LAN Technologies

Computer Center, University of Ulm

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Chapter 1

Introduction

Let me start this course with a question.

Why do we need networks?

The most commonly given answer is that we need them to transmit any kind of information like computer data, TV signals or new high-scores of popular games. Other answers will cover the more local aspect of sharing resources like printers, disks and other peripherals.

Since we are living in a world where information becomes obsolete after a short period of time we depend on fast and reliable networks that are able to support the information flux we need for our society.

This course will cover the main aspects of local area networks (LAN), the required physical background as well as and approach on how to start a structured network.

So, what do we need to make several computers form a network?

Networks need:

- ***a medium with an interface to it***
- ***a protocol defined for each medium***
- ***an interface protocol to make software independent of the medium***

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- We need a medium and an interface to it. Transparency of this interface is required because software has no need to know about the physical characteristics of the underlying medium.

- A protocol for each medium has to be defined which ensures that a reliable and effective method of transmission is chosen.
- An interface protocol between the physical- and the software-layer has to make sure that nodes in the network are addressable and that the network is shared fairly.

These 3 items and others like cost, easy-to-use and stability were the base on which the first Ethernet implementation was created in the late 70s. After an experimental stage it was made a standard together with the 3 companies DEC, Intel and Xerox and further on called DIX Ethernet.

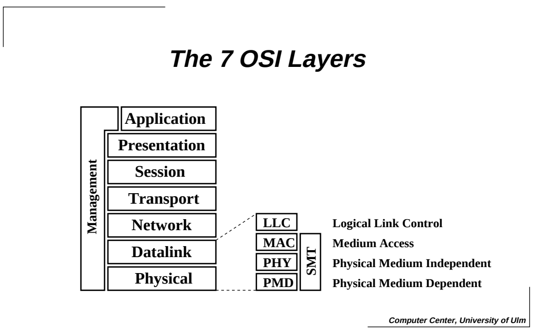
Before we start to discuss some LAN technologies that are used today we have to learn about network layers and about the physical problems that come with the use of wires or fibre.

Chapter 2

The OSI model layer 1 and 2

We already agreed that dividing responsibilities in several well defined layers would be a great advantage for portability of a network.

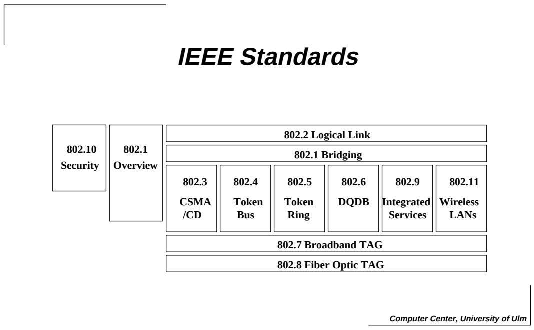
The OSI (Open System Interconnection) model divides responsibilities into 7 layers. This course will cover the 2 layers at the bottom of the protocol stack.



In addition, the 3rd layer will be touched when we talk about segmentation devices (routers).

Standards for the sub-layers are defined by the IEEE (Institute of Electrical and

Electronics Engineers)



2.1 Data-link layer

2.1.1 LLC, logical link control

The first of the four sub-layers, the logical link control, which is also a part of the data-link layer, is responsible for (de)multiplexing packets from the numerous network layers. For most LAN structures the LLC is covered by an own standard IEEE 802.2. Only Ethernet II covers all of the four sub-layers because it does not divide the data-link layer into LLC and MAC.

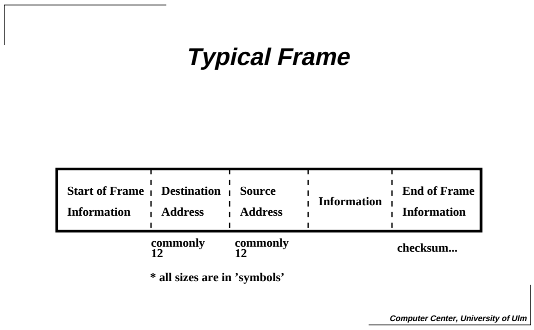
A brief description of the used headers will be given later in the course. SMT will be covered by the FDDI chapter.

2.1.2 MAC, media access control

The media access control sub-layer specifies how the stations share the common medium and divides the bandwidth in a fair way. It also specifies frame formats and, if necessary for some implementations, does some initialization on the network.

What is a frame and how does it look like?

A frame is something like an envelope for your data. It adds your address, the one of the receiver and some additional control information that depends on the used network.



It consists of several parts,

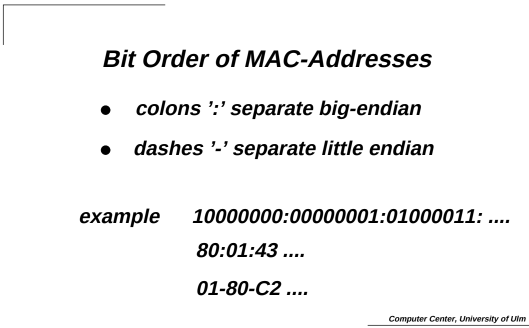
- an optional start information with additional control fields
- two MAC address entries
- information that is passed to higher layers
- and an optional delimiter which normally holds a checksum

This sub-layer also determines the address formats and the bit-order of the network. Please note that this bit-order is independent of the byte-order of upper-layer protocols or of the CPU.

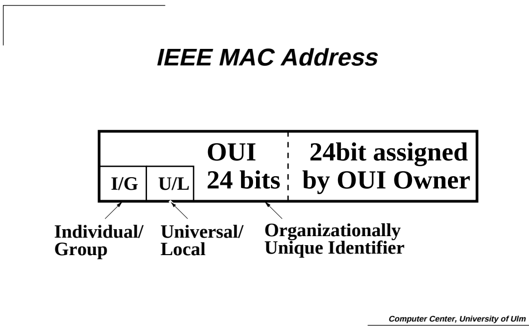
The Address representation is the same for all IEEE 802 LANs (FDDI, Ethernet II, 802.3 Ethernet...). The IEEE committee wanted a system connected to two LANs to have the same address on both of them and therefore decided to make the address a bit-string which means that the signal appearance for an address on the wire is the same for msb (most significant bit) and lsb (least significant bit) LANs. This is very important when a station is connected to LANs which use different bit-orders. To make confusion more complete, the IEEE decided for the following hint to make addresses more readable for humans:

- **colons ':'** are used to separate successive bytes in big-endian bit-order notation while
- **dashes '-'** are used for little-endian bit-order systems.

Here's an example:



The MAC address of a stations is comparable to your phone number which is required to be unique all over the world. To ensure that MAC addresses are also unique, the IEEE divided the 48 bit address field into 2 pieces of 24 bits.



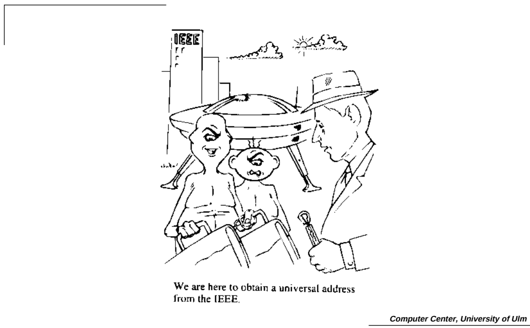
The first 2 bits of the OUI field are reserved for group addressing and for locally administered addresses. So there is space for 4.2 million organizations with 16.8 million addresses each.

What are group-addresses (first bit=1) good for? There are two ways to use them:

- they are used to send broadcast-messages which are evaluated by all stations (consists of all '1')
- they are also used for multicast-messages which are send to a special group of stations without forcing others to grab the frame and analyze it's contents. They therefore can significantly reduce interrupts of stations which are not involved in group transmissions.

The second reserved bit identifies a universal unique address when set to 0 or an address set by the local administrator if set to 1. This gives network administrators the possibility to encode the physical location or similar information into the address. But we also have to be careful about interference with already assigned addresses on the LAN.

By the way, some people are talking about changing the name of the second field from 'universal' to 'global'.



I don't know about a place where administrators use local addresses.

Evaluating the OUI code of a MAC address gives you also a chance to find out what type of machine, or at least from which vendor it comes from, misbehaves on the LAN even if no higher-level data is available.

2.2 Physical layer

The physical layer is also subdivided into two parts.

2.2.1 PHY, physical medium independent layer

The medium independent layer deals with all the physical things that do not depend on the medium that is used. It specified algorithms to detect errors in received bits, encodes/decodes bits into pulses and synchronizes the transceiver-/receiver clock between the stations.

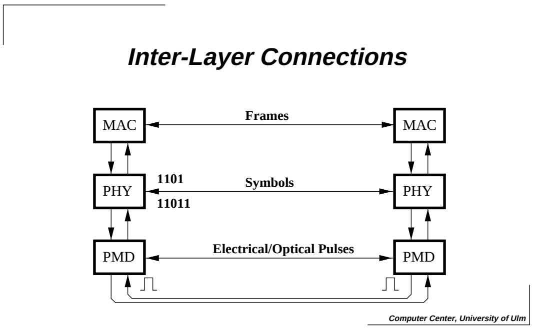
We will come back to the several encoding possibilities after discussing some media types and there special requirements.

2.2.2 PMD, physical medium dependent layer

This one handles the optical or electrical components such as fibres, transmitters or coax cable. Each medium is covered by a separate PMD standard. If an alternative is used, only this sub-layer has to be changed.

2.3 Summary

Here's an overview about the several sub-layers that handle different types of signals or pulses.



- A network is divided into seven layers with well defined responsibilities and interfaces.
- The physical layer is responsible for error detection on bit level, for decoding/encoding of pulses/bits and for synchronization. To make best use of the layer model it is subdivided into a medium independent and a medium dependent part which deals with the medium requirements themselves.
- The data-link layer defines frame and address formats as well as algorithms to fairly share the possible bandwidth. The MAC sub-layer provides this mechanisms whereas the LLC sub-layer (de)multiplexes packets from the network layer and provides flow-control if required. Group and Individual addresses are provided by the MAC layer.

Layer Responsibilities

- ***the physical layer is responsible for error detection, synchronization and coding***
- ***the data-link layer defines frame formats, access protocols and addresses***

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Discussing some media types will be next on the schedule.

Chapter 3

Physically problems, media types

3.1 Basic physical effects

The basic problems of signal transmission are caused by

Physical Effects

- ***attenuation***
- ***dispersion***
- ***EMI (electro-magnetic interference)***
- ***power limitations***
- ***rise and fall times***

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Not all of them apply to all types of media.

3.1.1 Attenuation

All electrical or optical signals normally loose energy when they travel through wires or fibres. This effect caused by absorption and scattering of energy by the surrounding material is called attenuation. It depends on several factors like material related constants, the geometry (diameter, length...), the frequency and others.

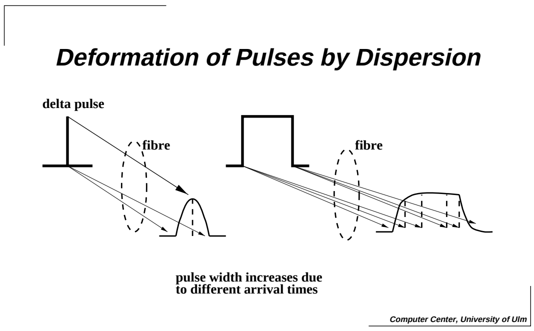
The reduction in power is geometric. For example after traveling 1km in a fibre the power of a 8mW may reduce to half (4mW). After another 1km it becomes one-fourth (2mW) and so on. It is therefore easier to do calculations on a log scale so that multiplications can be achieved by adding of log quantities. Communication engineers use a log scale to measure power and its attenuation:

$$Attenuation[dB] = 10 \times \log \frac{P_{in}}{P_{out}} \tag{3.1}$$

For given parameters, the attenuation is determined by the Maxwell Equations and material properties.

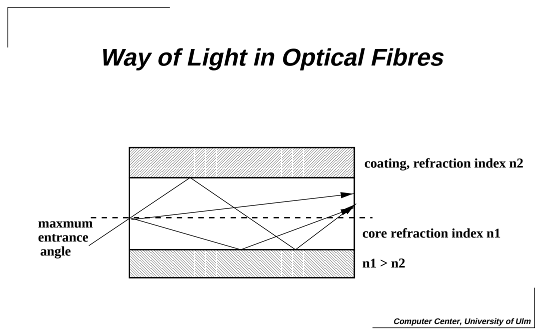
3.1.2 Dispersion

I already mentioned that the attenuation depends on the frequency of the signal that travels through the medium. The speed also depends on the frequency, on the material, the geometry and sometimes even on the direction inside the medium. Now think of a signal which very often



will be a series of pulses. Each of these pulses can be split into several sine-waves with different frequencies (Fourier Transformation). With the knowledge of the speed depending on the frequency it's easy to tell that a pulse will change it's shape while traveling through the medium. This effect limits the distance between transceiver and receiver because pulse edges get lost. This effect, the dependency of speed and frequency is called chromatic dispersion.

Another form of dispersion is generated by the different ways the light can take through a fibre if the fibre is thick enough. Some rays go straight through whereas others get reflected several times which means that they have to travel further which then means they will be late.



3.1.3 EMI

The electro-magnetic interference is caused by signals that are transmitted in cables. The wire acts like an broadcasting antenna and 'pollutes' the environment. In most countries including Germany, Japan and the United States, this pollution is limited by government regulations. The effect also works vice-versa which means that other signals, for example the ones from another network, are able to disturb transmission on cables. Big electric machines can also cause interference with networks if they are not very well shielded.

Some side-effects of EMI are security holes. The electric signals traveling through a wire produce electro-magnetic waves in the surrounding air making it is possible to listen to the signals without touching the wire.

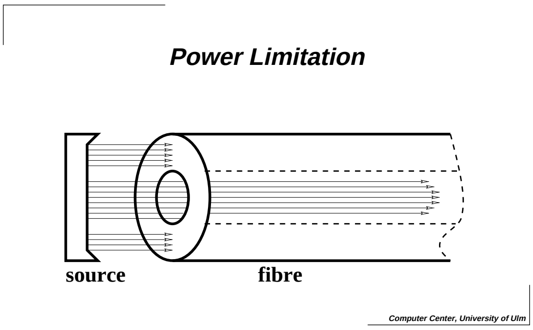
Another one is called crosstalk. Signals on two wires inside the same cable can interfere with each other. Crosstalk is always an serious issue when talking about twisted pair cabling.

The worst side-effect of EMI is lightning. A flash can cause a high-voltage pulse on cables which commonly burns out equipment attached to it.

The EMI effects on fibre based networks are nothing to worry about.

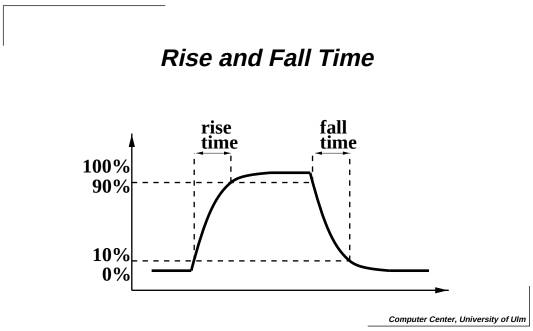
3.1.4 Power limitations

Every piece of equipment has properties that limit the power that can be transfered through it. One is a material constant which is the upper limit before it gets damaged. Another one in a geometrical limit that reduces the power a device can absorb and transfer (eg diameter of fibres).



3.1.5 Rise and fall times

All transmitting devices have two significant time constants. The rise time and the fall time of a signal. They are defined to be the time from 10% to 90% of the signals amplitude and vice versa. These times limit the number of pulses per second. Receivers have a similar time constant called dead time which is equal to the lowest pulse-time-difference they can separate.



3.2 Fibre optics

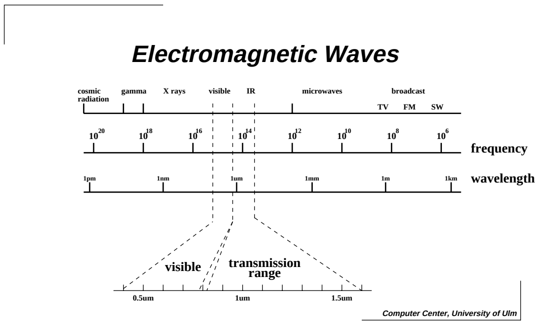
This section of the course will give you an introduction to fibre optics. The goal is to know why a certain type of fibre is selected to solve a certain problem.

As we already know from the former section, the performance of a fibre itself is determined by attenuation, dispersion and power which it is capable of transferring.

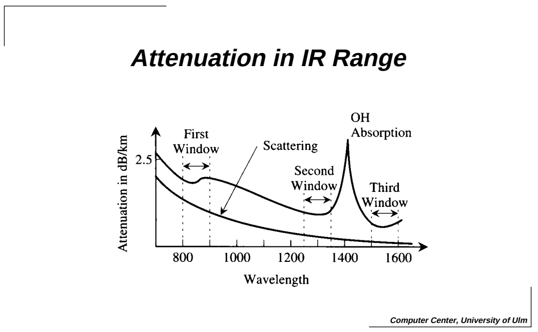
Other parts of the equipment are the receivers and the transceivers which are responsible for decoding and encoding of optical pulses into electrical. Connectors are also to be mentioned.

3.2.1 Propagation of light

We know that light consists of electro-magnetic waves. The same laws apply to all types of electro-magnetic waves independent of the frequency. Here is an overview of the spectrum of electro-magnetic waves:



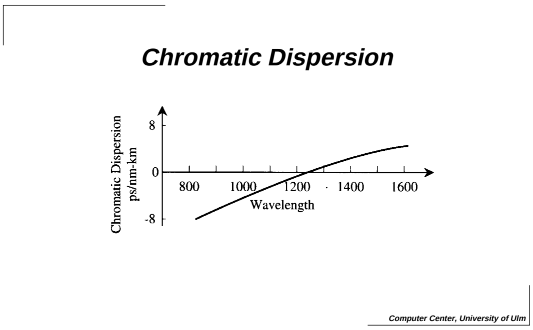
As you can see only a very small piece of the tremendous range is used by humans to transmit signals. The next picture shows you a blow-up of the interesting parts of the infrared spectrum from 600nm (orange) to 1800nm (IR).



There are 3 windows where attenuation has a local minimum. The 850nm, the 1300nm and the 1500nm window. Since scattering is a function of fourth power of the frequency its part drops very fast to the right (log scale). The absorption has a significant peak right of the 1300nm window which is caused by impurities in the form of OH (oxygen-hydrogen) ions.

The 850nm window was and still is used for Ethernet and 802.5/token ring networks whereas FDDI selected the 1300nm window. The reasons were simple. FDDI has been designed to be a backbone on a much larger scale than Ethernet and therefore had main advantages in selecting a window with a lower attenuation. 1500nm transmitters and receivers had not be available in quantitiy when

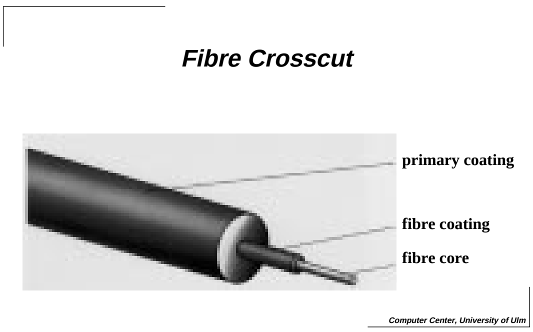
FDDI was specified and the prices were even higher. Another advantage of the 1300nm window comes with the next picture.



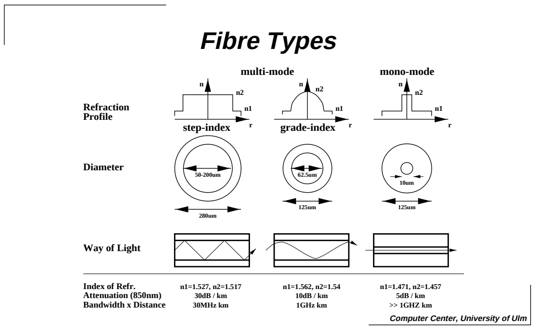
The chromatic dispersion is almost zero inside the 1300nm window which improves signal quality over long distances.

3.2.2 Fibre types

Three main fibre types are used today. All of them use the general building plan of fibres, a core with a slightly higher index of refraction than the surrounding cladding, both covered by a protective jacket.



The three types differ only in the diameter of core and cladding, or in the profile of the index of refraction.



Depending on the diameter of the core (actually the number of modes) and the profile they are called

Multi-mode step-index fibres

These are the ones easiest to produce. The core diameter range is typically from $50\mu m$ to $200\mu m$ with a cladding diameter of $280\mu m$. The thick core allows a large power to be easily launched into the fibre by using cheap LEDs (light emitting diodes). The main disadvantage is a very high modal dispersion which results in a low bandwidth-distance product of about 20MHz-km.

Multi-mode grade-index fibres

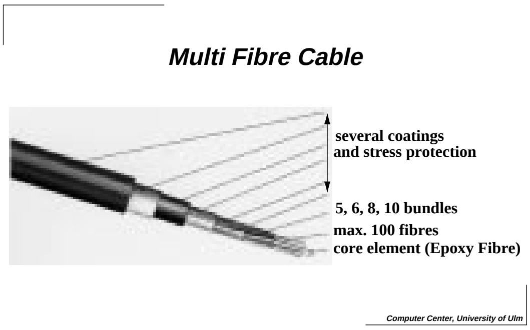
The grade-index multi-mode fibres are more complicated to produce but offer the best solution for midrange connections. The large core ($62.5\mu m$) allows also the use of cheap LEDs without the disadvantage of the very high modal dispersion. The bandwidth-distance is about 1GHz-km. This is the type of fibre that is used for FDDI campus backbones. One standard fibre is a 62.5-125-250 which means a $62.5\mu m$ core, a $125\mu m$ cladding and a $250\mu m$ jacket. There are also some low cost fibres of this type available which are used for links up to 500m. The cost reduction itself comes from cheaper transmitters and receivers.

Mono-mode fibres

When the core diameter is reduced, the number of possible solutions of the Maxwell Equations are reduced too. At a certain point only one solution (mode) exists.

These mono-mode fibres are used for long distance connections because they don't have modal dispersion. The bandwidth-distance can be as high as 1THz-km. The main problem is power coupling because of the thin $10\mu m$ core diameter. If this fibre is used for small distance connections, care must be taken that the receivers can handle the high power output that can be generated by the LASER-LED transmitters together with the low attenuation at small distances.

The next picture shows a commercial type of cable that hosts several fibres.



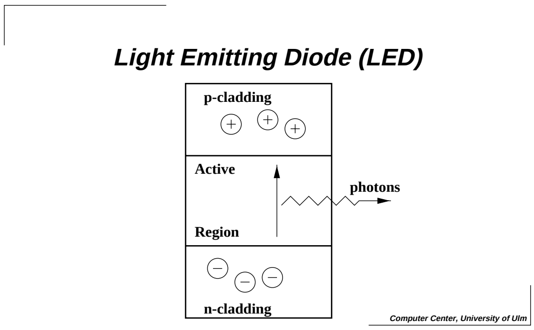
3.3 Light sources

There are several requirements which an ideal light-source for signal transmission must match:

- optical power
- spatial power distribution
- spectral width
- rise and fall times

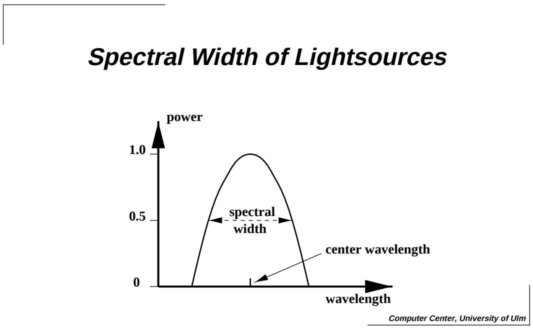
There are two different types of transceivers available which match the requirements, LED (light emitting diodes) and LASER diodes.

Both of them use the same physical principle. They consist of three layers of semiconductors called p-cladding, active region and n-cladding.



When a current is implied, electrons from the n-cladding and holes from the p-cladding recombine in the active region. The energy is emitted as photons (light). The emitted power increases when the current is increased. At first the light increases slowly while the diode is in the spontaneous emission regime but after a certain threshold the light output increases dramatically. The re-combination of one electron-hole pair triggers more of them. The diode now works in the stimulated emission regime. LASER diodes use this regime but have also some differences in the cladding.

Spectral width is defined to be the difference in the wavelengths at which the power is half (3dB below) the peak power.



The following table shows the main differences between the two types of transceivers:

LED-Laser Diode Comparison

	LED	Laser diode
power output	uW range	mW range
distance	some km	tens of km
spectral width [nm]	50..200	2..5
rise time [ns]	3..20	0.5 .. 2
fall time [ns]	3..20	0.5 .. 2
coupling efficiency	lower	higher
failure rate	lower	higher
safety	safe	unsafe
fibre type	multi-mode	mono-mode
cost	low	high

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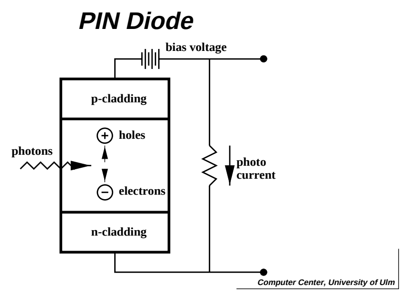
Therefore it's clear that LASER diodes are mainly used together with mono-mode fibre to transmit signals over long distances whereas the lower cost alternative LED plus multi-mode grade-index fibres are used for campus backbones and other inter-station distances in the km range.

Using LASER diodes for small distances would cause damage to the receivers if no additional attenuators are installed.

3.4 Light detectors

There are also two types of detectors that match the basic requirements of high speed signal transmission, PINs and APDs. The following picture shows the principle on which both of them operate.



A PIN photo-diode consists of a sandwich of p-doped semiconductor and a n-doped one separated by a very lightly n-doped intrinsic. This also gave the diodes their names: PIN. In normal operation, a bias voltage fully depletes the intrinsic region from charge carriers. Therefore the current flowing through the device is close to zero. When light falls onto the I-region, the incident photons excite electrons in the semiconductor material. The energy is absorbed and the electrons move from the valence to the conduction band. This process generates electron-hole pairs which themselves result in an electrical pulse, the photo current.
The goodness of photo-diodes is measured in $\frac{\mu A}{\mu W}$.

Avalanche photo-diodes (APDs) work similar to PIN diodes except that the electron-hole pairs travel through a very strong electrical field where they gain enough energy to generate more and more pairs by collision. This is known as the avalanche-effect. For this reason, APDs have a very good responsitivity but they also need time to recover from the last pulse. Also some safety problems occur because the operation voltage might be as high as 100V. One more problem is caused by the material. Most of the APDs are made of silicon which works well for the 850nm window. For the 1300nm and 1500nm windows germanium or other materials are needed which have limited ionization rates and hence limited avalanche gain.

The next table summarizes the differences between PINs and APDs:

PIN-APD Comparison

	PIN	APD
bias voltage [V]	10	100
responsitivity [uA/uW]	0.5 .. 0.7	30..80
temperature drift	less	more
availability	good	mostly 850nm
cost	less	more

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3.5 Summary

As you saw, fibre optics offer a great variety of solutions for almost every signal transmission problem. Nevertheless we have to keep in mind that optical solutions are the ones used for longer distances because of their costs and their benefits in this range.

So the summary is:

Summary

- ***mono-mode fibres, Laser diodes and high quality PINs are used for long distances***
- ***LEDs plus multi-mode fibres cover distances up to a few km***
- ***twisted-pair cover the 100m range***

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- mono-mode fibres together with LASER diodes and high quality PINs are used for distances up to some 10km
- the cheaper LEDs are used to cover the distances up to a few km together with multi-mode grade-index fibres and PINs.
- copper wires (twisted pair) cover the distance range up to some 100m
- small distance fibre links are expensive compared to copper-links but offer a much greater bandwidth and are therefore installed in very high-speed networks (computer cluster connections).

Another thing to mention is, that the receivers and transceivers do much more than converting electrical signals into pulses. They also deal with clocking, synchronization, jitter and delay handling of the several different encoding procedures.

Chapter 4

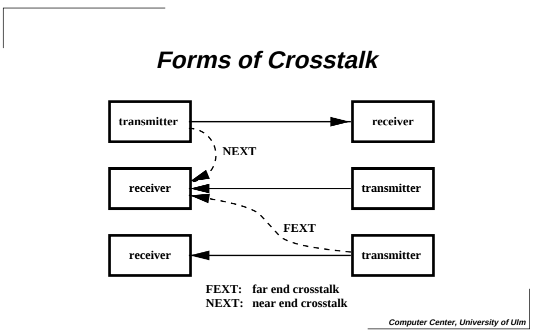
Cable categories and types

Most physical laws discussed so far also apply to transmission of signals through metal waveguides as coax-cables or twisted-pair cables. I will skip discussion about propagation of electro-magnetic fields in wires and reduce it to an explanation of cable types, cable categories and their usage.

The are two basic types of cables used for networks are coax and twisted-pair cables. Both of them share, at least when talking about high quality products, the same limitations, attenuation, crosstalk, capacitance and NEXT (near end crosstalk). The first two have already been explained when fibre optics were discussed.

Capacitance is caused by the geometric profile itself and results in the storage of electrical charges limiting the upper frequency and the data rate. This is because an electrical pulse starts a charging/discharging process whose time depends on the capacitance.

NEXT s an abbreviation for near end crosstalk and means that the disturbing signal is generated by a transceiver next to the receiver. The picture gives us some details.



The next two sections will emphasis the major differences of the two cables.

4.1 Twisted-pair

The simplest twisted-pair cable consists of two identical insulated wires that are stranded to reduce inductive coupling and crosstalk between pairs. The twist will cancel out opposing electro-magnetic fields. The greater the twist ratio the tighter the coupling. Todays twisted-pair cables are multi-pair cables that hold several pairs of individually insulated wires in a common protective sheath.

On the contrary, a higher number of twists causes a higher attenuation at high frequencies and crosstalk becomes worse. A way to protect from interference is to put a metallic shield around a pair.

Thus there are two basic types of twisted-pair cables: unshielded and shielded ones. Today this difference doesn't really exist any more. All high quality twisted-pair cables use individually shielded pairs of wires and are sometimes called S-UTP, shielded-unshielded twisted-pair. But another main difference remains the same:

- UTP (S-UTP) cables have an electrical impedance of 100 Ohm
- STP cables have an electrical impedance of 150 Ohm

Since all parts of a network link must have the same impedance it is not allowed to connect UTP and STP cables. If the impedance doesn't match reflections will occur that make transmission almost impossible.

4.2 Coax-cable

A coax-cable consists of a single wire conductor centered inside a cylindrical outer conductor. Both are insulated from another and covered by a protective jacket. This type of cables have very low loss at high frequencies and provide excellent isolation from external noise and from crosstalk. They also have a high bandwidth and carry a large number of TV channels, data transmissions or voice channels.

These cables can either be used in baseband or in broadband. In the first case, the signal is directly transmitted into the cable. In the later case it is first modulated onto a carrier and then transmitted using a radio-frequency modem (modulator-demodulator). In broadband mode multiple carriers can be used. Since the data rates are much higher in broadband mode, the cables need to have additional shielding to ensure signal integrity.

Ethernet and other LAN technologies use the baseband only.

The main problem with coax-cables in LANs today is that all new higher speed technologies (100Mbps and more) only support twisted-pair and no coax as a standard. I therefore recommend the use of high quality twisted-pair cables in LANs wherever possible.

4.3 Categories and types

4.3.1 Categories of UTP cables

The performance of UTP cables varies over a large scale from voice grade to high-speed networking grade. The following table shows the 5 categories of UTP cables.

Cable Categories

Category	Application	Impedanz	Attenuation
1	analogous signals (voice)		
2	low speed data ISDN	84-113 1MHz	13.1 - 26.3 -1MHz
3	LAN 10Mbps	85-115 16MHz	22.3 - 131.2 -16MHz
4	LAN 16Mbps	85-115 20MHz	18.7 - 101.7 -20MHz
5	LAN 100MBps	85-115 100MHz	18.1 - 219.8 -100 MHz

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The main difference between them is the bandwidth and the attenuation over the frequency. Today only category 5 should be used for new installations because it supports data rates up to 100Mbps. Some standards try to use 4 pairs of category 3 wires to make use of already installed cables but future standards will probably require the more sophisticated category 5.

4.3.2 IBM cable types

IBM uses a different classification for their cables. They call them 'type 1' to 'type 9' which has nothing to do with the mentioned categories. For example, type 1 is a twisted-pair data cable with two pairs of solid wires. Type 3 is used for phones, type 5 are fibre optic cables and so on.

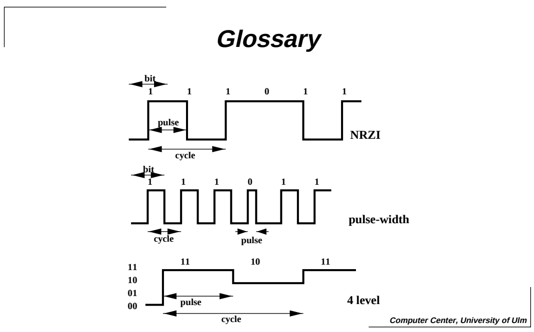
Chapter 5

Coding schemes

5.1 A glossary

Before we go any further, it is necessary to define some commonly and often wrong interpreted names. The following picture shows some pulse sequences which I will use to explain the following words:

Bit, Baud, Hertz and Efficiency



Let me use the FDDI specification as an example. The speed of the optical signal in the fibre is 125 megabits per second (125Mbps), 125 megabaud or 62.5 megahertz. Here comes the answer to your question what the difference might be.

A bit is simply a binary digit, the basic binary information, either a one or a zero. The next section will show us that some encoding schemes are capable of coding more that one bit into a single pulse. The response time for the devices and the upper frequency limit depend on the shortest possible pulse propagated by an encoding scheme. The inversion of this pulse duration is called a **BAUD**.

HERTZ is the unit of frequency in cycles per second. If we pick a cycle from the scheme we also got the frequency.

The ratio between bit rate, which is the clock that is used, and baud rate is called **EFFICIENCY**.

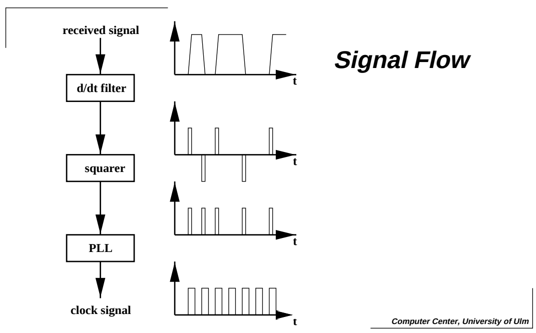
Example:
The topmost picture shows the encoding scheme on a FDDI fibre. It has 125Mbps, one pulse has a duration of 8ns which leads us to 125Mbaud. The shortest cycle (2 bits) covers 16ns which means that the upper frequency limit is 62.5MHz. The efficiency is 100%.

5.2 Data coding

Coding has to fulfill several duties. First of all it has to make sure that enough transitions occur.

Why that?

It's because the clock of the network is reproduced from the signal and not from a separate line. The PLL (phase lock loop) that is responsible in the receiver device needs an appropriate number of signal transitions to work properly and synchronize the logic to the incoming signal.



A second main duty is to reduce EMI by lowering the highest used frequencies. Another one is to keep the signal DC-balanced which means that the DC (direct current) part of the signal is below a certain level. An increased level causes bandwidth reduction and baseline drift because of the capacitors inside the receiver and transceiver devices.

Coding information into electrical or optical pulses means to define a translation table for them. Two translations are done by the physical layer of the OSI model. The first one, done by the PHY (medium independent), transforms groups of information bits into symbols. This is for example done by the FDDI PHY but not by the Ethernet PHYs.

5.2.1 Symbols

Adding one or more bits to the information does of course reduce the maximum throughput but also ensures that an appropriate number of transitions occur for any valid data.

4b/5b Encoding

data

code bits	symbol	original
11110	0	0000
01001	1	0001
10100	2	0010
10101	3	0011
01010	4	0100
01011	5	0101
01110	6	0110
01111	7	0111
10010	8	1000
10011	9	1001
10110	A	1010
10111	B	1011
11010	C	1100
11011	D	1101
11100	E	1110
11101	F	1111

control

11000	J
10001	K
00101	L
01101	T
00111	R
11001	S

invalid

00001
00010
00011
00110
01000
01100
10000

line state

00000	Q
11111	I
00100	H

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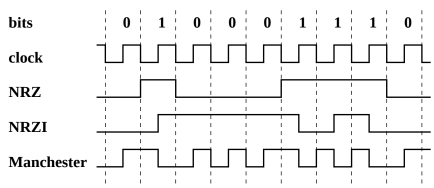
Example: FDDI uses a 4b/5b encoding which means that 4 data bits are represented by a 5 bit symbol. 16 of the 32 possible symbols are chosen in a way that any combination of them doesn't produce more than 3 zeros in a row. Some symbols are invalid while others are used for transmission of control information. The transition problem only occurs for data fields because their length and symbol combinations are not determined.

5.2.2 Pulse coding

The second encoding scheme is handled by the PMD (medium dependent). It transforms symbols into pulses. This can be done in several ways.

Coding Schemes



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NRZ

The NRZ (non return to zero) coding is the simplest one of them. A 1 bit is represented by high level, a 0 bit by a low level. The main disadvantage of is that a data field which consists of all ones or all zeros doesn't have any transitions and therefore requires are very stable clock. Also many receivers use the average signal as a baseline and get confused by a long period without signal transitions.

If many zeros occur in a row no signal will be received for quiet a time. This cannot be distinguished from a broken line so NRZ doesn't offer line control.

NRZI

A solution of some problems is offered by a modified NRZ algorithm called NRZI (non return to zero inverted). A 1 bit is encoded as a transition while a 0 bit doesn't change the signals level. This coding solves the 'too many ones' problem but also doesn't offer line control or clock information.

These problems are solved by a combination like the one that's used by the FDDI standard. 4b/5b symbols are NRZI encoded. The 4b/5b encoding solves the two open problems left by the NRZI coding.

Manchester

The Manchester coding is very simple and effective. The clock and the data signal are XOR'ed together (see picture) which results in a low-to-high transition for a 0 bit and a high-to-low transition for a 1 bit on the rising edge of the clock signal. A Manchester coded signal has no problems with synchronization nor with baseline drift. A disadvantage appears when we start to look at high frequencies. A worst case 100Mbps data stream would produce a 200Mbaud Manchester coded signal. This is an efficiency of 50% which is too less for high speed networks.

The following table gives you an overview of some coding schemes:

Coding

coding	efficiency	DC content	run length
NRZ	100%	50%	no limit
NRZI	100%	50%	no limit
Manchester	50%	0%	1
NRZI + 4b/5b	80%	10%	3

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Run length is the maximum number of code bit times between transitions.

DC content is the deviation of the worst average from the center. For example NRZ coding can produce long sequences of high output (+1). Assuming that the low level is -1 the resulting DC content would be

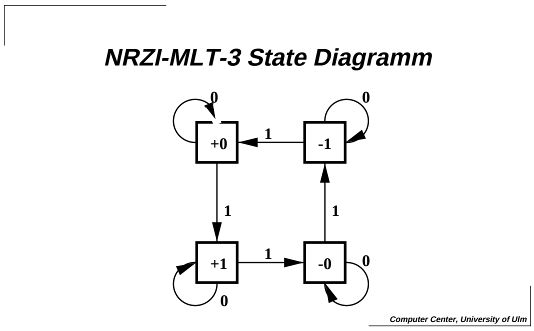
$$DCcontent_{NRZ} = \frac{1_{highpulse}}{+1-(-1)} = 0.5 \tag{5.1}$$

For FDDI:

$$DCcontent_{NRZI,4b/5b} = \frac{-3_{lowpulses} + 2_{highpulses}}{(2 \times 5_{pulses})} = -0.1 \tag{5.2}$$

NRZI-MLT3 coding

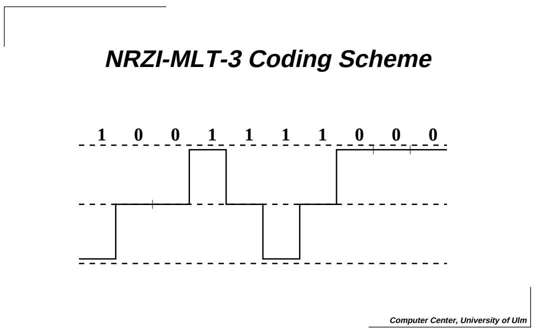
Another way of reducing the required bandwidth is to combine NRZI coding with more that 2 signal levels. Lets assume that there are 3 available signal levels (MLT-3).



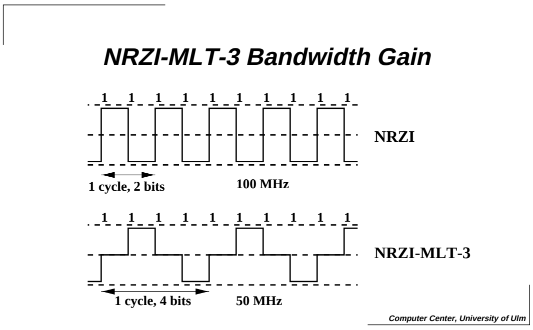
The picture shows the transition scheme for all four states.

A 1 bit is represented by a transition into the same direction as the last one except when the upper or lower signal level is reached. In this case the transition changes its sign (direction). A 0 bit is still represented by no transition.

A more obvious way of presenting the information is on the next picture.



The MLT-3 procedure has some impact on the bandwidth of a medium. The frequency of a signal is reduces by half. Here are worst case details:



5.3 Summary

The main purposes of coding schemes are

Summary of Coding Purposes

- prevent from loss of clock signal
- reduce the required bandwidth
- get line control signals

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Coding is implemented in the first two OSI layers.

Chapter 6

LAN technologies and protocols

As already mentioned in the introduction to this course the first LAN that is still available in a huge number of nodes today, showed up in the late 70es. Three companies, by name Digital, Intel and Xerox developed it and named it DIX-Ethernet or just Ethernet. At this time, it was only available using one medium: the thick yellow coax cable (10base5).

The naming means 10Mbps, baseband and 500m maximum length.

To make things more complicated that time, a company named Novell started an own product called NetWare. It used an own protocol which isn't compatible to the Ethernet protocol. The worst thing was that Novell named it after an already existing working group of the IEEE, 802.3.

This protocol has nothing to do with the IEEE 802.3 protocol that will be discussed in this chapter. Novell finally changed their name to 802.3raw after looking at a bunch of confused and upset network administrators.

But how can network devices handle these problems if even the administrators are confused? No problem. We will now start to discuss the most commonly used frame types in todays LANs to bring some light into the issue.

6.1 Ethernet II

The LAN that's today known as Ethernet II is the second revision of the DIX-Ethernet which was developed with the following goals:

6.1.1 Goals

Ethernet Goals

- ***goals***

  simplicity
  stability
  fair sharing
  performance
  flexible addressing

- ***not a goal***

  full duplex
  error control
  security
  station priority
  speed flexibility

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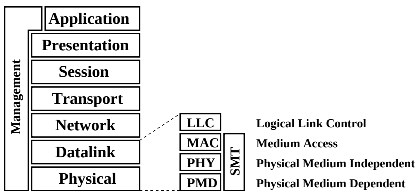
When we look back to these goals after the discussion, we'll find that all of them are matched by the suggested solution in a very nice and smooth way without having a lot of overhead. The simple design was the main advantage of Ethernet over almost 20 years.

6.1.2 Bandwidth sharing

Going back to the beginning of the course we see that LAN standards cover the first two layers of the OSI protocol stack.

The 7 OSI Layers



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The data-link layer, with some help of the physical layer, is responsible for bandwidth sharing.

Here is the historical development process of some implementations.

Pure Aloha

Pure Aloha

- ***any station starts transmission at any time***
- ***stations wait for acknowledge***
- ***retransmit if no ACK has arrived after a certain time interval***

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This solution works fine if only one station wants to transmit once in while but if you have many transmission requests it leads to a disaster because collisions can happen any time.

Slotted Aloha

When the engineers tried to fix the disastrous behavior of Pure Aloha they used a simple trick. The available bandwidth was split into equal time-slots. All other rules were left unchanged.

The only advantage from this was that collisions were now located at the beginning of a time slot but it still wasn't the thing they wanted.

CSMA

The CSMA (carrier sense multiple access) method adds an additional rule. The transmitting station has to wait till the medium is available.

CSMA (carrier sense multiple access)

- ***wait for free medium than start transmission, ignore collisions***
- ***stations wait for acknowledge***
- ***missing ACK is handled by upper layers***

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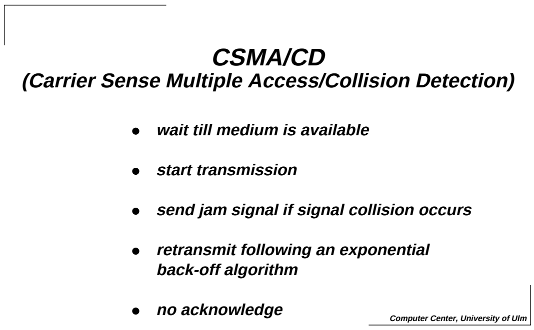
CSMA/CD

After all this interim solutions the one that was finally used follows these rules:



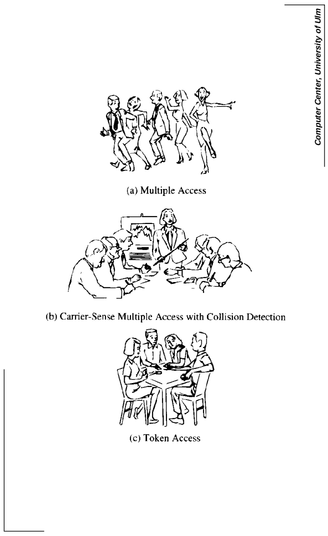
The algorithm that is used to determine the random wait time after a failed transmission simply doubles the time interval from which the random number is picked after each try.

$$time_{wait} = r \times time_{slot}, 0 \leq r \leq 2^l$$
r: equal distributed
$l = \text{MIN}(10, \text{number of tries})$
$number \leq 16$

The sending of a jam signal ensures that all stations will recognize the collision. Thinking about collision detection leads us to a special receiver which also listens to the own transceiver signal on the wire. The maximum jam time is equal to 48 bits.

This procedure is called CSMA/CD (carrier sense multiple access - collision detection).

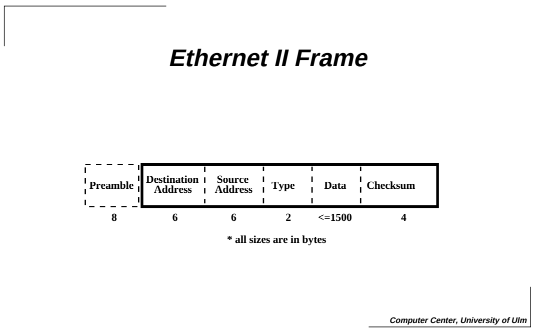
The following picture summarizes some sharing methods.



Token access will be discussed in the FDDI section of this chapter.

6.1.3 Frame format

The Ethernet frame looks very much like the address fields shown earlier.



The preamble itself is not a part of the frame but is used for clock synchronization. It consists of an alternating pattern of ones and zeros.

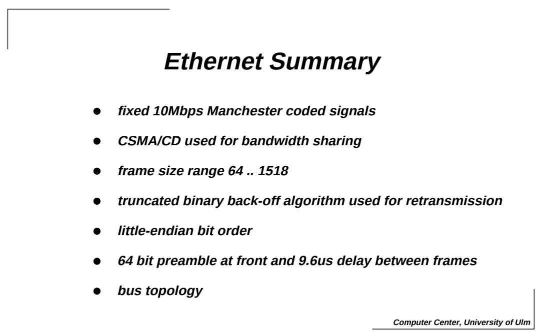
The MAC address itself does not have a universal/local bit but still has the individual/group bit as the first one. The type field determines the network layer that gets the packet. Some of the most important IDs are listed in the following table:

value	protocol
0x0800	IP
0x0806	ARP
0x8137	IPX
0x809B	Ethertalk

It's an important fact that all type field entries are greater than 1500 which is the maximum data portion of a frame. Please note this for comparison with the IEEE 802.3 frame later.

6.1.4 Summary

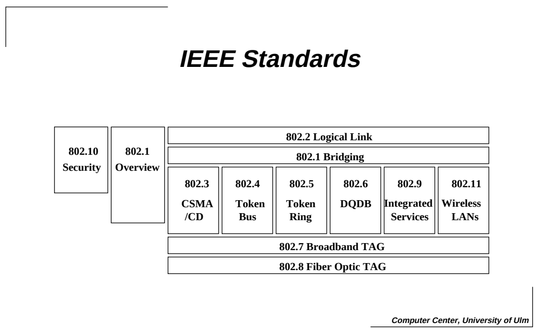
Here's a summary on the most important points of Ethernet II:



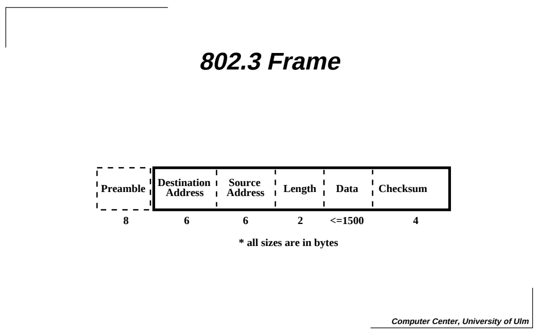
Ethernet is a passive network, stations that do not transmit cannot be detected. PMDs for twisted pair are also available today.

6.2 IEEE 802.3 Ethernet

As you may suppose from reading the name the IEEE 802.3 Ethernet isn't very different from the original Ethernet II.



This shows that the first two layers of the OSI model are covered by two separate standards. The 802.3 covers PMD, PHY and MAC whereas 802.2 covers the LLC part. The former Ethernet standard covered all of them in a single document.

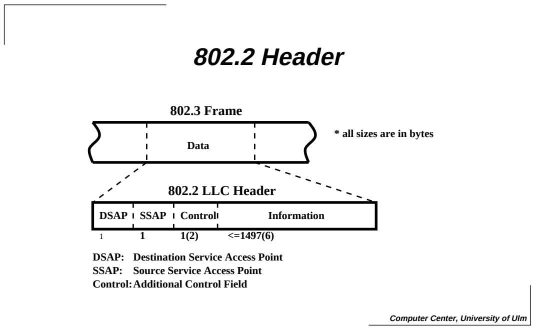


The most important difference is that the 802.3 frame does not have a type field. It instead supports a 2 byte length field. Remembering the note about the type IDs we now know why it was important to make sure that all of them are greater than 1500. It's used to distinguish between the two frame formats.

All other properties like coding, sharing and speed are the same.

Nevertheless it is necessary to know which protocol a node uses and which it does understand.

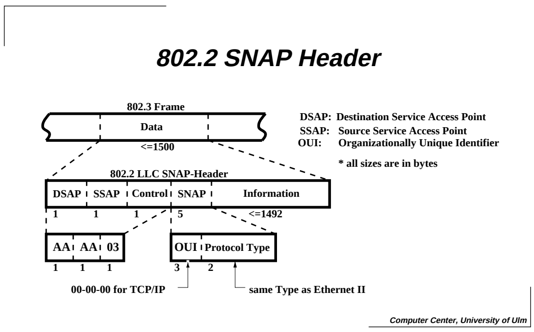
6.2.1 IEEE 802.2 header



Since the upper level layers need to know from which type of protocol a packet was send, the IEEE added two service access points (SAPs) to the LLC header to distinguish between upper level layers. The control field which is 1 or 2 bytes long is used to indicate frame types like supervisory, information and unnumbered frames. It also selects connection oriented and connection less frames.

The problem they ran into is, that 1 byte isn't enough for all protocols. It was solved by using the special DSAP-SSAP combination AA-AA that results in a 802.2-SNAP header.

6.2.2 IEEE 802.2-SNAP header



The combination of 802.3 and 802.2 header is the one that is used as an replacement for Ethernet II. SNAP means subnetwork access protocol. Most drivers today can be configured to either use Ethernet II or 802.3+802.2-SNAP frames.

6.3 Successors of Ethernet

During the last few years the upper limit of Ethernet implementations became obvious and companies thought of ways to cover the growing need for high speed LANs without forcing people to re-cable their buildings. Since most computer companies come from the US they mostly took care about the american cabling situation. Nearly all building in the US that have LAN connectivity use twisted-pair cables and not by coax like most european did in the late 80s and early 90s. This is the main reason why most of the successors use twisted-pair category 5, sometimes 3, for their PMDs.

6.3.1 Fast Ethernet

The one with the best chances is called Fast Ethernet or 100Base-T. It is a scaled version of the original Ethernet and runs with 100Mbps. It uses the same access method (CSMA/CD). It has been accepted by several companies like Intel, 3COM, SMC and others and is available for category 5 cable with 2 pairs or for fibre. There are also devices available that are able to connect to both, either Fast Ethernet or Ethernet devices. Because of the compatibility it is also possible to keep all the SNMP management information bases.

It's main two disadvantages compared to FDDI and ATM are length limitation and the un-flexible use of bandwidth that cannot guarantee a certain data rate or delay.

6.3.2 100VG-AnyLAN

This is an implementation mainly forced and developed by HP. The VG in it's name stands for voice grade which means that old category 3 cables can be used for it. But, it uses all 4 pairs of such a cable to reduce the upper frequency limit which often means that there are no more wires left to connect a phone.

HP also decided to replace the CSMA/CD access method by what they call 'demand priority'. A lot of intelligence is place in the central hubs which query all of their links in a round-robin procedure. Every station that wants to transmit has to signal this wish to the central dispatcher. A 2 level priority scheme has also been implemented.

To make devices ready for voice grade cables, the developers switched from Manchester coding to a 5b6b encoding plus NRZ.

HPs biggest problem is a weak acceptance from other vendors and the fact that there is no easy way to use old devices because 100VG-AnyLAN in fact is a new development.

6.4 FDDI

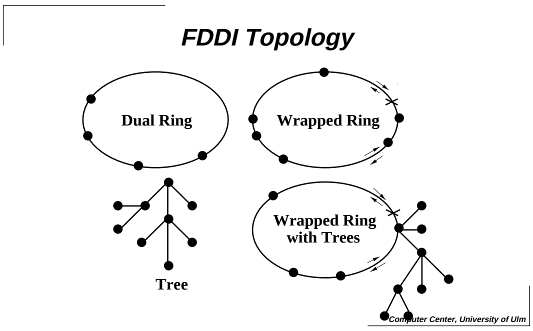
The fibre distributed data interface (FDDI) is quiet different from the LANs discussed so far. As you can imagine from the name, the intention was to use fibre and to distribute duties to the stations that are connected to it.

Not only that it offers a high bandwidth (100Mbps) and a large number of stations in the unsegmented network (up to 500), it also has build-in recovery from several hardware failures. Other goodies are the large distance of up to 60km between two stations and the total length of 200km which is suitable for multi-campus installations. FDDI also guarantees a bound on the waiting time to obtain a transmission grant.

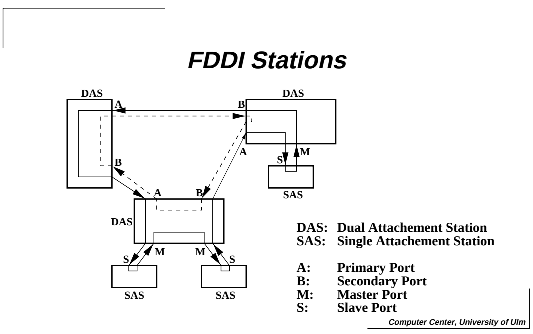
Using fibre also significantly improves noise problems and security.

6.4.1 Topology

FDDI networks use a **dual ring of trees** topology.



The main part of the network is covered by a 2-ring topology of independent fibres called primary and secondary ring. During normal operation all traffic uses the primary ring.



A ring is used because

- every station can talk to every other one using two ways instead of only one.
- point to point links are more appropriate for optical transmissions
- several different media types can be used in one ring because of the point-point nature

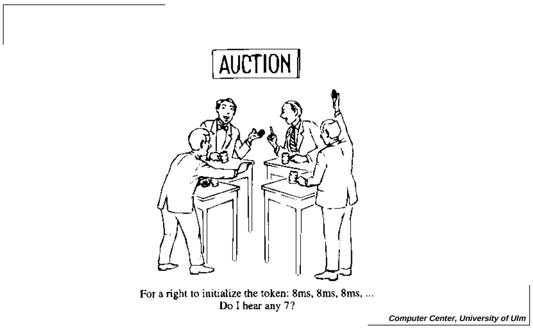
The two main station types are dual-attachment, single-attachment stations and concentrators. Dual-attachment stations are connected to both of the rings and are also used for fault recovery. Each of them has two ports called A and B with A being the primary one.

Concentrators are used to integrate single-attachment stations into the ring. The ports used for this are called master-ports whereas the ones of a single-attachment station are called slaves.

The dual ring feature is needed for recovery reasons and is optional.

6.4.2 Access method

FDDI does not used CSMA/CD as its access method but one called **timed token access**. During initialization of the ring all devices agree on a token rotation time suitable for their needs. It is the minimum requested time of all stations plus the ring delay. This ensures an upper limit for the delay between two frames of a single station. The one that gets it's own bet back wins the claim. If more than one station offers the same time, the one with the higher address wins.



The needed synchronous transmission time is also added to the agreed token rotation time.

After that, every station knows about the time limit and the token starts to get passed through the ring.

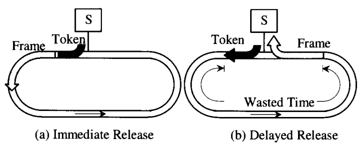
Here is how the bandwidth is shared:

FDDI Access Method

- there are 2 types of transfers, synchronous and asynchronous
- synchronous transfers can be done whenever the station gets the token
- asynchronous traffic can be started whenever a station gets a token that is not late
- the last frame is always allowed to complete
- the token is immediately released after transmission
- the transmitting station removes its own data

The token is immediately released after transmission. This saves one ring delay time compared to former token-ring implementations.

Token Release Methods



Another type of traffic uses restricted tokens but is almost never used, sometimes even forbidden in backbones and therefore not handled here.

An 8 level priority scheme is implemented by dividing the token rotation time into 8 slices. Only stations with a priority high enough for the remaining time are allowed to send. This feature is used very seldom.

6.4.3 Wrapping and hold

FDDI has build-in recovery features that keep the network running even if one of the rings is broken. This is one of the features in the distributed network.

In campus backbones the first one called **wrapping** is used. It means that if the primary connection between two stations is broken, the secondary ring is used for the broken part instead.

How does FDDI do that? Every station implements a watchdog timer that triggers an alarm when no token has arrived for a certain time. The station than starts to transmit a special frame called beacon.

FDDI Error Detection

- *a station suspects a fault in the ring*
- *it starts sending beacon frames*
- *every station that receives a beacon frame stops sending own beacons*
- *if a station receives its own beacon everything is OK*
- *else the ring is broken right before the station*
- *the SMT takes action*

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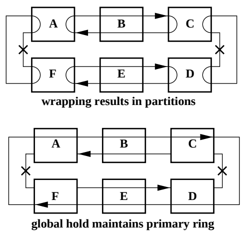
In naval implementations the two rings are located on two different sides of the ship. In case of damage, the probability of having problems with the second ring is very low. Instead of wrapping, switch-over to the backup ring is used. This is called hold.

FDDI Ring Wrapping and Hold



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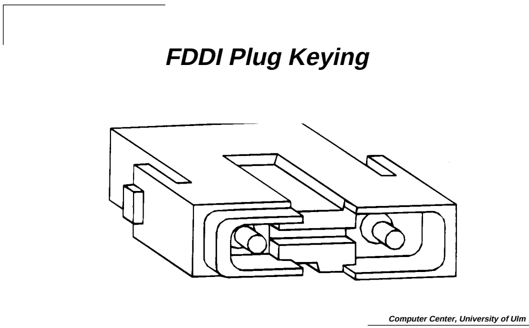
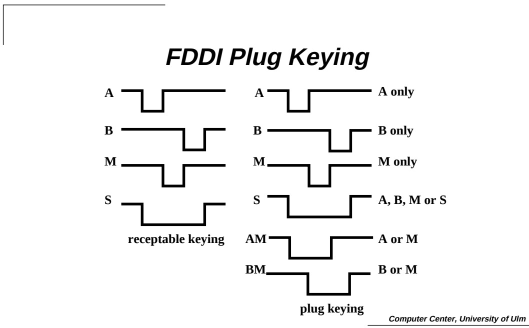
Beyond wrapping and holding, FDDI is also capable of isolation faulty or misbehaving stations. Attaching a new station to the ring is easily done by connecting it because the ring itself does reinitialize all the necessary things.

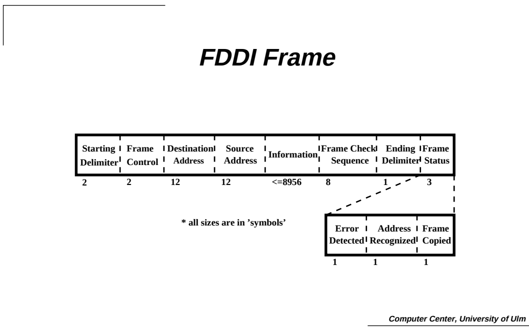
Special plugs prevent from attaching devices to the wrong ring.





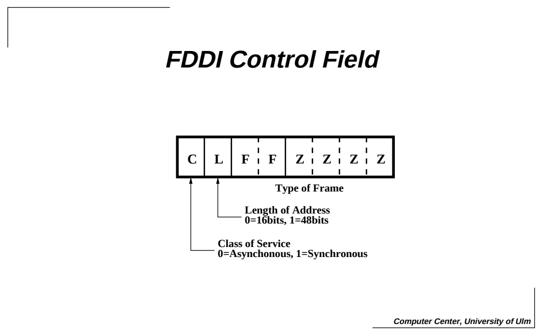
6.4.4 Frames

The picture shows a typical FDDI frame.



FDDI uses 4b/5b encoding and therefore has some additional symbols available with some combinations of them presenting unique pulses on the wire or fibre.

They are used to form the starting delimiter which is then easy detectable.



The control field is necessary to determine one of following frame types:

- LLC frames which have been passed to the MAC sub-layer from the LLC sub-layer
- tokens
- MAC frames which are used internally by the MAC sub-layer. One of them is the mentioned beacon frame.
- SMT frames are used to transfer station management information handled by the firmware of the FDDI interface
- void frames that are used as markers for bridges...
- implementor frames to be used by the network vendors the way they want
- reserved frames which are not to be used

A detailed description of which bits representing which frame type can be found in several books.

6.4.5 SMT, station management

A network like Ethernet does not provide any information to a manager by itself. FDDI in contrary implements several features handled by MAC, PHY and PMD sub-layers.

The list includes information of the neighbors of each station, status information like number and type of ports as well as managing the allocation of synchronous bandwidth. Using this together with SNMP and other management applications gives a very powerful management tool.

6.4.6 FDDI summary

FDDI Summary

- fixed 125Mbps 4b/5b coded signals
- timed token rotation used for bandwidth sharing
- frame size range 3 .. 4500 bytes
- dual ring of trees used as topology
- big-endian bit order
- offers synchronous and asynchronous transmissions
- stations have station-management duties

Computer Center, University of Ulm

FDDI is a powerful network for campus backbones especially because of the file-transfer performance and the build-in management features. When a twisted-pair PMD was introduced using NRZ-MLT-3, is also became a competitor to the new Ethernet standards.

A main disadvantage is that delay or bandwidth critical transmissions like voice and video are not usable in a typical environment. The upcoming star of this next-generation LANs will be handled in a separate course about **ATM**, the asynchronous transfer mode.

6.5 LAN technology summary

All of the discussed networks technologies have several advantages compared to the others. This can be cost as well as support for special applications like multimedia. The typical campus network in the next few years will have FDDI and ATM backbones with a trend going to ATM with 622Mbps in a combination with still existing Ethernet and new desktop ATM connections up to 155Mbps.

If interim solutions are required by users or applications, Fast Ethernet will probably win the race against FDDI because of its price.

100VG-AnyLAN a solution with less vendor support will disappear has not too many chances because for its need of new components that cannot be used for other technologies.

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