Local area networks

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EINDHOVEN UNIVERSITY OF TECHNOLOGY
Department of Mathematics and Computing Science

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Local Area Networks

A. Dekkers

Eindhoven University of Technology
Department of Mathematics and Computing Science
P.O. Box 513
5600 MB Eindhoven
The Netherlands

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The Netherlands

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Anton Dekkers[*]
Eindhoven University of Technology
Department of Mathematics and Computing Science
P.O. Box 513
5600 MB Eindhoven, The Netherlands
e-mail: wscoade@lso.win.tue.nl

1. INTRODUCTION

This paper gives a survey of the protocols and literature for the performance analysis for **local area networks** (LANs), that are available today. The aim of this paper is to get acquainted with all aspects of LANs, which are of importance to performance analysts. Thus we do not want to describe all technological details, not even if they are crucial for the existence or functioning of the network. But we want to understand good enough the consequences of the technical details of all protocols, switches, wires, machines, etc. which have an influence on the performance, in order to be able to model them appropriately. In our future research we will be interested in typical queueing entities as sojourn times, throughput, utilization and queue lengths in a LAN.

We first describe in section 2 what a LAN is and describe the most important of the technical conditions, with the emphasis on the performance aspects. In section 3 we will describe some of the relevant hardware, in particular the transmission media. In section 4 we describe several topologies for a computer network. And in section 5 we look at computer networks from a different point of view; the standard reference model. Also of great influence on the performance of a LAN are the medium access protocols. We will describe the three most common ones. In section 6 the CSMA/CD protocol will be treated, in section 7 the token ring and in section 8 the token bus. We will end this paper in section 9 with some conclusions, suggestions for the research and some general remarks.

This paper is just a summary of the most important items. There are many books about this subject. We refer to e.g. Tanenbaum [44], Schwartz [39], Black [13, 14], Hutchison [27] (with annotated bibliography), Tangey & O'Mahony [45], Meijer & Peeters [32] or an introduction by Digital [2]. Hutchison, Mariani & Shepherd [26] and Lam [30] contain articles about various aspects of computer networks. The report of a special working group on LANs [3] deals in several articles with the performance analysis of LANs. In Bertsekas & Gallager [12] are besides descriptions of data networks also queueing models given. Kleinrock [28] gives an overview of models for the performance evalution of distributed computer-communication

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systems. A more practical book is Verma [46] for a performance estimation of networks. In Bux [15, 16] a performance comparison is made between several types of LANs. In Svobodova [42] the performances of the transport services of different protocols are discussed. Murata & Takagi [35] give a model for a LAN based on the two lowest layers (see section 5). Molle [34] gives polling models in a network and uses these to model several types of LANs. Chlamtac & Ganz [18] and Zafirovic-Vukotic [49] discuss the performance of high speed LANs. A list of the many abbreviations in this area can be found in Barz [11].

We also refer to a forthcoming paper. In that paper we will discuss the situation at the Eindhoven University of Technology with regard to Local Area Networks. It will be a summary of the physical equipment, such as networks and computers, as well as a description of the workload and users on the LANs.

2. CHARACTERISTICS OF A LAN

It is hard to give a general accepted definition of a LAN, for each author has his or her own description of a LAN. Intuitively a LAN is meant for a group of hosts, spread over a moderate area, which communicate by means of a network. In this context a host can be any machine or program on a machine, not necessarily served by a user. By the IEEE, which IEEE 802 Committee developed the LAN standards, it is formulated as:

> "A local area network is a data communication system which allows a number of independent data devices to communicate with each other. A local area network is distinguished from other types of data networks in that the communication is usually confined to a moderate sized geographic area such as a single office building, a warehouse or a campus, and can depend on a physical communication channel of a moderate-to-high data rate which has a consistently low error rate."

Altough there is not one unique definition of a LAN, there are a few characteristics of a LAN, where each author will agree upon. Those characteristics of a LAN are (e.g. Black [13] or Tanenbaum [44]):

1. a diameter of not more than a few kilometers;
2. a data rate of more than 1 Mbps;
3. ownership of the LAN by a single organization.

The reason why there is made a distinction between wide area networks (WANs) and LANs, is that with the above characteristics of a LAN, a LAN will differ substantially from a WAN in architecture and performance. The qualities of the ideal local area network are summarized by Hutchison [27] as:

1. high speed
2. low cost
3. high reliability/integrity
4. installation flexibility
5. expandability
6. ease of access
7. application adaptability

8. interface standardization.

The LAN is a logical step in the evolution of the computer. First there was the valve-operated ENIAC machine of the 1950's which filled an entire room. Then there were the big mainframes with much more computing power, but with the disadvantage of inflexibility. The manufacturing of small chips with a large capacity made it possible that users got their own computer (a personal computer) which had the desired flexibility. Now, however, there was the disadvantage that expensive special products, e.g. plotters, laser printers and databases, could not be reached from ones own workstation. A LAN combines the advantages of one centralized computing center with the advantages of decentralized workstations. In a LAN, the expensive facilities (such as a mainframe computer or printers) and central background memory (a large database) can be used from any workstation in that LAN. But applications can also be run independently on other hosts in the network or on a PC. This has the advantage that there is less contention for computing power between users and that in case of a break-down a user can still work on his or her PC. The next step in the evolution will be the development of Integrated Services Digital Networks (ISDNs). In a ISDN the handling of voice, data and video-signals is integrated in one cable using a standard interface. The local analogon, Integrated Services Local Network (ISLN), is already subject of research and also subject of standardization committees. But a LAN is not a ISLN, for a LAN is not suited for the integration. Especially the handling of video-signals will cause some trouble, for this requires much of the capacity of the transmission medium. In the future there will probably be ISLNs, which are able to fulfil these tasks.

3. PHYSICAL ENVIRONMENT

In this section we will discuss the delay in a network caused by physical shortcomings of a system in delivering messages instantaneously to its destination.

It is obvious that the performance of a network partly depends on the performance of the nodes in it. So, although we are interested in the performance of the network as a whole, we have to consider the performance of the individual nodes in handling the messages. Here we will not specify this problem any further. But in evaluating the performance of a network, this point should be taken into account.

Another physical factor of delay is the transport medium. There are several often used media which we will mention.

The simplest and cheapest transmission medium is the **two-wire open line**, it has a bandwidth of at most 25 kbps and can bridge a distance of only 50 m. Disadvantages are crosstalk and the sensitivity to electro-magnetic interference. Another simple and cheap medium is **twisted pair**, it has a capacity of several Mbps and can bridge a distance of a few kilometers. This is an often used technique for telephone lines and therefore it may already be available. The disadvantage is that this medium too is sensitive to electro-magnetic interference. Probably the most common medium nowadays is **coaxial cable**. There is a baseband coaxial cable with a feasible capacity of 10 Mbps on a cable of 1 km. The advantages are the low cost to access a unit and the ease of adding taps to a baseband coaxial cable. The disadvantage again is the sensitivity to electro-magnetic interference. The second type of coaxial cable is the broadband coax with a bandwidth up to 300 MHz (sometimes up to 450 MHz) and a reach of nearly 100 km. A bandwidth of 300 MHz will support a data rate of 150 Mbps. The advantages are that broadband coax is less sensitive to electro-magnetic interference and the multiple services it can deliver. The disadvantages are the cost of modems and the inflexibility of the system once installed. The medium of the future seems to be the **optical fiber.** This is caused by its extremely high capacity of 1 Gbps and its immunity to the environment. This high capacity is for distances of 1 km (100 km can be bridged without repeaters at a lower speed). Its disadvantages are the costs of connectors and access and that optical fiber can only be used for point-to-point traffic. The last medium which we will mention here, is the **terrestial microwave.** This medium has a bandwidth varying from 500 MHz to 40 GHz and can bridge a distance of 100 km with towers of approximately 100 meters high (the transmission via satellite can cover half the globe). The advantage is that it is easy to install, the disadvantage is that the spectrum may be crowded.

For all these media is the speed of transmission of a single bit very high. The speed can therefore often be neglected for the performance of a network. The important items for the performance are the capacity of a medium, which can make it time-consuming to send a large file from one host to another one, and the maximum distance a medium can bridge without amplifiers. Such amplifiers mean extra protocols and this will take time. The costs of a medium are obviously of no importance for the performance of a LAN, but they are of importance for which medium will be most used in the future. For a LAN the most used media now are the coaxial cable and the optical fiber cable.

4. TOPOLOGY

In LANs there are two basic topologies, the bus network and the ring network. There are in practice other possibilities of which we will afterwards mention the two most common, they are often used outside LANs: the star network and the mesh network.

We will first concentrate on the two topologies best suited for LANs: the bus network and the ring network. Both topologies have in common that there is in general no central host which allows a station to send. If a station wants to send it can take a decision to do so independently of the other stations. Of course there are rules in the contention of the different hosts for the medium. They will be discussed later.

In the **ring network** the medium is a ring on which each station has its ring interface, which can listen to the broadcasting of other hosts and it can put data from the host on the ring. In the figure below a dot is a ring interface and a box is a host.

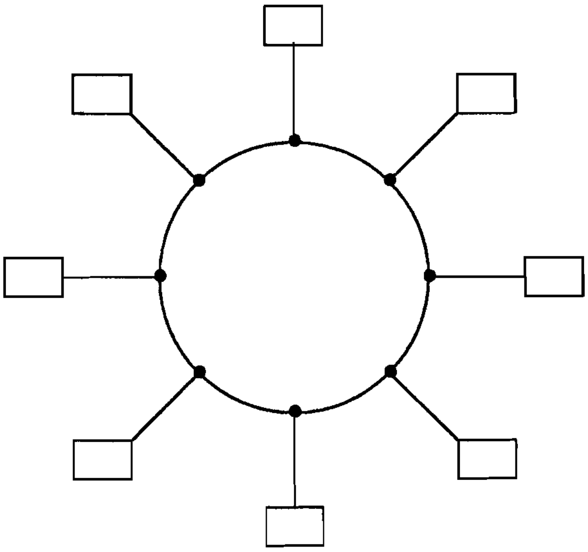

fig. 4.1: Ring network

This configuration is often used in LANs and IBM is studying hard on especially this kind of configuration. The ring architecture is often used in combination with a protocol which works with tokens and/or time slots, see section 7 for the ring protocols.

A token means that there is always a message on the medium. If a station wants to send and the message on the medium is a standard word, the token, it takes the token of the line and is allowed to put its message on the line. If the broadcasted message on the medium is not the token it waits until it can capture this token and starts then with transmitting. After its transmission it puts the token back on the ring again.

In the **bus network** the medium is a kind of backbone on which all stations are plugged with a bus interface. In the figure below a dot is a bus interface and a box is again a host.

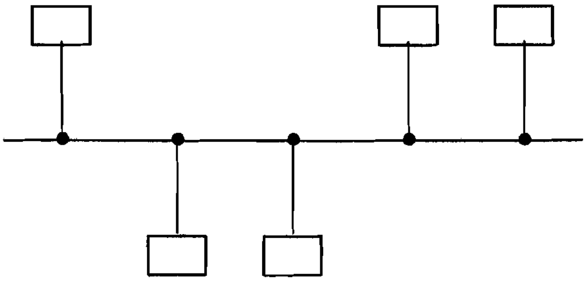

fig. 4.2: Bus network

This configuration is probably the best known architecture for a LAN nowadays, because of the popularity of Ethernet. Ethernet is a bus architecture with the CSMA/CD protocol, discussed in section 6. Together with ethernet and the ring protocols a token bus completes the list of best known medium access protocols, the token bus is discussed in section 8.

In the **star network** there is one cental interface message processor (IMP, or a computer playing this role). An IMP is a switching element on a transmission line between two hosts. Usually such an IMP is a specialized computer that arranges all traffic in that network. It is important that this central node is reliable. This kind of network is the oldest, for it is very suitable for a timesharing mainframe with the terminals geographically spread. The star network is, as mentioned, not often found in a LAN.

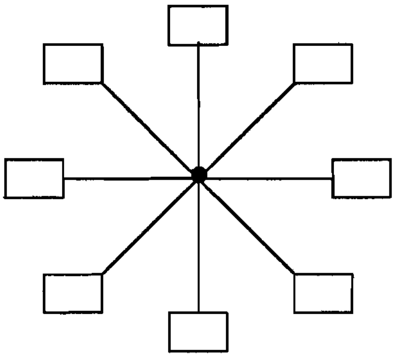

fig. 4.3: Star network

In the **mesh network** it is difficult to arrange the traffic properly. Each network can be called a mesh network, but the term is only used for networks with no evident structure, which the networks mentioned above did have. Because of its flexible structure it is often used in WANs. For LANs the costs of lines are not very important and therefore the architecture of LANs is mostly different from a mesh network.

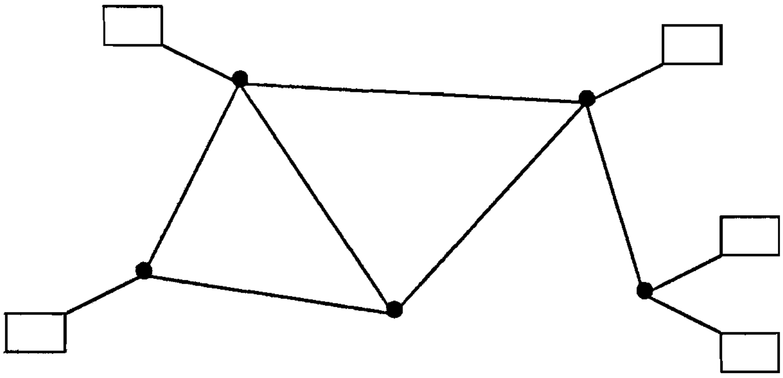

fig. 4.4: Mesh network

In this figure the boxes are again the hosts and the dots the IMPs in a network.

5. THE ISO REFERENCE MODEL

The architecture of a computer network has to be highly structured to handle the complexity of its environment. This structure is based on a layer model. The standard in this area is developed by the International Organization for Standardization (abbreviated by ISO). This institute began in 1977 its study to try to derive an international accepted standard and the basic reference model was ready in 1982 (draft of the ISO [1]). The model is known as the Open System Interconnection (OSI) model and is discussed in any book about computer networks.

Conway [20,21] gives a performance model for the OSI architecture.

A layer in this OSI model is chosen in a way that it only has to deal with the adjacent layers. One layer uses the services of the underlying layers and provides enhanced services to the next layer. These other layers should be seen as black boxes; a layer is not aware of the specific tasks and protocols of the other layers. This results in a decomposition of the complex network facilities of a machine in a number of less complex layers. For one such layer there are protocols developed for its specific task. The layers are designed to minimize the flow of information between them and such that each layer performs a well defined function.

All communication between layer N and layer $N-1$ goes via the Service Access Point (SAP) of layer $N-1$, which can be used by layer N according to a defined interface, the Interface Data Unit (IDU). This means that the $N-1$ subsystem (i.e. layer $N-1$) provides on request services to the N subsystem by the entities in the $N-1$ subsystem. These entities can cooperate with entities in subsystems of the same rank through the (logical) peer-to-peer communications. The physical route of these peer-to-peer communications goes through the layer(s) below. The information exchanged in the IDU consists of two parts, the Interface Control Information (ICI) and the Protocol Data Unit (PDU). The PDU on its turn is built of the Protocol Control Information (PCI) and Service Data Unit (SDU).

In all layers there are a number of functions to enable a layer to fulfil its tasks. Some of these functions allow one unit to communicate with more units above or with more units below, thus not only 1 to 1 relations between layers exist.

There are seven layers in the OSI model, of which the lower three are the most important ones for us. In the figure below the OSI model architecture is given for two communicating hosts. The IMP is a node in the network that lies on the path from host A to host B.

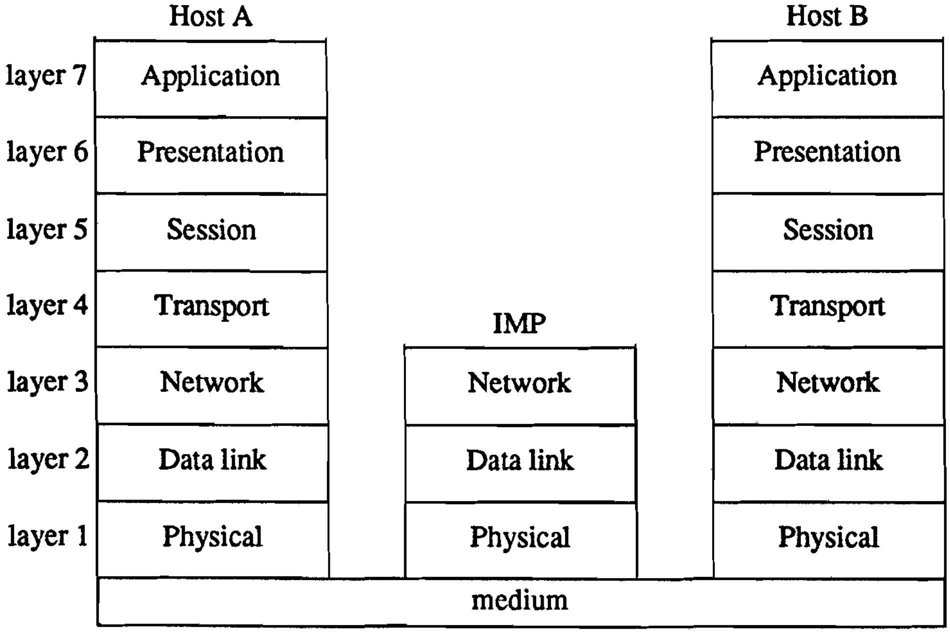

fig. 5.1: The layers of the OSI model

We will shortly describe the functions of each layer. These descriptions can be found in all books about computer networks (Tanenbaum [44] is entirely based on this OSI model, each chapter describes one layer).

The function of the **physical layer** is to transmit bits over a communication channel. It has to convert bits into an electronical signal and convert a signal into bits again. The interface for this function of modulation and demodulation is often called a modem. Other tasks are bit synchronization and activating, maintaining and deactivating a physical circuit between two nodes. The medium is not a part of the physical layer.

The function of the **data link layer** is to take care of a reliable transmission of data frames between two adjacent hosts. The physical layer is just transmitting a stream of raw bits, without considering the meaning. In the data link layer frames are sent to another host and at the other host the frames are put in the right order again. Thus in this layer problems with damaged, lost or duplicated frames should be solved. The functions of this layer includes also error detecting and, if possible, error correction. This layer can be split into two sublayers the Medium Access Control (MAC) layer and the Logical Link Control (LLC) layer. The MAC layer is what makes this layer very important to us, here the protocol is implemented which determines whether a host may start transmitting. The LLC layer provides to the network layer a connectionless or connection-oriented service. In a connection-oriented service a connection is established for the complete session (like telephone service), in a connectionless service each packet is routed and delivered individually (like postal service). In case of connectionless service this can be with or without acknowledgements.

The functions of the **network layer** are routing, flow control and congestion control. Thus in the network layer is determined which IMPs are needed to send a message from host A to host B. Furthermore this layer can determine when to accept packets from higher levels and when to transmit packets to other nodes. In broadcast networks the routing is simple and the network layer will be thin or nonexistent.

The function of the **transport layer** is to accept data from the upper layer and prepare this data to be send to another host. This layer is also known as end-to-end layer because from this layer upwards the intermediate IMPs are no longer “seen”. It is meant to shield the layers above from network dependent details. The layers below the transport layer give the network oriented service and the layers above give the application oriented service. In the transport layer messages are cut into packets for the lower layers and packets are pasted again into messages for the higher layers. In case of an unreliable network the transport layer should provide a reliable end-to-end communication.

The function of the **session layer** is to coordinate the dialog between the two communicating hosts. It binds two presentation layers, and manages the data exchange when the connection is established. It also deals with access rights of users/hosts. Other session services are the token management in case of a protocol with a token and synchronization between hosts.

The function of the **presentation layer** is to present information in a form that is meaningful to the application entities. It translates the information if it is given by another representation as needed by the application process. And if the information is formatted differently this layer has to ensure the compatibility between the cooperating processes. Furthermore the encription and decription of confidential messages and the compression of data is done in the presentation layer. Thus the presentation layer passes on a message to the session layer in a form that can be send directly to another host and it has to receive a message from another host, which it (possibly) has to convert in a clear message for the application layer.

The function of the **application layer** is to provide services to the external users. The contents of this layer is up to the individual user, it is therefore hard to give a clear, general description of this layer. But for a specific application, e.g. electronic mail, it is possible to define exact the services asked from the presentation layer and the data passed to this layer.

Note that much vendors have their own layer model that differs slightly from the OSI model. Best known are SNA (Systems Network Architecture) from IBM and DECNET from DEC. In Meijer & Peeters [32] these and other architectures are described extensively. In Tanenbaum [44] each description of an OSI layer contains some remarks on the organization of this layer in SNA and DECNET. Malamud [31] is a book mainly based on DECNET.

Another protocol which is widely used and not vendor dependent is the TCP/IP protocol (Transmission Control Protocol/Internet Protocol). This protocol too is not based on the OSI model. Of course it is based on a similar layering architecture. In Comer [19] TCP/IP is discussed extensively.

6. CSMA/CD AND OTHER BROADCAST PROTOCOLS

In this section we will discuss a class of broadcast protocols, for situations in which there is a contention by the stations for the channel and no central intelligence nor tokens. The best of this class is **the Carrier Sense Multiple Access with Collision Detection (CSMA/CD)** protocol. This in one of the most used protocols, because the well known and widely spread Ethernet is based on this protocol. An international standard for the CSMA/CD protocol is IEEE 802.3 [4,5]. Descriptions of Ethernet, CSMA/CD and/or other broadcast protocols are given in almost any book on this subject, see e.g. Tanenbaum [44], Tangey & O'Mahony [45] Bertsekas & Gallager [12] or Black [13]. In Comer [19] a description of the Ethernet technology is given.

In the early seventies Abramson [8-10] introduced on the university of Hawaii a protocol, called **ALOHA**, which is the origin of most packet broadcasting protocols. It was designed for communication between the widespread buildings of the university over different isles and used ground-based radio. But it is applicable to any system without central intelligence because of its simplicity.

In the ALOHA system every station may transmit whenever it gets data to send. As a consequence there will be collisions, but a station will detect these by listening if its message is broadcasted correctly. If not, a station will try to broadcast its message again after a random amount of time. As a result of the contention for the broadcast medium the performance will decrease rapidly if the load is above 18% (Kleinrock [28], p. 27): there will be many collisions and these will cause retrials with a large probability on another collision.

A refinement of the "pure" ALOHA is the "slotted" ALOHA. In slotted ALOHA a station is only allowed to start its broadcast on certain discrete moments in time, this will result in a maximum possible channel utilization of 37% (Kleinrock [28], p. 27).

Both protocols above have the disadvantage that a station starts to broadcast at the moment a packet is delivered. A class of protocols where a station first listens to the channel before taking action is known as the class of **carrier sense** protocols. In this case a collision can only occur if two or more stations start to transmit almost simultaneously. Then they can not hear that another station is already broadcasting. Almost simultaneously is within a small time interval, the propagation delay. This propagation delay is the time the first bit of a message needs to go from one end of the channel to the other end.

There are three variants of such CSMA protocols. The first is **persistent CSMA** or **1-persistent CSMA**. Before transmitting a station listens if the channel is busy. If it is busy it waits. As soon as the channel is idle the station starts transmitting. If a collision occurs the station waits a random amount of time before trying again. Disadvantage of this method is that if two or more stations are waiting for the channel to become idle, there will be a collision, because they all start transmitting simultaneously.

The second protocol is the **nonpersistent CSMA**. Again a station listens before transmitting. If the channel is idle a station starts transmitting. If not it waits a random amount of time before it listens again. Now there will be less collisions, but the delay for a message will be larger.

The third protocol is for slotted channels and is **p-persistent CSMA**. In this case a station again senses the channel until it is idle. Then it starts transmitting with probability p and waits with probability $1-p$ until the next slot. In the next slot the station again starts with probability p and waits with probability $1-p$. This process continues until a station starts transmitting. If this results in a collision or if another station started transmitting a station will wait for a random amount of time and then starts again with sensing the channel.

The first improvement made to the ALOHA system was to sense the channel before transmitting. The second improvement is that a station stops to transmit at the moment it "hears" a collision. This is referred to as **Collision Detection**. So in the CSMA/CD protocol a station that wants to transmit a message first listens to the channel until it is idle. Then it will start transmitting. If another station too is transmitting, both stations will notice this after a short time (maximal twice the propagation delay) and abort transmission. They will wait a random amount of time before they start again with sensing the channel. Note that CSMA/CD uses the 1-persistent CSMA. The great advantage of this method is that the collisions will only last for a short period of time. This will result in both a high utilization and a low message delay.

The CSMA/CD protocol is a very important one, especially for LANs. The IEEE 802 committee has formulated a standard protocol, IEEE 802.3, for LANs based on this protocol. The well known **Ethernet** was the model for the description of IEEE 802.3. Ethernet is an implementation of the CSMA/CD protocol by Xerox (Metcalfe & Boggs [33] and Shoch, Dalal, Redell & Crane [40]) on a bus topology (see fig. 4.2). For a performance description of Ethernet see Bertsekas & Gallager [12], Hammond & O'Reilly [24], Hayes [25] or Tanenbaum [44].

7. TOKEN RING PROTOCOL

A second well-known configuration for a LAN is the token ring (see fig. 4.1). Especially IBM is a supporter of it; the first prototype of the token ring was installed in the IBM Laboratory in Zürich. The international standards for the token ring are given in IEEE 802.5 [6]. Detailed descriptions of the token ring can be found in Schwartz [38], Bux, Closs, Kuemmerle, Keller & Mueller [17] or in a set of articles by Willett [47], Dixon [22], Pitt [37] and Strole [41]. But also in most books mentioned before (e.g. Tanenbaum [44], Bertsekas & Gallager [12]) a special chapter is devoted to the token ring. In Takagi [43] one can find models for token rings (polling models) and an exhaustive list of references on polling models up to 1989. Kuruppillai & Bengtson [29] give a performance analysis of interconnected token rings.

In a token ring there are several stations logically lying in a circle. Each station is only connected to both its neighbours. In such a system in general each station takes the incoming traffic from its neighbour from the cable, looks what it is and puts it back on the cable again to send it to the other neighbour. This causes a delay to the message from 1 bit for each station on its way from source to destination. Furthermore there is the propagation delay for a message on this route.

In the token ring protocol there will never be a collision. This is due to the control over the line. In the CSMA/CD protocol there was no unique station, which was allowed to send. But in the token ring on the contrary there is always only one station, the station with the token, which is allowed to send. The token is a special short word circulating on the ring from one station to another. A station that wants to send, waits until the token passes and then grabs it from the line. Instead of transmitting the token again such a station may now start to transmit its message. After it has finished sending its message it will put the token back on the line and the next station will get the possibility to seize the token.

A message will be put on the ring and deleted from the ring by the same station. In this way a station can see that its message has rounded the circle correctly and prevent the message from rounding the circle twice. All stations in between will look at the message; if it is meant for a station, this station will copy the message and put it back on the ring, else it will be put back immediately without being looked at.

A disadvantage of a ring is that each station must be functioning well, otherwise the whole ring will not function. Therefore the physical layout of a token ring will often be a star, in which one station, which is turned of or behaving badly, can be bypassed. In the next figure we illustrated this; a dotted line is a bypass.

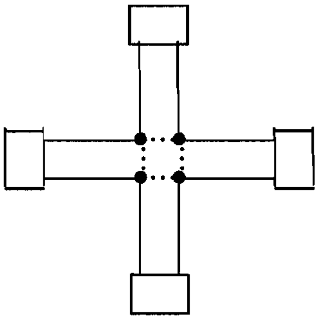

fig. 7.1: Bypasses in a token ring network

Another problem can be the loss of the token by some malfunctioning part; then each station will wait forever to the token to appear. To overcome this difficulty there is a time-out rule. If a station that wants to transmit can not seize the token within some time-out interval it acts as if it has grabbed the token. This means it transmits its message, followed by the token to release the ring again. If more station do this almost simultaneously, there will be a collision and after a random delay they will try again, until the ring is working well again.

Another protocol for ring architectures is the slotted ring. In a slotted ring there are a fixed number of slots circulating around the ring. A station that wants to transmit waits for an empty slot (the first bit indicates whether or not a slot is empty), and fills this with data. The length of a message can not exceed the slot length. The destination station for a message empties the slot again by adapting its first bit. For a performance analysis of the slotted ring see Wu & Spratt [48].

8. TOKEN BUS PROTOCOL

A third protocol which we discuss here is the token-passing bus access method. It is standardized by the IEEE 802 Committee in IEEE 802.4 [7] and is a mixture of the two LANs mentioned above, it has the configuration of Ethernet and a protocol similar to the token ring.

During the meetings of the IEEE committee over the CSMA/CD protocol there were two main objections against it by companies interested in factory automation. The first one was that in the worst case a message has to wait arbitrarily long before it can be broadcasted. The second objection was, that there are no priorities in a CSMA/CD system, while priorities are important for the performance and reliability of real-time systems. To overcome this difficulties the IEEE 802.4 token bus standard is developed, see the IEEE standard [7] (much more complicated than the IEEE 802.3 CSMA/CD standard [4]) and Phinney & Jelatis [36]. Furthermore in most general books about networks (see e.g. Tanenbaum [44] and Bertsekas & Gallager [12]) the token bus protocol is discussed.

The token bus protocol is a broadcasting protocol as CSMA/CD, which means that each station can here everything on the cable. But in this protocol there is a mechanism to control which station may broadcast. Again the stations are logically ordered in a circle as with the token ring, but now they do not pass a token, but broadcast a message to give their successor permission to broadcast. If the successor does not have a message to send, it broadcasts again to the next station in line to go ahead. A result is that the performance equations of such a system are equal to the performance of the token ring, be it with another delay. In the token ring the delay was one bit, in the token bus a complete message has to be read and interpreted. A way to speed the ring is therefore to let a successor in the logical ring be a station which is physically close.

The polling models of Takagi [43] can also be used to model the token bus protocol.

Periodically the station with the token sends an invitation to stations which want to be in the ring too, to join. If there is a reaction the inviting station will send the next time the token to the new station and the new station will send the token to the successor of the inviting station. If there are several reactions a splitting algorithm is used to choose one. A station that wants to quit and be out of the ring sends a message to its predecessor to send the token the next time to its successor. Note that the physical order is not crucial in a token bus.

After a breakdown in this way the ring is built up again: first there will only be one station which initiates the token and after successive invitations all stations will be in the ring again.

A drawback of this protocol is the rather large delay between two transmissions caused by the token-message. A simple way to overcome this difficulty is to send no tokens. A listening station starts sending if the channel is idle after a transmission of its predecessor. If a station has nothing to send, it remains quiet and the next in line will start after a small waiting time. And so on, with an increasing waiting time for stations further along the line, until a station starts transmitting a message. Especially the synchronization and recovery after a breakdown will now be cumbersome. In Fine & Tobagi [23] a summary of several variations is given.

9. CONCLUDING REMARKS

In this paper we provided an introduction to Local Area Networks. We briefly discussed the most interesting features, especially with regard to those which influence the performance. Details over exact protocol descriptions and technological constraints are omitted. Most of these items can be found in the references, general books on this subject often mentioned here are Tanenbaum [44] and Bertsekas & Gallager [12]. But there are numerous other books and articles about LANs, because of the popularity and importance of this research topic.

In future research on performance evaluation of LANs we will emphasize on the modeling and (approximate) analysis of parts of a LAN or combinations of LANs which are not yet described properly in literature. The main performance characteristic in studies so far is the utilization of the channel. A less considered and in our opinion also important characteristic is the response time for a user or application from the time it generates a message until that message is fully processed.

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EINDHOVEN UNIVERSITY OF TECHNOLOGY
Department of Mathematics and Computing Science
PROBABILITY THEORY, STATISTICS, OPERATIONS RESEARCH AND SYSTEMS THEORY
P.O. Box 513
5600 MB Eindhoven - The Netherlands
Secretariate: Dommelbuilding 0.03
Telephone: 040 - 47 3130

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