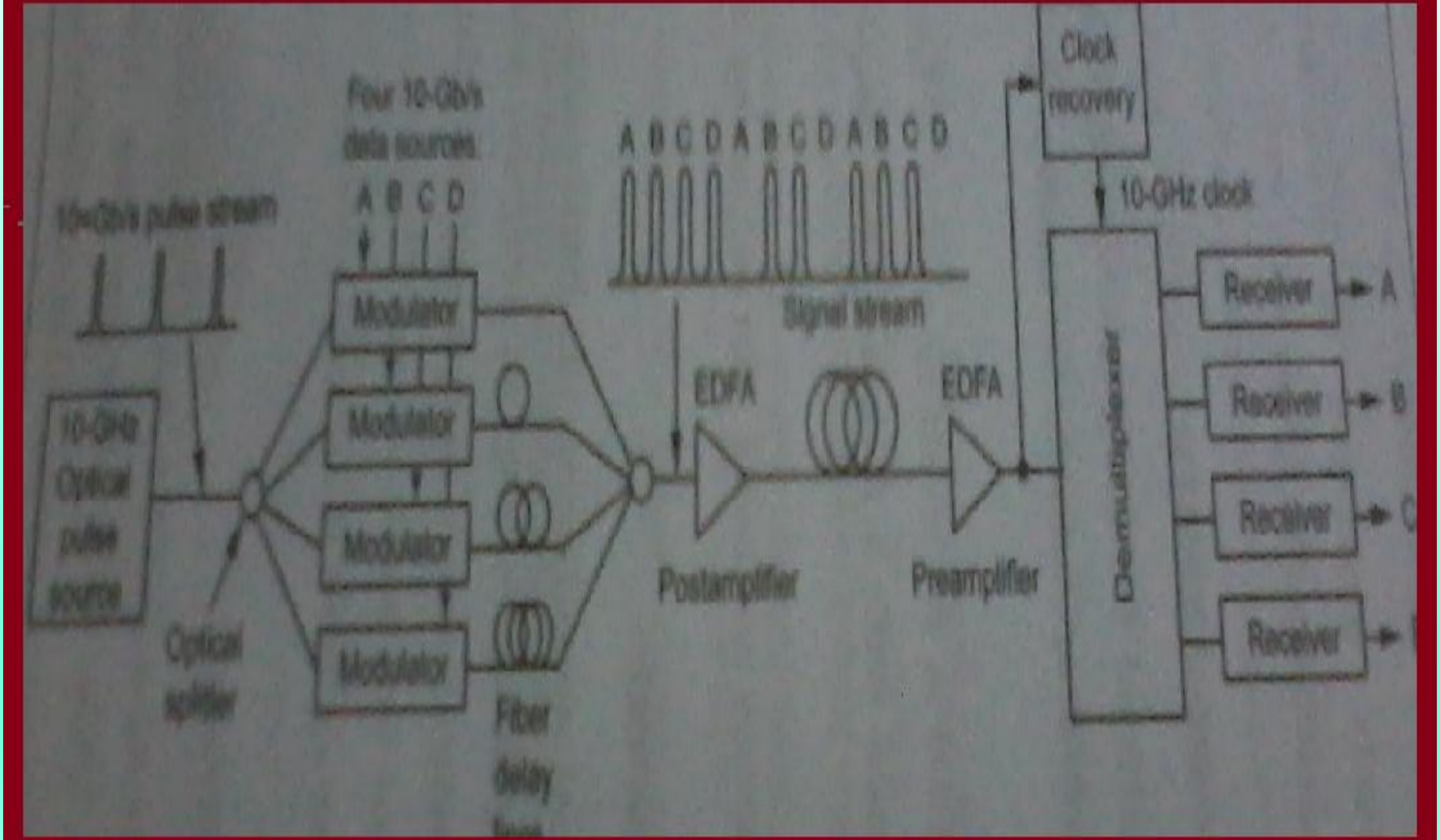
- Improve spectral efficiency:

Increase total transmission capacity independent of any expansion of the EDFA bandwidths.

Bit interleaved Optical TDM



Bit interleaved Optical TDM



BIT Interleaved optical TDM

- ✓Bit interleaved TDM is similar to WDM
- ✓Access node share many small channels operating at a peak rate that is a fraction of the media rate.
- ✓Channel rate could vary from 100 Mb/s to 1Gb/s. Time multiplexed media rate is around 100Gb/sec.
- ✓Laser source produce a regular stream of very narrow R-Z optical pulses.

- This rate typically ranges from 2.5 to 10 Gb/s.
- Optical splitter – Divide the pulse train into N separate streams.
- Modulated o/p delayed by different fraction of the clock period.
- Interleaved by optical combiner to produce bitrate NxB.
- Post and pre amplifier – compensate attenuation and splitting loss.
- Rx end-aggregate pulse stream demultiplexed into original N independent data for further signal processing.
- Clock recovery- sync the demux.

TIME SLOTTED OPTICAL TDM

- Access node share one fast channel 100 Gb/s.
- Pulse separation is important- for suppressing crosstalk and jitter during time extraction.
- This N/W backbone for high speed N/Ws.
- Provide high data rate & low data rate access.
- Speed range from 10 to 100Gb/s- high speed videos,terabyte media banks and supercomputer.
- Advantages:
- Depending on user date rate and traffic satatistics.
- Improve-shorter user-access time,lower delay,higher throughput.