Local Area Networks

A Local Area Network is a communications network that provides interconnection of a variety of data communicating devices within a small area.

Typical Characteristics

! High Data Rates (0.1 to 1000 Mbps)
! Short Distances (0.1 to 25 km)
! Low Error Rate ($10^{-8}$ to $10^{-11}$)
Local Area Network Topologies

Star Topology

Bus Topology

Tree Topology

Ring Topology
Shared Media vs. Switching LAN Architectures

Shared-Media LAN Architecture

shared, single 10Mbps LAN segment

only one 10Mbps connection at a time

10 Mbps

10 Mbps

client workstations

servers

*10 Mbps for ALL*

Switch-Based LAN Architecture

multiple dedicated 10Mbps LAN segments

Multiple, simultaneous 10Mbps connections

shared-media hub

Workgroup with shared connection

Servers with dedicated connections

Workgroup with shared connection

Workstations with dedicated connections

*10 Mbps for EACH*

Switched LAN Architectures Versus Media-Sharing LAN Architectures Wiring Center Functionality
LAN Transmission Media

Twisted Pair:
Consists of two insulated wires (unshielded or shielded) arranged in a regular spiral pattern.

- Inexpensive
- Bandwidth is limited
- Cost effective for single building, low traffic network

Coaxial Cable:
Consists of a hollow outer cylindrical conductor which surrounds a single inner wire conductor.

- Greater capacity than twisted pair
- Can handle a considerable amount of data
- Two types:
  - 50 ohm (used in baseband networks)
  - 75 ohm (used in broadband networks)

Fiber Optic Cable:
The fiber is a thin, flexible (glass or plastic) medium having a high index of refraction.

The fiber is surrounded by a "Cladding" material with a slightly lower index of refraction. The Cladding layer isolates the fiber (no crosstalk).

An absorptive jacket surrounds the cladding layer.
- Low Noise Susceptibility, low loss, small size.
- Very high data rates possible.
LAN Transmission Media cont.

(a) Twisted pair

- Separately insulated
- Twisted together
- Often "bundled" into cables
- Usually installed in building when built

(b) Coaxial cable

- Outer conductor braided shield
- Inner conductor solid metal
- Separated by insulating material
- Covered by padding

(c) Optical fiber

Guided Transmission Media

- Glass or plastic core
- Laser or light-emitting diode
- Specially designed jacket
- Small size and weight

Light at less than critical angle is absorbed in jacket

Angle of incidence

Angle of reflection
Local Area Network Protocols

IEEE 802 Architecture

<table>
<thead>
<tr>
<th>OSI MODEL</th>
<th>IEEE 802 MODEL</th>
</tr>
</thead>
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<tr>
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<td>LOGICAL LINK CONTROL</td>
</tr>
<tr>
<td>PRESENTATION</td>
<td>MEDIUM ACCESS CONTROL</td>
</tr>
<tr>
<td>SESSION</td>
<td></td>
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<tr>
<td>TRANSPORT</td>
<td></td>
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<tr>
<td>NETWORK</td>
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</tr>
<tr>
<td>DATA LINK</td>
<td></td>
</tr>
<tr>
<td>PHYSICAL</td>
<td>PHYSICAL</td>
</tr>
</tbody>
</table>

1. IEEE 802 Model vs. OSI Model

1. Logical Link Control (LLC):

2. Medium Access Control (MAC):
   - Functions of the LLC and MAC layers:
     - Provide one or more Service Access Points (SAPs)
     - Provide frame assembly/disassembly
     - Perform address recognition
     - Perform error detection
     - Manage communications over the link

3. Physical Layer:
   - Functions of the Physical layer:
     - Encoding/decoding of signals
     - Preamble generation/removal (for synchronization)
     - Bit transmission/reception
IEEE 802 Model vs. OSI Model
IEEE 802 PDU Structure
IEEE 802 Standards

IEEE 802 Subcommittees

- 802.1: Higher Layer LAN Protocols
- 802.2: Logical Link Control
- 802.3: CSMA/CD Networks
- 802.4: Token Bus Networks
- 802.5: Token Ring Networks
- 802.6: Metropolitan Area Networks
- 802.7: Broadband Technical Advisory Group
- 802.8: Fiber Optic Technical Advisory Group
- 802.9: Isochronous LAN Networks
- 802.10: LAN Security
- 802.11: Wireless LAN networks
- 802.12: Demand Priority Networks
- 802.14: Cable Modem Networks
- 802.15: Wireless Personal Area Networks
- 802.16: Broadband Wireless Access Study Group
- QoS/Flow Control Study Group
## LAN Standards

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<th>IEEE 802.2</th>
<th>CSMA/CD</th>
<th>IEEE 802.3</th>
<th>IEEE 802.4</th>
<th>IEEE 802.5</th>
<th>IEEE 802.6</th>
<th>IEEE 802.11</th>
<th>IEEE 802.12</th>
<th>IEEE 802.15</th>
<th>IEEE 802.16</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unacknowledged connectionless service</strong></td>
<td><strong>Unacknowledged connectionless service</strong></td>
<td><strong>Unacknowledged connectionless service</strong></td>
<td><strong>Unacknowledged connectionless service</strong></td>
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<td><strong>Unacknowledged connectionless service</strong></td>
<td><strong>Unacknowledged connectionless service</strong></td>
</tr>
<tr>
<td><strong>Token ring</strong></td>
<td><strong>Token ring</strong></td>
<td><strong>Token ring</strong></td>
<td><strong>Token ring</strong></td>
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<td><strong>Token ring</strong></td>
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<td><strong>Token ring</strong></td>
<td><strong>Token ring</strong></td>
<td><strong>Token ring</strong></td>
</tr>
<tr>
<td><strong>Round robin: priority</strong></td>
<td><strong>Round robin: priority</strong></td>
<td><strong>Round robin: priority</strong></td>
<td><strong>Round robin: priority</strong></td>
<td><strong>Round robin: priority</strong></td>
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<td><strong>Round robin: priority</strong></td>
</tr>
<tr>
<td><strong>Physical</strong></td>
<td><strong>Physical</strong></td>
<td><strong>Physical</strong></td>
<td><strong>Physical</strong></td>
<td><strong>Physical</strong></td>
<td><strong>Physical</strong></td>
<td><strong>Physical</strong></td>
<td><strong>Physical</strong></td>
<td><strong>Physical</strong></td>
<td><strong>Physical</strong></td>
</tr>
</tbody>
</table>

**IEEE 802.3**: Baseband coaxial, 10 Mbps; Unshielded twisted pair, 10 Mbps; Shielded twisted pair, 100 Mbps; Optical fiber, 10 Mbps

**IEEE 802.4**: Baseband coaxial, 10 Mbps; Unshielded twisted pair, 10 Mbps; Shielded twisted pair, 100 Mbps; Optical fiber, 10 Mbps

**IEEE 802.5**: Token ring, 10 Mbps; Unshielded twisted pair, 10 Mbps; Shielded twisted pair, 100 Mbps; Optical fiber, 10 Mbps

**IEEE 802.6**: Token ring, 10 Mbps; Unshielded twisted pair, 10 Mbps; Shielded twisted pair, 100 Mbps; Optical fiber, 10 Mbps

**IEEE 802.11**: Infrared, 1.2 Mbps; Spread spectrum, 1.2 Mbps

**IEEE 802.12**: Token ring, 10 Mbps; Unshielded twisted pair, 10 Mbps; Shielded twisted pair, 100 Mbps; Optical fiber, 10 Mbps

**IEEE 802.15**: Unacknowledged connectionless service, Connection-mode service

**IEEE 802.16**: Unacknowledged connectionless service, Connection-mode service

**IEEE 802.2**: Connection-mode service, Unacknowledged connectionless service

**LAN/MAN Standards**: Bus/tree/star topologies, Ring topology, Dual bus topology, Wireless

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LANS-10
LLC Services

1. Unacknowledged Connectionless Service:
   ! Datagram service
   ! Supports point-to-point, multipoint, and broadcast

2. Connection-Mode Service:
   ! Provides virtual circuit connections between a pair of SAPs
   ! Provides flow control, sequencing, and error recovery

3. Acknowledged Connectionless Service:
   ! A connectionless service that provides acknowledgements
   ! Supports point-to-point transfers
LLC Protocol Data Unit Format

I/G = Individual/Group DSAP
0 - Individual DSAP
1 - Group DSAP

C/R = Command/Response
0 - Command
1 - Response
## LLC Command/Response Repertoire

<table>
<thead>
<tr>
<th>Format</th>
<th>Commands</th>
<th>Responses</th>
<th>C-Field Format</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>I</strong> (Information)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>RR</strong> (Receive Ready)</td>
<td><strong>RR</strong> (Receive Ready)</td>
<td>0 0 0 0 0 0 0 1</td>
</tr>
<tr>
<td>Supervisory</td>
<td><strong>RNR</strong> (Receive Not Ready)</td>
<td><strong>RNR</strong> (Receive Not Ready)</td>
<td>0 0 0 0 0 1 0 1</td>
</tr>
<tr>
<td></td>
<td><strong>REJ</strong> (Reject)</td>
<td><strong>REJ</strong> (Reject)</td>
<td>0 0 0 0 1 0 0 1</td>
</tr>
<tr>
<td></td>
<td><strong>SABME</strong> (Set Asynch. Balanced Mode)</td>
<td></td>
<td>0 1 1 P 1 1 1 1</td>
</tr>
<tr>
<td></td>
<td><strong>DM</strong> (Disconnect Mode)</td>
<td></td>
<td>0 0 0 F 1 1 1 1</td>
</tr>
<tr>
<td></td>
<td><strong>DISC</strong> (Disconnect)</td>
<td></td>
<td>0 1 0 P 0 0 1 1</td>
</tr>
<tr>
<td>Unnumbered</td>
<td><strong>UA</strong> (Unnumbered Ack)</td>
<td></td>
<td>0 1 1 F 0 0 1 1</td>
</tr>
<tr>
<td></td>
<td><strong>FRMR</strong> (Frame Reject)</td>
<td></td>
<td>1 0 0 F 0 1 1 1</td>
</tr>
<tr>
<td></td>
<td><strong>UI</strong> (Unnumbered Info)</td>
<td></td>
<td>0 0 0 P 0 0 1 1</td>
</tr>
<tr>
<td></td>
<td><strong>XID</strong> (Exchange ID)</td>
<td></td>
<td>1 0 1 P 1 1 1 1</td>
</tr>
<tr>
<td></td>
<td><strong>AC0</strong> (Acknowledged Connectionless, Sequence 0)</td>
<td></td>
<td>0 1 1 P F 0 1 1 1</td>
</tr>
<tr>
<td></td>
<td><strong>AC1</strong> (Acknowledged Connectionless, Sequence 1)</td>
<td></td>
<td>1 1 1 P F 0 1 1 1</td>
</tr>
</tbody>
</table>
Carrier Sense Multiple Access (CSMA):

Listen Before Talking (LBT)

Station listens to the channel to determine if it is idle.

Non-persistent CSMA:

! If the channel is sensed idle, the station transmits.
! If the channel is sensed busy, reschedule.
! If rescheduled, repeat algorithm at new point.

1-persistent CSMA:

! If the channel is sensed idle, the station transmits.
! If the channel is sensed busy, wait until the channel is sensed idle and then transmit.
! If a collision occurs, reschedule.

p-persistent CSMA:

! If the channel is sensed idle, the station transmits with probability p and delays transmission for one time slot with probability (1-p) and repeats algorithm at new slot.
! If the channel is sensed busy, wait until the channel is sensed idle and then proceed as above.
! If a collision occurs, reschedule.
CSMA Persistence and Backoff

Non-Persistent:
- Transmit if idle;
- Otherwise, delay & try again

Constant or Variable Delay

- Transmit as soon as channel goes idle;
- If collision, backoff & try again

1-Persistent:

p-Persistent:
- Transmit as soon as channel goes idle with probability p;
- Otherwise, delay 1 slot and repeat.
- If collision, backoff & try again

Ready

CHANNEL BUSY
Local Area Network Topologies Using CSMA Methods

Bus Topology

Data Flow

A
B
C
D

Tree Topology

Headend

A
B
C
D
E
F
G

Star Topology

A
B
C
D
Carrier Sense Multiple Access with Collision Detection (CSMA/CD)

Listen While Talking (LWT)

1-persistent CSMA/CD:

! If the channel is sensed idle, the station transmits (with probability 1).

! If the channel is sensed busy, wait (persist) until the channel is sensed idle and then transmit.

! If a collision is detected during transmission:
    - Cease transmitting the frame.
    - Send out a jamming signal to inform other stations.
    - Reschedule the frame for later transmission.
IEEE 802.3 MAC Protocol

![ Uses 1-persistent CSMA/CD

![ Retransmission scheme: Truncated Binary Exponential Back-off

- After each collision, the mean retransmission delay is doubled.

- The doubling occurs only for the first ten attempts after which the mean retransmission delay is held fixed.

- After 16 unsuccessful attempts, the station gives up.
### IEEE 802.3 Frame Format

<table>
<thead>
<tr>
<th>Field</th>
<th>Octets</th>
</tr>
</thead>
<tbody>
<tr>
<td>PREAMBLE</td>
<td>7</td>
</tr>
<tr>
<td>START FRAME DELIMITER</td>
<td>1</td>
</tr>
<tr>
<td>DESTINATION ADDRESS</td>
<td>2 or 6</td>
</tr>
<tr>
<td>SOURCE ADDRESS</td>
<td>2 or 6</td>
</tr>
<tr>
<td>LENGTH</td>
<td>2</td>
</tr>
<tr>
<td>LLC DATA</td>
<td>&lt; 1500</td>
</tr>
<tr>
<td>PAD</td>
<td>To insure minimum frame size (64 Octets)</td>
</tr>
<tr>
<td>FRAME CHECK SEQUENCE</td>
<td>4</td>
</tr>
</tbody>
</table>

#### 16-bit ADDRESS FORMAT

<table>
<thead>
<tr>
<th>I/G</th>
<th>15-bit ADDRESS</th>
</tr>
</thead>
</table>

#### 48-bit ADDRESS FORMAT

<table>
<thead>
<tr>
<th>I/G</th>
<th>U/L</th>
<th>48-bit ADDRESS</th>
</tr>
</thead>
</table>

I/G - Individual/Group (0/1)  
U/L - Globally/Locally Administered Address (0/1)
IEEE 802.3 Frame Format

! Preamble:
- A 7-byte pattern used to establish bit synchronization.
- The pattern is an alternating sequence of 1s and 0s, with the last bit being a zero.
- The nature of the pattern is that for Manchester encoding, it appears as a periodic square wave.

! Start Frame Delimiter (SFD):
- The sequence 10101011.

! Destination Address:
- Specifies the destination station(s).
- Address may be unique, multicast, or broadcast.
- The choice of 16-bit or 48-bit addresses is an implementation decision and must be the same for all stations on the LAN.

! Source Address:
- Specifies the source station address.

! Length:
- Specifies the number of LLC bytes that follow

! LLC Data:
- The data unit supplied by the LLC.

! Pad:
- Bytes added to insure minimum frame size for CD operation.

! Frame Check Sequence:
- 32-bit CRC (does not cover Preamble and SFD).
<table>
<thead>
<tr>
<th>Parameter</th>
<th>10base5</th>
<th>10base2</th>
<th>1base5</th>
<th>10base-T</th>
<th>10broad36</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transmission Medium</strong></td>
<td>Coaxial Cable (50 ohm)</td>
<td>Coaxial Cable (50 ohm)</td>
<td>Unshielded Twisted Pair</td>
<td>Unshielded Twisted Pair</td>
<td>Coaxial Cable (75 ohm)</td>
</tr>
<tr>
<td><strong>Signaling Technique</strong></td>
<td>Baseband Manchester</td>
<td>Baseband Manchester</td>
<td>Baseband Manchester</td>
<td>Baseband Manchester</td>
<td>Broadband DPSK</td>
</tr>
<tr>
<td><strong>Data Rate (Mbps)</strong></td>
<td>10</td>
<td>10</td>
<td>1</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td><strong>Maximum Segment Length (m)</strong></td>
<td>500</td>
<td>185</td>
<td>250</td>
<td>100</td>
<td>1800</td>
</tr>
<tr>
<td><strong>Network Span (m)</strong></td>
<td>2500</td>
<td>925</td>
<td>2500</td>
<td>1000</td>
<td>3600</td>
</tr>
<tr>
<td><strong>Slot Time (bit times)</strong></td>
<td>512</td>
<td>512</td>
<td>512</td>
<td>512</td>
<td>512</td>
</tr>
<tr>
<td><strong>Interframe Gap (μs)</strong></td>
<td>9.6</td>
<td>9.6</td>
<td>96</td>
<td>9.6</td>
<td>9.6</td>
</tr>
<tr>
<td><strong>Attempt Limit</strong></td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td><strong>Backoff Limit</strong></td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td><strong>Jam Size</strong></td>
<td>32</td>
<td>32</td>
<td>32</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td><strong>Max Frame Size (octets)</strong></td>
<td>1518</td>
<td>1518</td>
<td>1518</td>
<td>1518</td>
<td>1518</td>
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<tr>
<td><strong>Min Frame Size (octets)</strong></td>
<td>64</td>
<td>64</td>
<td>64</td>
<td>64</td>
<td>64</td>
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</table>
Multisegment Baseband Bus Configuration

Sample IEEE Specifications - 10Mbps Baseband Coax Bus

<table>
<thead>
<tr>
<th>Parameter</th>
<th>10base5</th>
<th>10base2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Rate</td>
<td>10Mbps</td>
<td>10Mbps</td>
</tr>
<tr>
<td>Max. Segment Len.</td>
<td>500m</td>
<td>185m</td>
</tr>
<tr>
<td>Network Span</td>
<td>2500m</td>
<td>925m</td>
</tr>
<tr>
<td>Nodes per Segment</td>
<td>100</td>
<td>30</td>
</tr>
<tr>
<td>Node Spacing</td>
<td>2.5m</td>
<td>0.5m</td>
</tr>
<tr>
<td>Cable Diameter</td>
<td>0.4in</td>
<td>0.25in</td>
</tr>
</tbody>
</table>
10baseT Configuration

Multiport Repeater Operation:

A valid signal appearing on any input is repeated on all other links.

If two inputs occur, causing a collision, a collision enforcement signal is transmitted on all links.

If a collision enforcement signal is detected on any input, it is repeated on all other links.
10baseT Multiple Repeater Configuration
Mixed 10baseT and 10base5 Configuration
Fast Ethernet

100Base-T (part of IEEE 802.3):
- CSMA/CD at 100Mbps.
- Supported by the Fast Ethernet Alliance (Intel, Grand Junction Networks, et. al.)
- Supports multiple physical layer implementations:
  ! 100Base-T4:
    4-pair UTP
  ! 100Base-TX:
    2-pair STP or category 5 UTP
  ! 100Base-FX:
    2 optical fibers

100VG (100VG-AnyLAN) (IEEE 802.12):
- Uses demand priority technology.
- Stations 'demand' access from the switching hub at one of two 'priority' levels.
- The switching hub grants access to the stations with priority packets given precedence.
- Eliminates network collisions.
- Minimizes delay for time-sensitive applications.
- Supports both Ethernet and Token-Ring frame types.
- Supported by HP, IBM, et. al.
IEEE 802.3 100Base-T Options

IEEE 802.3 CSMA/CD

100BASE-X

100BASE-TX 100BASE-FX 100BASE-T4

Two Category 5 UTP Two STP Two Optical Fiber Four Category 3 or Category 5 UTP

IEEE 802.3 100BASE-T Options

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<table>
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<tr>
<th>IEEE 802.3 100BASE-T Physical Layer Medium Alternatives</th>
</tr>
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<tr>
<td>100BASE-TX</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Transmission medium</td>
</tr>
<tr>
<td>Signaling technique</td>
</tr>
<tr>
<td>Data rate</td>
</tr>
<tr>
<td>Maximum segment length</td>
</tr>
<tr>
<td>Network span</td>
</tr>
</tbody>
</table>

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100Base-T Use of Wire Pairs

(a) 100BASE-X Configuration

(b) 100BASE-T4 Configuration

100BASE-T Use of Wire Pairs
### 4B/5B Code Groups

<table>
<thead>
<tr>
<th>Data Input (4 bits)</th>
<th>Code Group (5 bits)</th>
<th>NRZI Pattern</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>11110</td>
<td></td>
<td>Data 0</td>
</tr>
<tr>
<td>0001</td>
<td>01001</td>
<td></td>
<td>Data 1</td>
</tr>
<tr>
<td>0010</td>
<td>10100</td>
<td></td>
<td>Data 2</td>
</tr>
<tr>
<td>0011</td>
<td>10101</td>
<td></td>
<td>Data 3</td>
</tr>
<tr>
<td>0100</td>
<td>01010</td>
<td></td>
<td>Data 4</td>
</tr>
<tr>
<td>0101</td>
<td>01011</td>
<td></td>
<td>Data 5</td>
</tr>
<tr>
<td>0110</td>
<td>01110</td>
<td></td>
<td>Data 6</td>
</tr>
<tr>
<td>0111</td>
<td>01111</td>
<td></td>
<td>Data 7</td>
</tr>
<tr>
<td>1000</td>
<td>10010</td>
<td></td>
<td>Data 8</td>
</tr>
<tr>
<td>1001</td>
<td>10011</td>
<td></td>
<td>Data 9</td>
</tr>
<tr>
<td>1010</td>
<td>10110</td>
<td></td>
<td>Data A</td>
</tr>
<tr>
<td>1011</td>
<td>10111</td>
<td></td>
<td>Data B</td>
</tr>
<tr>
<td>1100</td>
<td>11010</td>
<td></td>
<td>Data C</td>
</tr>
</tbody>
</table>
100Base-X Signal Encoding: 4B/5B - NRZI cont.

<table>
<thead>
<tr>
<th>Data Input (4 bits)</th>
<th>Code Group (5 bits)</th>
<th>NRZI Pattern</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1101</td>
<td>11011</td>
<td></td>
<td>Data D</td>
</tr>
<tr>
<td>1110</td>
<td>11100</td>
<td></td>
<td>Data E</td>
</tr>
<tr>
<td>1111</td>
<td>11101</td>
<td></td>
<td>Data F</td>
</tr>
<tr>
<td>11111</td>
<td></td>
<td></td>
<td>Idle</td>
</tr>
<tr>
<td>11000</td>
<td></td>
<td></td>
<td>Start of stream delimiter, part 1</td>
</tr>
<tr>
<td>10001</td>
<td></td>
<td></td>
<td>Start of stream delimiter, part 2</td>
</tr>
<tr>
<td>01101</td>
<td></td>
<td></td>
<td>End of stream delimiter, part 1</td>
</tr>
<tr>
<td>00111</td>
<td></td>
<td></td>
<td>End of stream delimiter, part 2</td>
</tr>
<tr>
<td>00100</td>
<td></td>
<td></td>
<td>Transmit error</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td>Invalid codes</td>
</tr>
</tbody>
</table>

100Base-X refers to a set of options that use the physical medium specifications originally defined for FDDI.
100Base-TX Signal Encoding

In order to concentrate most of the energy of the transmitted signal below 30MHz, 100Base-TX follows the 4B/5B conversion with a scrambler and an MLT-3 encoder which produces a pseudoternary signal.
Gigabit Ethernet

Retains the CSMA/CD access protocol and Ethernet frame format of its predecessors.

For Shared Medium Hubs;
- Carrier Extension:
  Appends a set of special symbols to the end of short MAC frames so that the resultant block is at least 4096 bit-times.
- Frame Bursting:
  Allows for multiple short frames to be transmitted consecutively, up to a limit, without relinquishing control of the medium between frames. (Avoids the overhead of carrier extension.)

Physical Layer Alternatives:
- 1000Base-SX:
  Short wavelength option. Supports links up to 275m-550m depending on the type of fiber.
- 1000Base-LX:
  Long wavelength option. Supports links up to 550m-5km depending on the type of fiber.
- 1000Base-CX:
  Uses special shielded-pair copper cable that spans no more than 25m.
- 1000Base-T:
  Uses 4 pairs of category 5 unshielded twisted pair wire over a range up to 100m.

The signal encoding scheme is 8B/10B.
100VG (100VG-AnyLAN) (IEEE 802.12):

! Single Level Network Topology

IEEE 802.12 Single Level Network

! Multilevel Network Topology

IEEE 802.12 Multilevel Network
IEEE 802.4 Token Bus Protocol

The stations on the bus form a LOGICAL RING.

Each station knows the identity of the stations preceding and following it.

A control frame known as a TOKEN regulates right of access.

The station in control of the token may:
- transmit data frames
- poll stations and receive responses

When finished the station passes the token to the next station in logical sequence.

Non-token using stations are allowed onto the bus in response to polls or selections.

Station Functions:
- Ring Initialization
- Addition to the Ring
- Deletion from Ring
- Recovery
- Priority
Token Ring

! A station wishing to transmit waits until it detects a FREE TOKEN passing by.

! The station marks the token as BUSY and transmits its frame.

! A new free token is inserted when:
   - It has completed transmitting its frame.
   - The busy token has returned to the station.

! Under light loads there is some inefficiency.

! Under heavy loads, the ring functions in a round-robin fashion.

! Provides a regulated access.

! Must provide for token maintenance.
(a) Sender looks for free token and send data

(b) Receiver copies data addressed to it.

(c) Sender generates new free token
IEEE 802.5 Token Ring Protocol

Characteristics:

! Single Token Protocol:

! Priority Bits:

! Monitor Bit:

! Reservation Indicators:
   - Reserve priority level of next token.

! Token-Holding Timing:
   - Controls the length of time a station may occupy
     the medium before transmitting a token.

! Acknowledgement Bits:
   - Error Detected (E) : set by any station
   - Address Recognized (A) : set by addressed station
   - Frame Copied (C) : set by addressed station
The MAC protocol is a token ring similar (not including priority and maintenance mechanisms) to IEEE 802.5.

A station wishing to transmit waits for a free token.

The station captures the token (by absorbing it) and begins transmitting one or more frames.

The frame(s) make a round trip and are purged by the transmitting station.

A station releases a new token as soon as it completes its frame transmission.