INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
34100 TRIESTE (ITALY) - P.O.B. 586 - MIRAMARE - STRADA COSTIERA 11 - TELEPHONE: 2240-1
CABLE: CENTRATOM - TELEX 460392-I

SMR/169 - 17

WORKSHOP ON OPTICAL FIBER COMMUNICATION
(24 February - 21 March 1986)

# CIRCUIT DESIGN FOR OPTICAL TRANSMISSION SYSTEMS ( II PART )

presented by

A. MONCALVO

Centro Studi e Laboratori
Telecomunicazioni S.p.A.

Via Reiss Romoli, 274

10148 Torino

Italy

These are preliminary lecture notes, intended only for distribution to participants.

# LOCAL AREA NETWORKS

## LANs

- DEFINITIONS AND SCOPE
- FIELDS OF APPLICATION
- BASIC CONSTITUENTS
- SOLUTIONS ON METALLIC CABLES
- IMPACT OF THE OPTICAL TECHNOLOGY
  - TOPOLOGY
  - ACCESS PROTOCOLS
  - DEVICES
- POWER BUDGET



# FROM THE ORIGIN ...

A LOCAL AREA NETWORK IS A DATA COMMUNICATIONS SYSTEM WHICH ALLOWS A NUMBER OF INDEPENDENT DATA DEVICES TO COMMUNICATE DIRECTLY WITH EACH OTHER WITHIN A MODERATE SIZED GEOGRAPHIC AREA (SUCH AS A SINGLE OFFICE BUILDING, A WAREHOUSE OR A CAMPUS) OVER A PHYSICAL COMMUNICATION CHANNEL OF MODERATE TO HIGH DATA RATES AND CONSISTENTLY LOW ERROR RATE.

IEEE LOCAL AREA NETWORK STANDARD COMMITTEE
(PROJECT 802)

CSELT 09588/42

# ... TO THE PRESENT POSITION

A LOCAL AREA NETWORK IS AN INFORMATION TRANSPORTATION SYSTEM THAT SUSTAINS SPEECH, DATA, TEST, GRAPHICS, AND VIDEO, AND PROVIDES FOR HIGH-SPEED CONNECTION BETWEEN USERS WITHIN A SINGLE BUILDING OR A CAMPUS-THROUGH A COMMON WIRING SYSTEM, COMMON COMMUNICATION ADAPTER, COMMON ACCESS PROTOCOL TO ALLOW CONNECTION BETWEEN USERS, AND COMMON SHARED RESOURCES.

↑

ECONOMIC EUROPEAN COMMUNITY ESPRIT PROGRAM

CSELT 09588/43

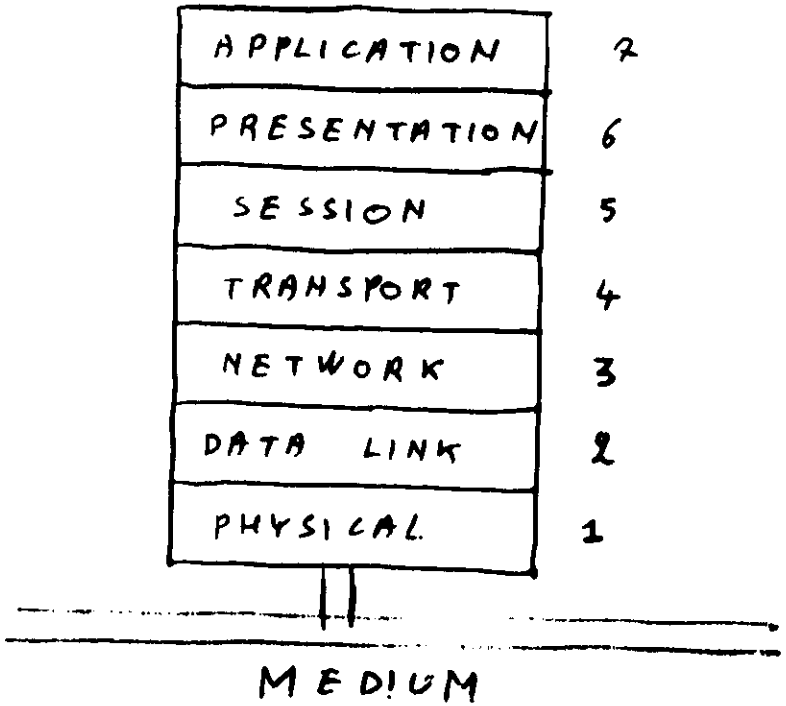
# Business Service Characterization

| SERVICE CLASS | SERVICE DESCRIPTION | SOURCE TRAFFIC TYPE | BIT-RATE kbit/s | BUSY-HOUR UTILIZATION | BUSY-HOUR THROUGHPUT kbit/s |
|---|---|---|---|---|---|
| 0: TELEPHONY | STANDARD DIGITAL TEL.<br>DSI, COMPRESSION TECHN. | STREAM | 64 | 0.25<br>0.125 | 16<br>8 |
| 1: LOW-SPEED DATA | FACSIMILE<br>VIDEOTEX<br>INTERACTIVE DATA<br>TEXT PROCESSING<br>... | BURSTY | 1.2 ÷ 9.6 | 0.12 | 0.6 |
| 2: MEDIUM-SPEED DATA | FACSIMILE (high-speed)<br>HOST-TO-HOST COMM.<br>LINE PRINTING<br>... | BURSTY | 19.2 ÷ 64 | 0.2 | 12.8 |
| 3: HIGH-SPEED DATA | MAINFRAME COMM.<br>FILE TRANSFER<br>HIGH-VOLUME PRINTING<br>... | BURSTY | 500 ÷ 1000 | 0.3 | 150 |
| 4: COMPRESSED DIGITAL VIDEO AND GRAPHICS | DESK-TOP<br>VIDEOTELEPHONY<br>VIDEOCONFERENCE<br>HIG-RES. GRAPHICS<br>... | STREAM | ≥2000 | 0.15 | 300 |
| 5: HIGH-QUALITY VIDEO | ANALOG or DIGITAL TV | – | 6 MHz/<br>≥100 Mbit/s | – | – |

CSELT 09588/76

OSI REFERENCE MODEL

OPEN SYSTEM INTERCONNECTION






LANs APPLICATIONS

- OFFICE AUTOMATION
- NEWSPAPER EDITING SYSTEMS
- FACTORY AUTOMATION
- PROCESS CONTROL
- HOSPITALS
- UNIVERSITIES AND RESEARCH LABORATORIES

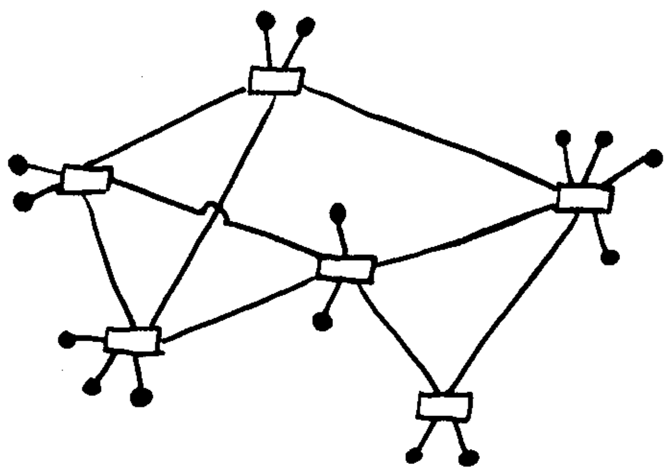
BASIC CONSTITUENTS OF LANs

- TRANSMISSION NETWORK
- MECHANISM FOR THE CONTROL OF THE TRANSMISSION
- INTERFACES TO CONNECT TERMI= NALS
- PROTOCOLS TO CONTROL THE INFOR= MATION FLOW
- GATEWAYS TO COMMUNICATE TO THE EXTERNAL PUBLIC TELECOM NETWORK



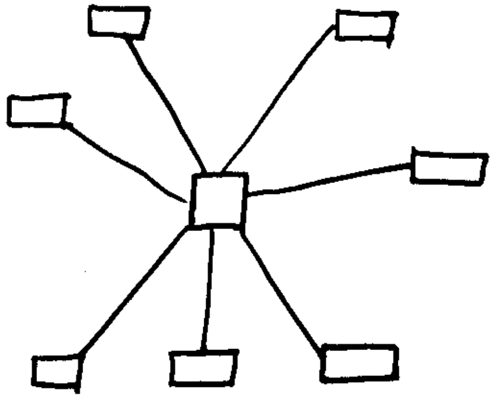
NETWORK TOPOLOGY

PATTERN OF THE INTERCONNECTIONS BETWEEN THE NODES OF THE NETWORK



● USER
▭ NODE
— INTERCONNECTION (LAYER 1)

## THE STAR NETWORK

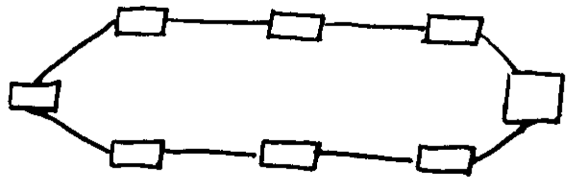


- SUITABLE FOR A CENTRALIZED CONTROL
- RELIABILITY FOR THE CENTRAL NODE
- MORE COMPLEX WIRING

NETWORK CONTROL CENTRE

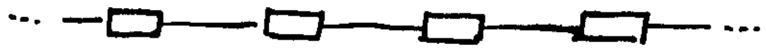


## THE RING NETWORK



- NO ROUTING DECISIONS
- NEED FOR RECOGNIZING THE ADDRESSES
- DISTRIBUTED CONTROL POSSIBLE
- RELIABILITY FOR EVERY NODE

## THE BUS NETWORK



- REDUCED AMOUNT OF WIRING
- NO ROUTING DECISIONS
- NEED OF RECOGNIZING THE ADDRESS
- DISTRIBUTED CONTROL POSSIBLE
- MANY DIFFERENT VARIATIONS:
  + UNIDIRECTIONAL/BIDIRECTIONAL
  + ONE/TWO CABLES

## NETWORK CONTROL

PROBLEM: WHICH NODE MAY TRANSMIT AT ANY GIVEN TIME?

SOLUTION: ACCESS PROTOCOLS

RULES THAT ALLOW THE USE OF A COMMON COMMUNICATION RESOURCE BY MANY DISTANT NODES

## PROTOCOL CLASSIFICATION

- FIXED / VARIABLE ALLOCATION
- TOPOLOGY
- NUMBER OF SERVED NODES
- DISTRIBUTED / CENTRALIZED CONTROL

## CHOICE

- TOPOLOGY
- TRAFFIC REQUIREMENTS
- EFFICIENCY

$$E = \frac{\text{CAPACITY USABLE BY A STATION}}{\text{TOTAL CHANNEL CAPACITY}}$$

- TECHNOLOGY



## CONTROL PASSING

THE TRANSMISSION CHANNEL IS ASSIGNE IN CYCLE TO THE STATIONS
A SILENT STATION RELEASES IT IMMEDIATELY

POLLING - CONTROL DISTRIBUTED BY A MASTER STATION (NCC). SUITABLE FOR STAR NETWORKS

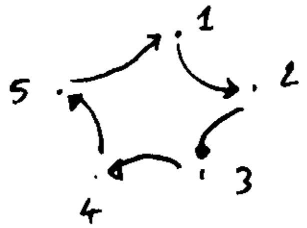
TOKEN - DAISY CHAIN

CONTROL PASSED DIRECTLY FROM A STATION TO THE NEXT ONE

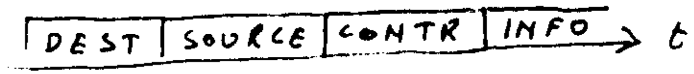
EXPLICIT TOKEN : MESSAGE WITH ADDRESS, INFORMATION, CONTROLS, ETC USED IN BUS

IMPLICIT TOKEN : PARTICULAR BIT PATTERN, FIXED. USED IN RINGS

CONTROL TOKEN




EXPLICIT TOKEN




IMPLICIT TOKEN


## RANDOM ACCESS PROTOCOLS

WITH MANY STATIONS, CONTROL PASSING PROTOCOLS BECOME LESS EFFICIENT

ACCESS TIME CAN BE REDUCED CONSIDERING THAT ONLY A FEW STATIONS WANT TO TRANSMIT AT A GIVEN INSTANT.

THE ACTIVITY OF THE CHANNEL IS MONITORED TO DETECT:

- ABSENCE OF TRANSMISSION
- CORRECT TRANSMISSION
- COLLISION - SIMULTANEOUS TRANSMISSION ATTEMPT BY SEVERAL STATIONS

## ALHOA (1970)

- A PACKET IS TRANSMITTED AS SOON AS AVAILABLE
- AFTER A COLLISION A RETRANSMISSION IS MADE AFTER A RANDOM TIME

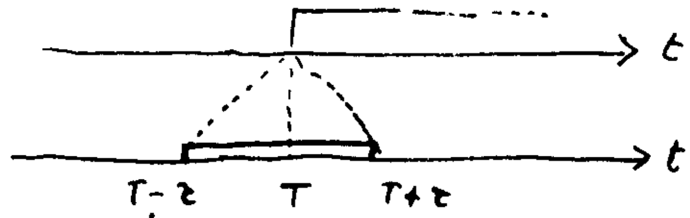

+ SIMPLEST ALGORITHM
+ SUITABLE FOR ALMOST EVERY TO-POLOCY
- VARIABLE DELAY - NOT SUITABLE FOR STREAM TRAFFIC.



## CARRIER SENSE MULTIPLE ACCESS

## CSMA

- A PACKET IS TRANSMITTED ONLY IF THE CHANNEL IS FREE




VULNERABLE WINDOW

$\tau$ = END TO END TRANSMISSION DELAY

NO COLLISION OUTSIDE THE WINDOW

AFTER A COLLISION NEW ATTEMPT AFER A RANDOM DELAY

IF THE CHANNEL IS BUSY, STATUS IS MONI-TORED (WITH PROBABILITY P) OR A NEW ATTEMPT IS MADE (WITH PRO-BABILITY 1-P) AFTER A RANDOM DELAY

PROTOCOL SUITABLE FOR BUSES

## CSMA-CD (COLLISION DETECTION)

WHEN A COLLISION IS DETECTED THE TRANSMISSION IS STOPPED

THE TIME IN WHICH COLLISIONS TAKE PLACE IS NO MORE WAISTED. EFFICIENCY IS IMPROVED.

COLLISION MUST BE DETECTED IN TIME! A MORE COMPLICATED MONITORING RECEIVER IS NEEDED.

## SPECIFIC ACCESS PROTOCOLS

WHEN THE TOPOLOGY IS A RING OR A BUS AND

- THE STATIONS CAN BE LABELED IN ORDER
- THE BIT TIMING IS CONTINUOUSLY AVAILABLE

* THE EFFICIENCY CAN BE FURTHER IMPROVED

* IT IS EASY TO ACCOMODATE BOTH PACKET AND STREAM SERVICES.

## EMPTY SLOTS


THE TIME IS SUBDIVIDED IN CONSTANT INTERVALS AVAILABLE TO EACH STATION

A STATION WILLING TO TRANSMIT TAKES AN EMPTY SLOT, CHANGES THE STATUS BIT S AND SENDS OUT HIS INFORMATION

- VERY FAST SIGNAL PROCESSING IS REQUIRED
- THE OVERHEAD CAN BE KEPT AT A MINIMUM – VERY GREAT EFFICIENCY



## CONTROL TOKEN

AN IMPLICIT TOKEN IS PASSED FROM A STATION TO THE NEXT ONE (TOPOLOGICAL ORDER)

EACH STATION MAY APPEND:

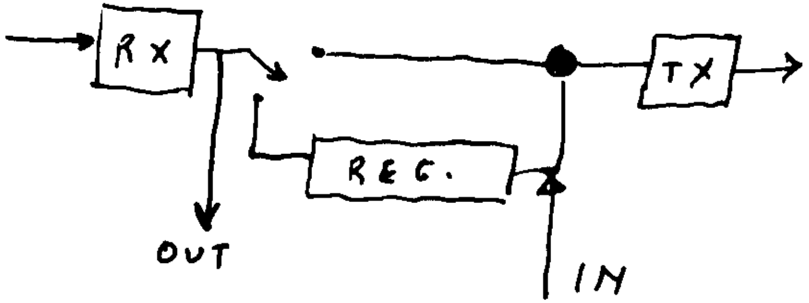
- NO MESSAGE
- A FIXED-LENGTH MESSAGE
- A VARIABLE-LENGTH MESSAGE

PROBLEMS

IN BUSES! A HEAD STATION MUST ISSUE A NEW TOKEN AT EVERY CYCLE

IN RINGS ! THE TOKEN MUST BE UNIQUE AND MUST BE PROTECTED AGAINST THE ERRORS

## REGISTER INSERTION




A STATION TRANSMITS WHEN THE CHANNEL IS FREE. INCOMING MESSAGES ARE BUFFERED IN THE REGISTER. TRANSMITTED MESSAGES ARE REMOVED WHEN THEY COME BACK IN THE REGISTER.

+ SIMPLE, FULLY DISTRIBUTED ALGORITHM
+ HIGH EFFICIENCY
- MESSAGES OF FIXED LENCHT
- SUPERVISION AGAINST INDEFINITE CIRCULATION OF CORRUPTED MESSAGES

## TRANSMISSION MEDIA

### COPPER PAIR

+ LOW COST
+ EASY INSTALLATION
• BANDWIDTH UP TO 5 MHz
- ATTENUATION MEDIUM TO HIGH
- NEEDS SCREENING

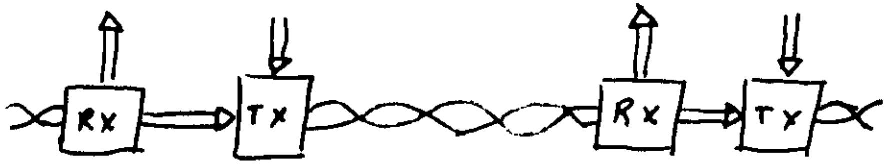
# TRANSMISSION MEDIA

## COAXIAL CABLE

+ SCREENED
+ 5-50 MHz BANDWIDTH PER CARRIER
+ CATV TECHNOLOGY AVAILABLE (USA)
- MODERATE COST
- CAREFUL INSTALLATION

# EXAMPLE OF IMPLEMENTATION

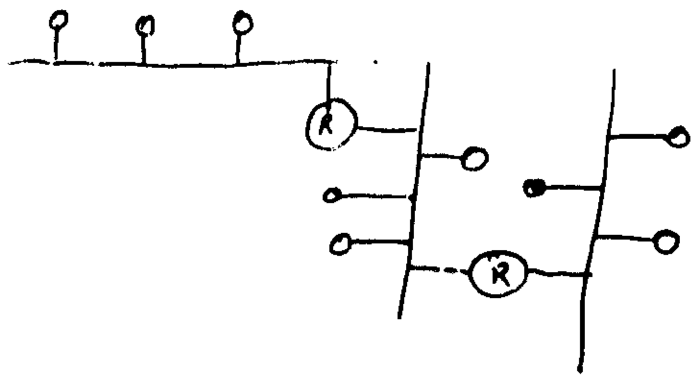
## IBM ZURICH RING




- RING WITH ACTIVE STATIONS
- POINT TO POINT UNIDIRECTIONAL LINKS
- STATION DISTANCE $\leq$ 1 km
- TOKEN PASSING PROTOCOL
- TWISTED PAIR, 4 Mbit/s
- ERROR RATE $10^{-9}$

EXAMPLE OF IMPLEMENTATION

XEROX'S ETHERNET




- MULTISEGMENT (MAX. 3) BUS
- COAXIAL CABLE, 2.5 Km MAX.
- CSMA-CD AT 10 Mbit/s
- MAX. 300 STATIONS

ADVANTAGES OF OPTICAL FIBRES

- LOW ATTENUATION $\leq$ 3 dB/Km
- WIDE BANDWIDTH $\geq$ 600 MHz · Km
- REDUCED SIZE AND WEIGTH
- IMMUNITY TO ELECTRIC INTERFERENCE
- ELECTRICAL INSULATION
- NO PECULIAR CONSTRAINTS ON ACCESS PROTOCOLS

## DRAWBACKS OF FIBRES

- REDUCED COUPLING EFFICIENCY (SIDE COUPLING)
- HIGH IMPEDANCE TAPPING IS NOT POSSIBLE



## WHICH FIBRE FOR LANs ?

G.I. 50/125 μm MULTIMODE

S.I. 10/125 μm SINGLE MODE

S.I. LARGE CORE MULTIMODE (> 100 μm)

CHOICE ACCORDING TO :

- ATTENUATION
- BANDWIDTH
- SPLICE LOSS
- COST

SINGLE FIBRE INTERCONNECTION CABLE

- G.I. 50/125 $\mu m$
- ATTENUATION: 2.5 dB/Km @ 860 nm
- BANDWIDTH: 500 MHz · Km
- EXTERNAL DIAMETER: 2.5 mm
- TENSILE STRENGTH: 20 Kg
- BENDING RADIUS: 30 mm MIN
- TEMPERATURE RANGE: $-20°C \div +60°C$
- SECTION LENGTH: $250 \div 1000$ m

## OPTICAL SOURCES

| TYPE | WAVELENGTH | PEAK POWER | BANDWIDTH | SPECTRAL WIDTH |
|---|---|---|---|---|
| LED | 0,8 - 0,9 $\mu m$ | 50 $\mu W$ | 50 MHz | 40 nm |
| | 1,3 $\mu m$ | 50 $\mu W$ | 100 MHz | 100 nm |
| LASER | 0,8 - 0,9 $\mu m$ | 2 mW | $\geqslant$ 500 MHz | $\geqslant$ 4 nm |
| | 1,3 $\mu m$ | 2 mW | $\geqslant$ 500 MHz | $\geqslant$ 4 nm |
| | 1,5 $\mu m$ | 2 mW | $\geqslant$ 500 MHz | $\geqslant$ 4 nm |

CSELT 09588/92

37

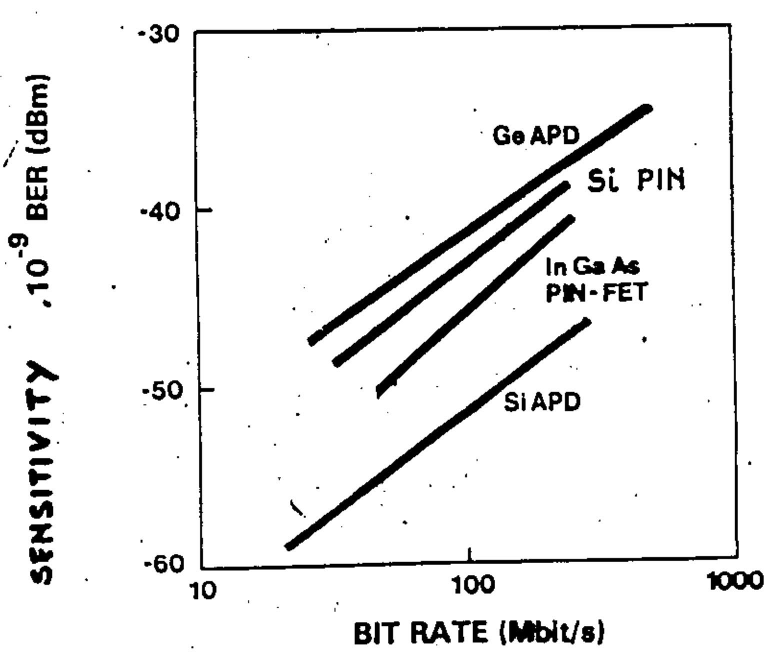
# OPTICAL DETECTORS

| TYPE | WAVELENGTH | GAIN | BANDWIDTH |
|---|---|---|---|
| Si-ADP | 0,8 - 0,9 μm | ~ 100 | ⩾ 500 MHz |
| Ge-APD | 1,1 - 1,6 μm | ~ 10 | ⩾ 500 MHz |
| p-i-n InGaAs InGaAsP | 1,3 - 1,6 μm | 1 | ⩾ 500 MHz |

CSELT 09586/90

38

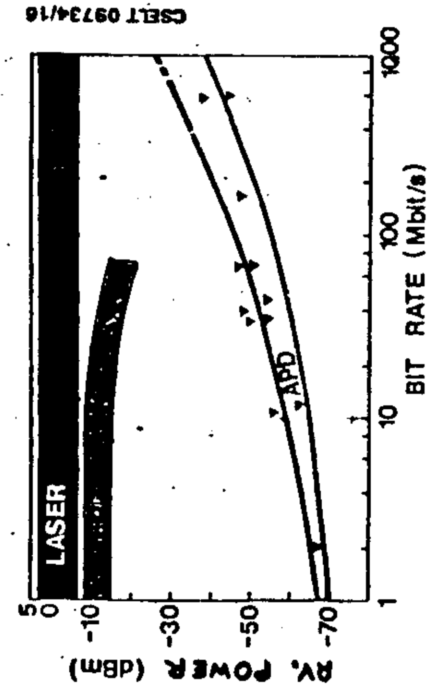
## OPTICAL RECEIVERS SENSITIVITY




CSELT 09734/13

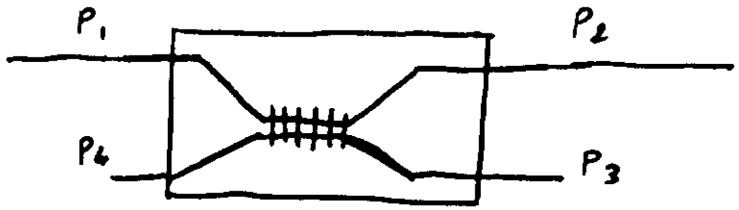
## OPTICAL SOURCES AND RECEIVERS

average power vs. bit rate




## OPTICAL COUPLERS

MULTIPORT DEVICES FOR LAUNCHING OR EXTRACTING POWER FROM A FIBRE



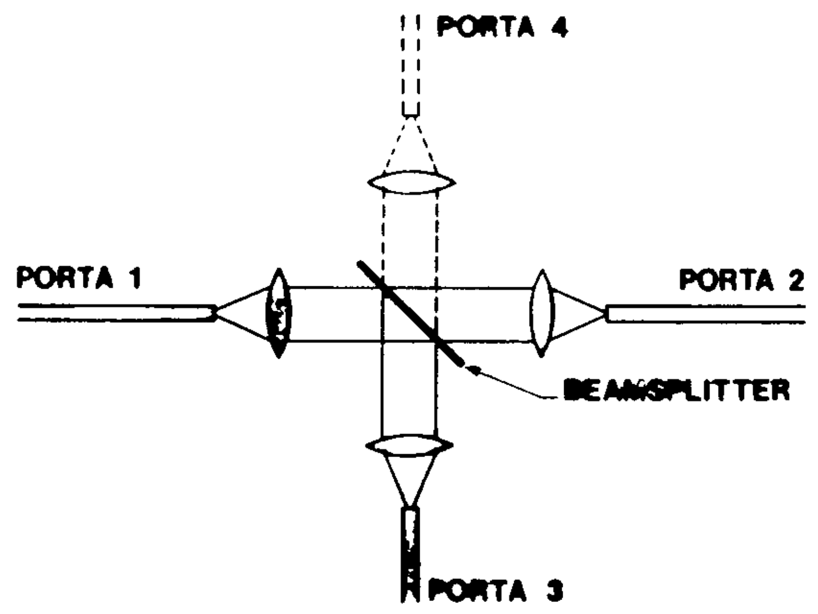

COUPLING $1 \rightarrow 2$ $\quad P_2 / P_1$

COUPLING $1 \rightarrow 3$ $\quad P_3 / P_1$

OUTPUT RATIO $\quad P_2 / P_3$

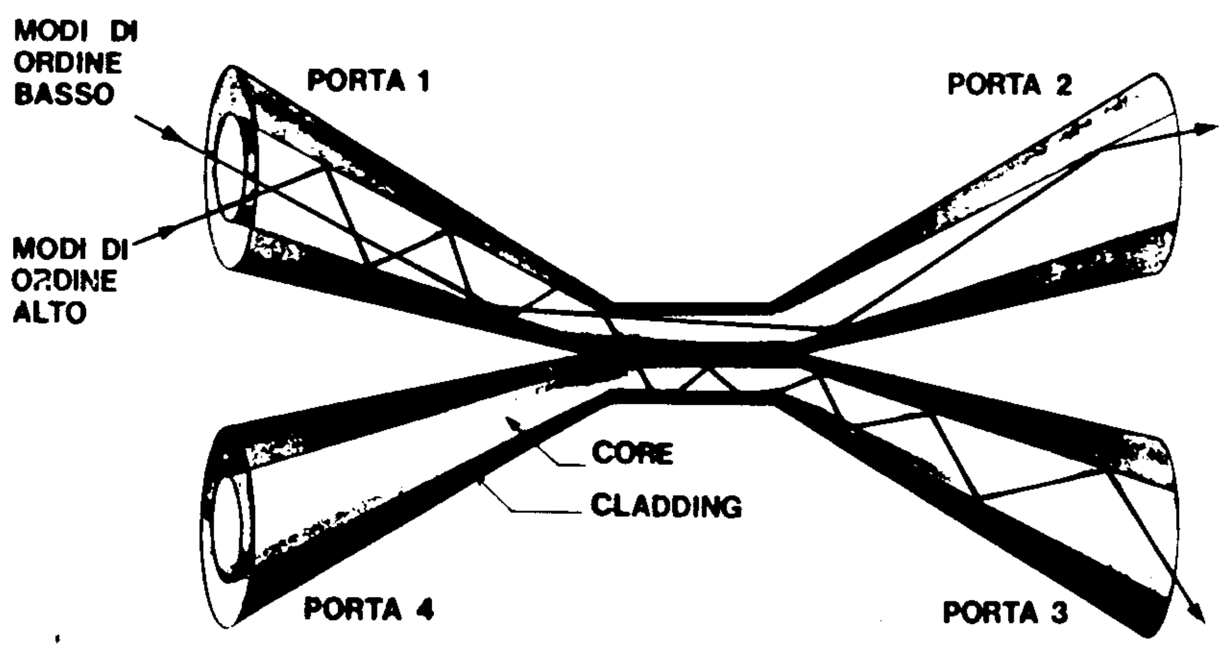
INSERTION LOSS $\quad \dfrac{P_1 - (P_2 + P_3)}{P_1}$

## ESEMPIO DI UN ACCOPPIATORE DEL TIPO A RIFLESSIONE




CSELT 16860

## ESEMPIO DI ACCOPPIATORE DEL TIPO AD ACCOPPIAMENTO DI MODI




CSELT

## OPTICAL COUPLERS

### POWER BUDGET

- RING
- BIT RATE 34 MBIT/s
- $P_{TX} = -5$ dBm (LASER)

  $S_{RX} = -49$ dBm

- INSERTION LOSS WITH CONNECTORS

  3.5 dB

OPTIMAL OUTPUT RATIO 10/1

AFTER 5 COUPLERS A REGENERATOR IS REQUIRED

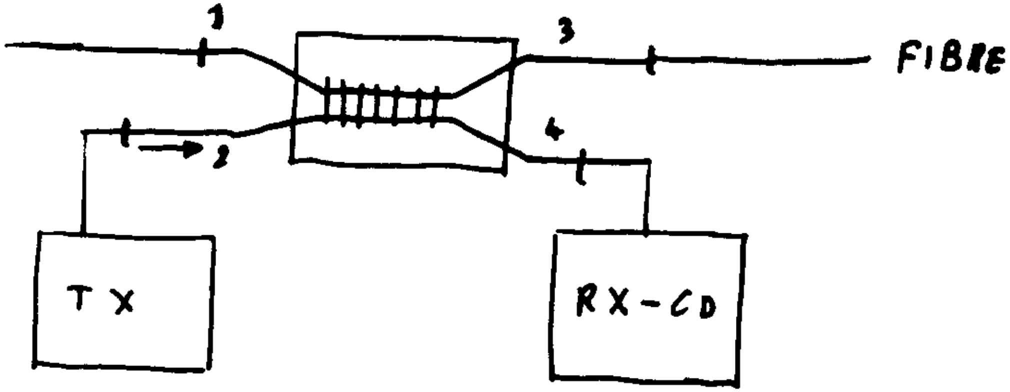
## TOPOLOGIES FOR OPTICAL LANs

### RING

- WITH OPTICAL COUPLERS
  * REPEATERS EVERY $5 \div 10$ STATIONS
  * PROBLEMS WITH CIRCUITS: TIMING, DYNAMIC RANGE
- FULLY ACTIVE
  * SEQUENCE OF POINT-TO-POINT LINKS
  * PROBLEMS OF RELIABILITY AND FAILURE

# OPTICAL COUPLERS

## EXAMPLE OF INSERTION




$$\frac{P_4}{P_1} = \frac{P_3}{P_2} \qquad \frac{P_3}{P_1} = \frac{P_4}{P_2}$$

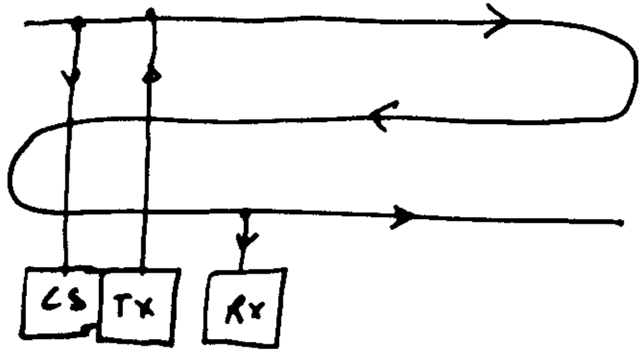
COUPLERS ARE RECIPROCAL AND SYMMETRICAL

COUPLING RATIO IS TO BE OPTIMIZED ACCORDING TO THE APPLICATION

# TOPOLOGIES FOR OPTICAL LANS

## BUS

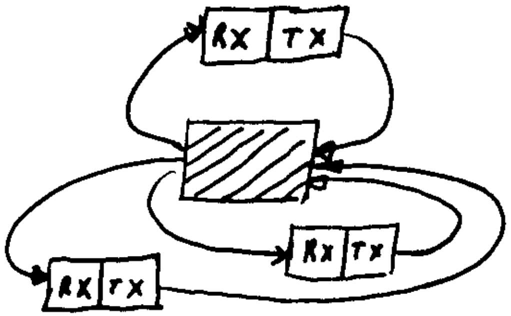
- MONODIRECTIONAL BUS FAVOURED
  LESS REPEATERS (WITH COUPLERS)
  PROTOCOLS WITH BETTER PERFORMANCES (ORDERED STATIONS)
- REPEATERS REQUIRED
- SAME RELIABILITY AND CIRCUIT PROBLEMS AS FOR RING




2 - BUS

# TOPOLOGIES FOR OPTICAL LANS

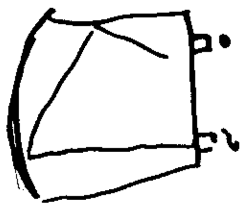
## PASSIVE STAR




- FULLY PASSIVE STRUCTURE
  HIGH RELIABILITY

- EQUIVALENT TO A BUS
  THE BUS PROTOCOLS CAN BE USED, EXCLUDING THOSE REQUIRING AN ORDERING IN THE STATIONS

- LIMITS : NUMBER OF PORTS



# LINE CODES FOR LANS

## REQUIREMENTS

- SPECTRUM SHAPING
- LOW REDUNDANCY ADDED
- MANY TRANSITIONS TO EXTRACT TIMING
- WORDS FOR COMMANDS
- EASY WORD ALIGNMENT
- PERFORMANCE MONITORING
- EASE OF IMPLEMENTATION
- 2 LEVELS ONLY

# EXAMPLES OF CODES

- 8B 1C

$\bar{D}_0$ $D_0$ $D_1$ $D_2$ $D_3$ $D_4$ $D_5$ $D_6$ $D_7$

- SIMPLE TO BE IMPLEMENTED
- DC COMPONENT IN THE CONTINUOUS SPECTRUM
- COMMAND WORD BY CODE VIOLATION
- ERROR MONITORING AND FRAME ALIGNMENT ON $\bar{D}_0 D_0$



# EXAMPLES OF CODES

16 B 18 B

$D_0$ $D_1$ $D_2$ ····· $D_{15}$ I P

I = INVERSION

P = PARITY

- RUNNING DIGITAL SUM IS LIMITED
  NO DC COMPONENT IN THE SPECTRUM
- ERROR MONITORING AND ALIGNMENT BASED ON I P
- COMMAND WORDS BY VIOLATIONS

## EXAMPLES OF CODES

FIBER DISTRIBUTED DATA INTERFACE

4B - 5B

16 DATA WORDS
8 COMMAND WORDS
8 PROHIBITED WORDS

FRAME ALIGNMENT AND ERROR MONITORING WITH PROHIBITED WORDS

SUITABLE UP TO 20-30 Mbit/s

## EXAMPLES OF CODES

CMI - CODED MARK INVERSION

$0 \rightarrow 01$

$1 \rightarrow 00$ / $1 \rightarrow 11$ ALTERNATE

- SIMPLE CIRCUITS
- EASY CLOCK RECOVERY
- MONITORING OF ERRORS ON ALTERNATIONS
- COMMAND WORDS BY VIOLATIONS

DRAWBACK: THE BANDWIDTH IS DOUBLED

# SYNCHRONIZATION IN LANS

- THE RECEIVER EXTRACTS TIMING FROM THE INCOMING SIGNAL

- THE ONLY POSSIBLE SOLUTIONS ON BUSES WITH BURSTY ACTI=VITY

- PREAMBLE FOR TRAINING NEEDED

- DIFFICULT MATCHING WITH HIGHER LEVEL CLOCK



# SYNCHRONIZATION IN LANS

THE RECEIVER IS PERMANENTLY LOCKED TO THE SIGNAL FROM THE PREVIOUS TRANSMITTER AND FEEDS ALL THE NODE.

- SUITABLE IN RINGS

- RELIABLE MASTER CLOCK REQUIRED

- JITTER IF THE NODES ARE MANY

- JITTER REDUCER IN THE RECEIVER OF THE MASTER STATION

## SYNCHRONIZATION IN LANS

THE RECEIVER IS LOCKED TO THE PREVIOUS NODE, BUT IT HAS ALSO A LOCAL CLOCK
DATA ARE WRITTEN IN AN ELASTIC BUFFER AND READ BY THE LOCAL CLOCK. THE DIFFERENCE IN FREQUENCY IS COMPENSATED IN IDLE PERIODS

- SUITABLE FOR RINGS
- NO MASTER CLOCK
- UNTITTERED CLOCK IN THE NODES
- SMALL OVERHEAD

- MORE COMPLEX CIRCUITS

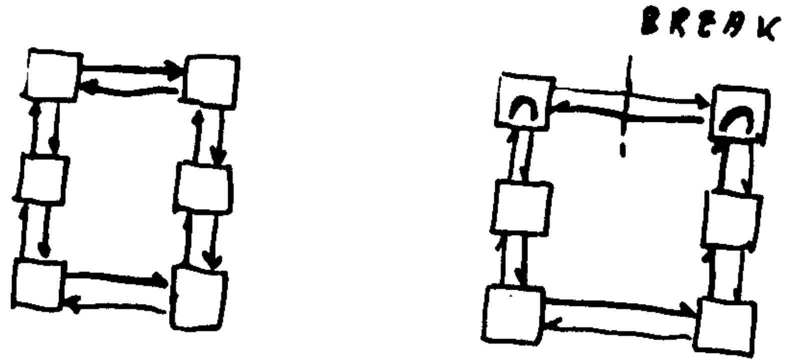
## RELIABILITY OF A LAN

| MALFUNCTION | COUNTERMEASURE |
|---|---|
| NODE FAILURE | BY PASS |
| CABLE BREAK | CABLE DUPLICATION |

### IN GENERAL

- NETWORK DUPLICATION IS EXPENSIVE

- NETWORK RECONFIGURATION DEPENDS ON THE PROTOCOLS




NORMAL RING

EMERGENCY LOOP

RECONFIGURED RING