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Title : **A WIRELESS OFFICE COMMUNICATION SYSTEM FOR CONSTANT AND VARIABLE BANDWIDTH DEMAND TRAFFIC.**

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This report discusses a detailed qualitative study of a Wireless Office Communication System. The system is built up of separate groups. Each group consists of a base station and two types of users, viz i) one with constant bandwidth demand requirement and ii) other with variable bandwidth demand requirement. A new proposed Circuit Reservation Multiple Access method is used to transport data over a group radio link. Communication between base stations of different groups is possible over a Distribute Queue Dual Bus backbone network.

Indexing terms : Wireless Office Communication System, Packet Reservation Multiple Access, Circuit Reservation Multiple Access and Distributed Queue Dual Bus.

SUMMARY

Adjusting the internal structure is an ongoing process for almost every organisation. With every reorganisation, not only personal, but also equipment has to be moved.
Because the costs of changing the infrastructure of the wiring between communicating devices is very high, a wireless communication system is the appropriate way to bring down this aspect of the reorganisation costs.

The Wireless Office Communication System, which is designed, has to deliver an efficient integrated transport service. This service has to fulfil the requirements of both constant as well as variable bandwidth demand traffic. The system has to be flexible to do this, not only for present, but also for possible future traffic types.

First the different traffic types and their requirements to a transport service are investigated. Thereafter possible structures are discussed to achieve an efficient data transport for the various traffic types. Several protocols to access the systems network links are compared, and a model of an interface between them is given. Finally a number of control aspects to optimise the systems service characteristics are described.

The resulting system consists of several separate groups. Each group contains a mixture of users with a constant and a variable bandwidth demand. The groups are coupled by a Distributed Queue Dual Bus backbone network. Data transport from the users of a group to an interface on the backbone network is done over a half duplex radio link. The radio link is accessed by a new proposed protocol. This protocol may allow an efficient integration of traffic types, with divergent service requirements.

LIST OF SYMBOLS AND ABBREVIATIONS

a	: Worst case propagation delay.
act fact	: Activity factor CBO traffic; Fraction of talkspurts.
ATM	: Asynchronous Transfer Mode.
CBO	: Continuous Bitstream Oriented.
CD	: Count Down counter.
CDMA	: Code Division Multiple Access.
CRMA	: Circuit Reservation Multiple Access.
CSMA/CD	: Carrier Sense Multiple Access with Collision Detection.
CSMA	: Carrier Sense Multiple Access.
CUGBS	: Control Unit Group Base Station.
DBO	: Discontinuous Bitstream Oriented.
DQDB	: Distributed Queue Dual Bus.
DQPSK	: Differential QuadriPhase Shift Keying.
eff fract DBO	: Effective fraction of DBO user data in a timeslot.
f_tr	: Transmission rate.
FDDI	: Fibre Distributed Data Interface.
FIFO	: First In First Out.
GBS	: Group Base Station.
inb tr/CBO term	: Inbound traffic per CBO terminal.
ISDN	: Integrated Service Digital Network.
ISMA	: Inhibit Sense Multiple Access.
LAN	: Local Area Network.
M	: Number of users.
MAC	: Medium Access Control.
MAN	: Metropolitan Area Network.
max eff DBO time	: Maximum effective transmission time of DBO user data per frame.
max # succ DBO sl	: Maximum number of successful DBO slots per frame, given the slotted ALOHA access protocol.
n	: Number of backlogged terminals.
N^t	: Random variable, which represents number of backlogged terminals at time t.
OSI	: Open Systems Interconnection.
outb tr/CBO term	: Outbound traffic per CBO terminal.

p	: Chance of delivering a packet by source, in time period.
p_0	: Chance of transmission in time period.
p_i	: Chance of delivering one packet by source in "i" time periods.
p_r	: Chance of retransmission in time period.
PABX	: Public Automatic Branch eXchange.
PRMA	: Packet Reservation Multiple Access.
QPSX	: Queued Packet and Synchronous circuit eXchange.
REQ	: Request.
RQ	: Request counter.
rx/tx	: Receiver and transmitter.
S	: Channel input rate.
SRU	: Segmentation and Reassemble Unit.
S^t	: Channel input rate at time t.
STM	: Synchronous Transmission Mode.
T_ack	: Time necessary to generate and transmit an acknowledgement.
T_data	: Time of data transmission per DBO packet.
T_fr	: Time duration of one frame period.
T_proc	: Processing time; Time to check received packet for correct transmission.
transm cap DBO	: Maximum effective transmission capacity for DBO data.
T_sl	: Time duration of one slot period.
TDM	: Time Division Multiplex.
THT	: Token Holding Timer.
tot CBO tr	: Total inbound and outbound CBO traffic per group.
TTR	: Time Token Rotation.
TTRT	: Time Token Rotation Time.
UHF	: Ultra High Frequency.
VC	: Virtual Circuit.
VCI	: Virtual Circuit Identifier.
WAN	: Wide Area Network.
WOCS	: Wireless Office Communication System.
# ack	: Number of acknowledgement bits.
# chk	: Number of check bits in a DBO packet.

# hdr	: Number of header bits in a DBO packet.
# CTR sl	: Number of CONTROL slots per frame.
# CBO term	: Number of CBO terminals per group.
# sl DBO	: Number of slots available for DBO data per frame.
# sl/fr	: Number of slots per frame.
# DBO term	: Number of DBO terminals per group.
# bit CBO	: Number of databits in a CBO packet.
# sl CBO	: Number of effectively used slots by CBO data per frame.
σ	: Probability that user generates and transmits a packet in a timeslot.

CONTENTS

1 INTRODUCTION

In a fast changing environment, organisations constantly have to be readjusted. This to be able to efficiently and effectively realise customers requirements. Along with the reorganisation personal and equipment have to be moved to a new location. Because a lot of the equipment performs electronic communication with each other, old networks have to be readjusted and new ones may have to be installed. To bring down the infrastructural maintenance costs for these networks, a wireless communication system is desired, which makes a flexible network structure possible.

For decades telephone has been the most important telecommunication service for most offices. Next to this, dedicated networks have been installed since the seventies, to make data communication between intelligent devices possible. It is expected that in the near future new services, like for instance videophone and videoconferencing, penetrate the office environment. All services have different demands for the requirements of the transport service. Important service parameters are bandwidth, loss probability, blocking probability and transport delay.

Up till now most networks are optimised for circuit switched or for packet switched data transport. Circuit switched transmission, like for instance telephone or video, requires a constant bandwidth during the connection period. This type is called the Continuous Bitstream Oriented (CBO) traffic. On the other hand packet switched data transport, like for instance terminal-to-host communication or file transfer, has a bursty character and the demanded bandwidth varies while the connection lasts. This traffic type is called the Discontinuous Bitstream Oriented (DBO) traffic.

The design goal for the Wireless Office Communication System (WOCS), which has to be investigated, can be formulated as follows:

> The WOCS has to deliver an efficient integrated transport service to fulfil the requirements of various CBO and the DBO traffic types. This should be done not only for known present, but also for unknown future traffic types.

Figure 1 shows a possible WOCS, which fulfils the above mentioned goal. The data networks of a hypothetical organisation, which is settled in three buildings are depicted. A detailed study of all relevant components of this system will follow in this report.

Therefore, in chapter 2 a blackbox model of the system is described. In that chapter the possible data types and the requirements they demand from the transport service are given. Besides this, several aspects are described, which influence the WOCS. In chapter 3 a closer look at the inside of the blackbox is taken, and several subsystems are defined.

In chapter 4 a theoretical intermezzo will follow, in which is analyzed whether a deterministical or a statistical resource allocation method is the best one to achieve the demands of the various traffic types. As a result of this, the structure of the WOCS can be determined. This is discussed in chapter 5.

In chapter 6 first the Packet Reservation Multiple Access (PRMA) protocol is described. This is an efficient protocol for the integration of speech and data on a radio link. The main part of this chapter however discusses a proposal for the Circuit Reservation Multiple Access (CRMA) protocol. This protocol makes it possible to transport not only speech as represent of the CBO traffic over a radio link, but also CBO traffic types which require a low loss probability.

Chapter 7 discusses several low and high speed Local Area Networks, which can be used as a backbone network to couple several distinct groups of users.

In chapter 8 a model of an interface between the radiolink and the backbone network, which is called the Group Base Station (GBS), is presented.
To realise a stable system, which can deliver an efficient and fair transport service for all users, a management element has to be a part of the WOCS. Several possible control parameters for this element are discussed in chapter 9.
In chapter 10 the conclusions and recommendations are given.

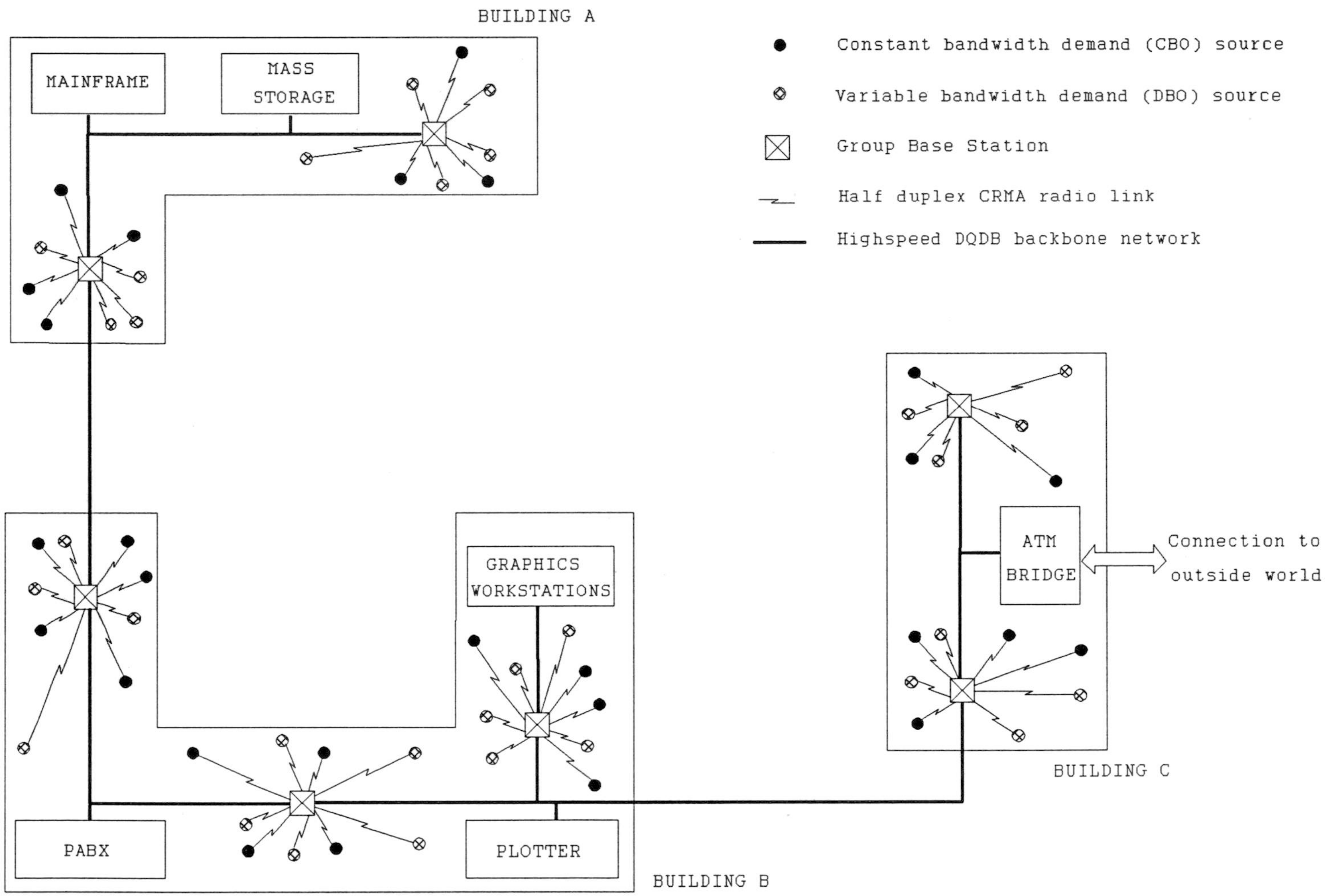

Figure 1: A Wireless Office Communication System for a hypothetical organisation.

2 BLACKBOX DESCRIPTION OF THE WOCS

In this chapter the WOCS is described according to the system theory as described in [1]. First the highest blackbox level is described. In the next chapter the most important subsystems are investigated in more detail.

In figure 2 the highest hierarchical system level of the WOCS is depicted.

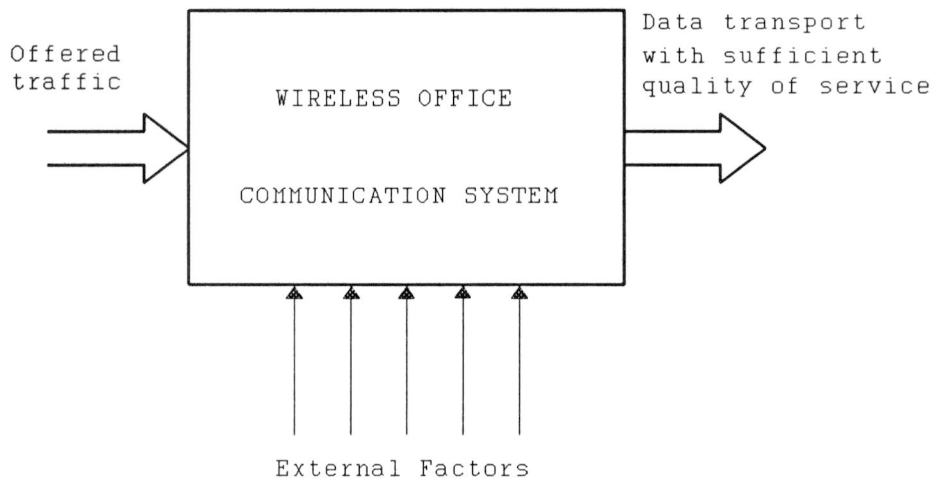

Figure 2: Blackbox system level of WOCS

The first step to be made is to define the input and the output of the system. Hereafter the external factors which have influence on the system have to be found.

2.1 The input specification

In this report the input traffic stream is split in two groups with a different statistical bandwidth demand.
The first group has a constant bandwidth demand, as long as the connection between the two communicating devices last. Examples of this type of traffic are telephone, videophone and video.

The second group has a variable bandwidth demand, with a relative high peak to average ratio, during the time it is serviced by the network. Examples of this type are terminal to host communication and file transfer.
In [2] this distinction is also made. The first type is called the Continuous Bitstream Oriented (CBO) traffic type and requires a circuit switch mode of network allocation. The second type is called Distributed Bitstream Oriented (DBO) traffic and is best serviced with a packet switched mode of network allocation.

2.1.1 Characteristics of speech traffic

Speech conversation is at the moment the most spreaded CBO traffic type, and will probably also demand a high portion of the WOCS capacity assigned to CBO traffic. For this reason we will look a little closer to the characteristics of speech sources. For further research this traffic type will be the model for the CBO data, which is offered at the systems input.
We must however not forget that the system has to satisfy also the requirements of other CBO traffic types like videophone, video conferencing, audio programmes and television programmes.

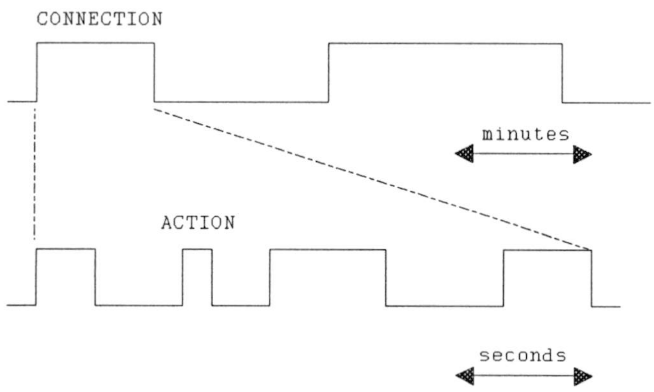

Figure 3 : Two levels of speech traffic

A speech source creates a pattern of talking periods (called talkspurts) and silent periods. In a talkspurt period the full bandwidth is required, and in the silent periods none. By using a speech detector these two periods can be separated, with the benefit that the bandwidth which is not necessary in the silent periods can be used by other sources.
In figure 3 the two levels of description of the speech traffic is shown. At the highest, the CONNECTION level, the traffic source establishes and breaks down the connection. At this level, congestion may occur in a similar way as for the circuit switched type of connection in the Erlang loss model, which is described in [3].
At the second, the ACTION level, the talkspurt or ACTION periods are alternated with the silent periods. There are two different speech detectors, which can be distinguished, a fast and a slow detector. A slow speech detector can only detect the principal spurts and gaps, due to the pattern of speaking, pausing and listening in a conversation. A fast speech detector can also detect very small gaps in a principal talkspurt due to punctuation in continuous speech.
According to [4], all spurts and gaps have a negative exponential distribution while they are acting. In [4] the MARKOV models for the slow as well as the fast detector are presented. For our calculations it is sufficient to know the average spurt and silent periods. The average time for the talkspurt and the silent periods appear to be 1,00s and 1,35s respectively, which results in an activity factor of 0,427 . For a fast detector an activity factor of 0,368 is found.
For the WOCS the slow activity detector is assumed. So 57,3% of the capacity assigned to a speech source can be used by other sources.

2.1.2 Characteristics of DBO traffic

The delivery of data packets by DBO sources are considered to be memoryless with a constant chance of occurrence. Under these constraints the flow of data from the DBO sources has a geometric distribution [3].
If the chance that the source delivers a packet to the WOCS for transmission in a specific small period of time is "p" then the chance that one packet has to be transmitted in "i" of this time periods is:

$$p_i = (1 - p)^{i-1} * p \qquad i = 1,2,.. \qquad (1)$$

It easy to prove that the average time between two data deliveries equals "1/p".
When a DBO packet is lost, for instance by collision with another data packet, or because of a high noise level, it is retransmitted. This has to be done because this kind of traffic type is not allowed to have any data loss. This is why the data packets from the DBO sources are buffered, to make a retransmission possible.
Three possible modes are described for this type of data terminals. The originating mode , the transmission mode, and the backlog mode. In the originating mode, new packets are generated and transmitted in the next time slot with probability p_o. Terminals enter the backlog mode when a packet is transmitted unsuccessfully. The terminal can only be in one state at the time. This means that terminals in the backlog mode can not transmit new packets until the backlog packet is transmitted correctly. The model uses different probabilities of new packets being transmitted in any slot with probability p_o and retransmission of a backlog packet in any given slot with probability p_r, as depicted in figure 4. With the general arrival model, the subsystem can be described as a markov chain model. In [5] this markov chain model is worked out.

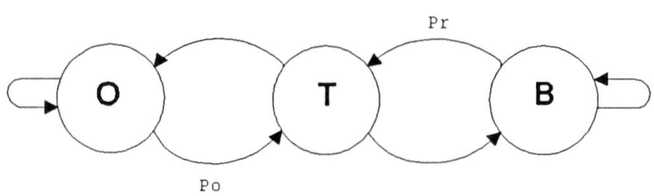

Figure 4 : DBO terminal states.

2.2 The output specification

The output of the system is the transportation of the offered data from source to destination, which fulfils a specified quality of service.
For the CBO traffic the real-time requirements are most important and a low error rate has a lower priority. This can be characterised as the "no delay - little loss" requirement.

Typical quality requirements for speech traffic are:

- maximum transfer delay of 32 msec
- maximum blocking probability of 1%
- maximum loss probability of 1%

On the other hand for the DBO traffic very high requirements are given for the loss of data and there is some delay acceptable. This is called the "no loss - little delay" requirement.

Typical quality requirements for DBO traffic are:

- maximum transfer delay of 1 sec
- maximum loss probability of 1 E-08

2.3 The external factors

There are a lot of aspects, which influence the WOCS. Here some major ones will be described and a summarization of several others will be given.

2.3.1 Hidden Terminal problem

A problem in an office environment is that there are many situations in which terminals are hidden from each other. This could simply be because of a long distance, or for instance caused by a concrete wall, ceiling or floor.

To overcome this hidden terminal problem, the complete user population is divided into groups of users, which are relative close to each other. Within each group there are CBO as well as DBO sources. We consider each source stationary coupled to one group. The groups are separated from each other by a relative high attenuation.

Neglecting the influence of noise, fading and interference we consider that all sources within a group can receive each other perfectly, and sources from different groups have no influence on each other. How this separation can be achieved is discussed in the next subsection.

As a starting point we take a medium size office, which consists of ten groups and a maximum of 20 CBO and 20 DBO traffic sources per group.

2.3.2 Available bandwidth

It is clear that the available bandwidth is dependant on the used carrier frequency. For this reason the 20-60 Ghz, the UHF and the infrared frequency regions will be evaluated.

In the infrared region at about 300 Ghz, only line of sight links can be used. Because in an office environment a lot of obstacles are present between the terminals of a group this is not a practical solution.

Advantages of the 20-60 Ghz region above the UHF region from about 900 Mhz - 1.7 Ghz are according to [6] :

- unlike UHF signals, the signal is shielded within the room, bounded by concrete or steel walls.
- because of the millimetre wavelength, antenna size can be very small.
- the frequency region is not in use by any other communication medium, so every channel can be allocated a large bandwidth: 100Mhz channels can be used without any bandwidth problem.

A major drawback of the 20-60 Ghz frequency region is the fact that the technology for transmitters and receivers has not yet been developed. As a consequence of this, the hardware will not be available for quite some time and will be expensive in the early stages. Because of this reason the investigation will concentrate on the UHF region.

In Europe the available bandwidth for the LAN's and WAN's is from 1880-1900 Mhz. [7]
In [8] a possible data rate of 2 Mbit/s is achieved in an 11 Mhz spread spectrum bandwidth, using DQPSK modulation at a carrier frequency of 915 Mhz. In [9] however is stated that with technology developed by the US military a maximum bandwidth of 1 Mbit/s is achieved in the UHF band using the spread spectrum technology.
In this report a maximum available capacity of 1 Mbit/s for every link is assumed for the WOCS.
Using the spread spectrum technology or cellular frequency allocation several of these links can be used in the WOCS.

In the former section is stated that within every group each terminal can perfectly hear every other terminal of the same group, and cannot hear a terminal from another group. So it is assumed that all the terminals of one group have to share the capacity of 1 Mbit/s. How the communication between the groups is done is described later on.

2.3.3 System costs

When the system has to be realised it is very important this can be done as inexpensive as possible. When choosing the medium access technic and a modulation type the availability on the marked for reasonable prices has to be taken into account. If some wiring is necessary the costs of exploitation must be low. For all items in the system choosing a standardised version will also decrease the overall system costs.
For the system specific parts, which are not standardised, we do not calculate on much higher costs for a more complex system. With the state-of-art technology of today, microelectronics, monolithic integrated circuits and digital processing techniques, cost and complexity are not strongly linked.

2.3.4 Other design aspects

When making choices in the design of the WOCS the next aspects have to be taken into consideration:

- connectivity
- availability
- flexibility
- maintainability
- reliability
- standard interfaces
- standardization
- expansion capability

3 THE SUBSYSTEMS OF THE WOCS

In this chapter we will open the blackbox and look at the main subsystems of the WOCS.

In the former chapter we considered several distinguished groups of users. All users of one group share a common radio link. Traffic between the groups has to be transported over a separate link. Giving these transmission paths, a possible internal structure of the WOCS is shown in figure 5.

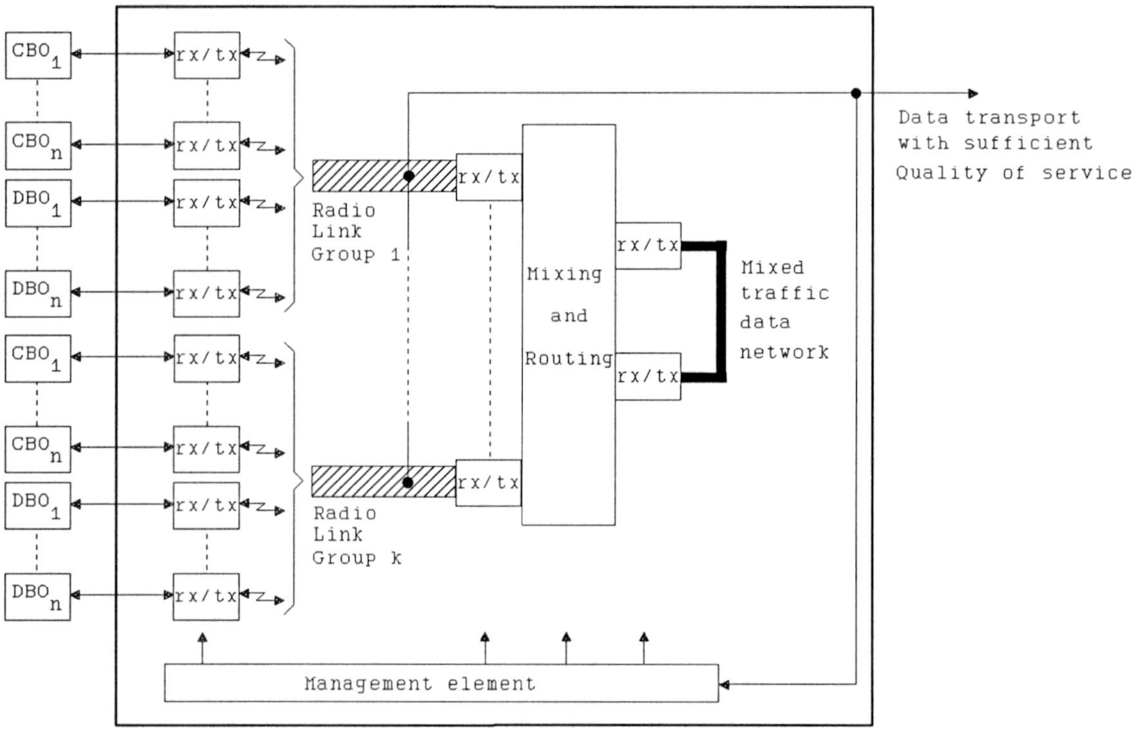

Figure 5 : The subsystems of the WOCS

The following subsystems can be distinguished:

1) The receiver/transmitter (rx/tx) on the group radio link.
   This rx/tx takes care of the data transport to and from the data sources and represents the first two OSI levels.

The only aspect that is investigated about this subsystem, is the access protocol to the radio link, which is described in chapter 6.

2) The receiver/transmitter (rx/tx) on the data network link.
   This subsystem takes care of the mixed data transport between the nodes, which are attached to the mixed traffic data network. This device delivers a service for the first two OSI levels.
   Also for this subsystem the access protocol to the network is the only aspect, which is worked out. This can be found in chapter 7.
3) The group radio link
   This link performs the physical data transport to and from the group terminals. As already mentioned, for our investigation we assume an available capacity of 1 Mbit/s. Physical aspects like spectrum allocation, noise, capture, fading and multipath propagation are not subjects of this report.
4) The mixed traffic data network.
   This network performs the physical data transport between the groups. The medium over which this network transports its data, like for instance a radio link, copper wire or fibre, has to be determined. Some notes on this are made when describing the access protocol in chapter 5. Further aspects of this subsystem are not discussed in this report.
5) The mixing and routing subsystem.
   This device picks the data from the group radio link, it looks at the address and sends it to the appropriate destination group link. Therefore it mixes the data from several sources and transports it over the data network.
   In chapter 8 the internal structure of this subsystem is described.
6) The management subsystem.
   This subsystem measures the output of the system, and controls the Medium Access Control (MAC) layers of the rx/tx on the radio link and the mixed data network, and the mixing and routing subsystem. How this can be done is described in chapter 9.

Before looking to some internal aspects of several subsystems, as mentioned above, the next chapter contains an intermezzo about resource allocation methods.

4 RESOURCE ALLOCATION METHOD.

Examining the different connection resource allocation mechanisms, which can be applied for the data links of the WOCS, one can distinguish between two extremes with regard to the method of connection resource allocation. This allocation method can be either on deterministic basis or on statistical basis.

In the case of deterministic resource allocation the maximum amount of required resources per source (peak bit rate , memory occupancy) is reserved during the connection, whereas in the case of statistical resource allocation a statistical rule for the utilization of resources is maintained.
By definition statistical resource allocation for a number of sources requires fewer resources than the accumulated peak demands of the individual sources.

In [2] an analysis is given for the CBO/DBO source type versus connection resource allocation. Here a brief summarization will be given with the main conclusions.

Mapping the CBO/DBO traffic source types onto the deterministic /statistical network connection resource allocation mechanisms, leads to a matrix as depicted in figure 6. This matrix gives rise to the analysis of four different cases.

Case 1: CBO-traffic related with deterministic resource allocation.
The continuous bit-rate nature of the CBO sources are allocated a constant bit-rate service by the network during the connection period. This solution is robust and guarantees a constant quality of service for the traffic sources.

Case 2 : DBO-traffic related with deterministic resource allocation.
The maximum peak bit-rate, which can be generated by the DBO source is taken for network resource allocation. This method results in inefficient use of network resources, all the more if the peak bit-rate is much higher than the average demand.

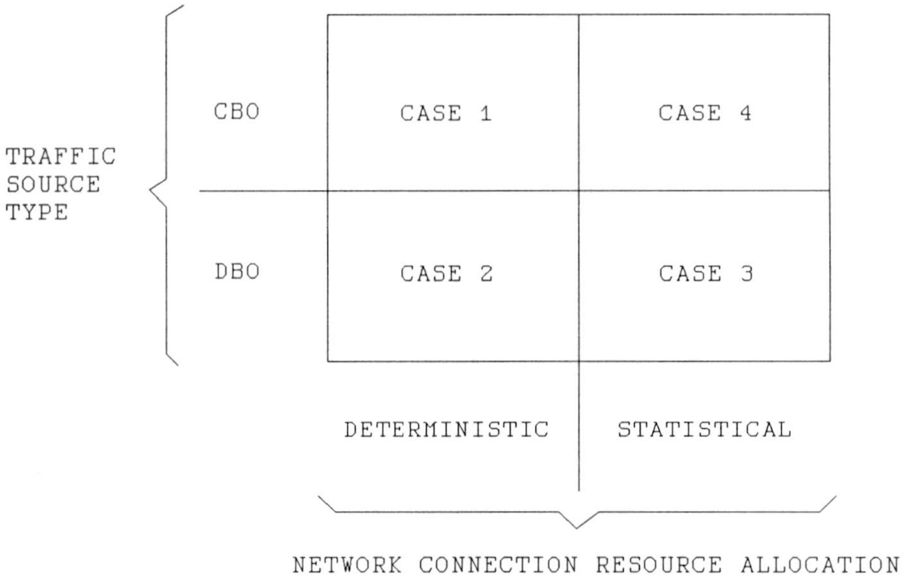

Figure 6 : Traffic source verses network connection resource allocation.

Case 3: DBO–traffic related with statistical resource allocation.
As a substantial part of data traffic sources have a bursty nature, network resources can be utilised in an efficient way by allocating less than the accumulated peak bandwidth demand of the individual sources. In extreme cases of congestion, serious transfer delays may occur during a connection.

Case 4: CBO–traffic related with statistical resource allocation.
Statistical connection resource allocation of CBO traffic sources may easily lead to unacceptable quality of service due to the high transfer delay and/or high user information loss probabilities. Only in the case of low traffic load, or in the case of intentional overdimensioning of network resources, acceptable quality of service may be achieved.

From the four different cases it can be concluded that optimally feasible and economical solutions are offered by Case 1 and 3. Hence, an optimal network connection resource allocation concept will apply deterministic as well as statistical allocation, dependant on the type of traffic source, namely CBO and DBO respectively.

The conclusion is that the optimised transfer network concept is achieved if both Case 1 and 3 are applied in a dynamic fashion.

5 SYSTEM STRUCTURE

5.1 Structure of the radio link

With the conclusion of the former chapter we can split the radio link into three parts.

1) A deterministic part for the data to and from the CBO sources.
   Each source is assigned a fixed slice during the time of the connection. Depending on the number of communicating sources the total deterministic part will vary in time.
2) A stochastic part for the data to and from the DBO sources.
   All DBO sources have to content for a slice the capacity, which is assigned for DBO traffic. Because the deterministic capacity part is variable, also the total size of this stochastic capacity part will vary in time.
3) A part of the capacity must be reserved for CONTROL data to and from the management system.
   This is necessary to determine the size of the CBO and DBO capacity part. Also CONTROL data must be exchanged to prevent the links from congestion and achieve a maximum throughput. This type of data must always come through; it therefore gets the highest priority. On the other hand the size of the flow of this data does not vary much in time. For these reasons a fixed part of the link capacity is assigned to the CONTROL data.

The most common way to transport digital data over medium is to apply time division between separate data packets. Here a slotted version will be used. So every traffic source has during a short period of time the total link capacity at its disposal. A CBO source is assigned a fixed number of timeslots during the duration of the connection. All DBO sources must try to get there data packets transported by applying a slotted ALOHA scheme on the available time slots. For the CONTROL data a fixed number of time slots are assigned. In figure 7 this scheduling is schematically shown.

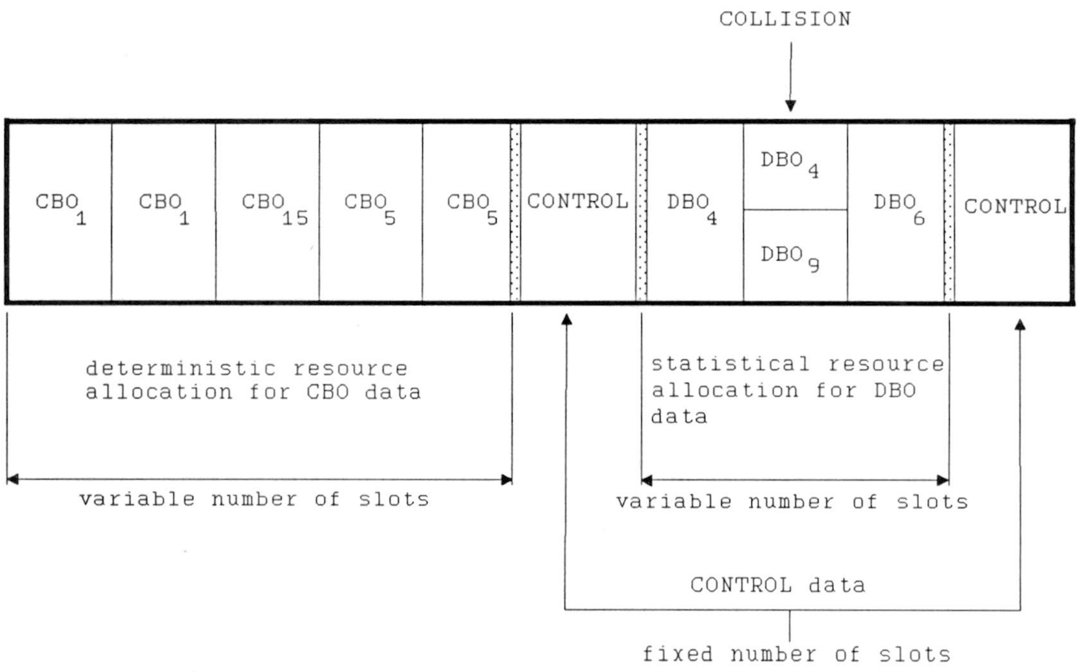

Figure 7 : Time division of a group radio link

5.2 Structure of the mixed data network

When the data is received from a radio link of one group all packets must be split, and routed to the appropriate destination, link belonging to the group, which contains the destination of the packet.

The network has to have a relative high capacity because it has to transport all generated data by all terminals.
This is why the application of a radio link for this network will restrict the systems capacity in a disproportional way. Consider for instance the Inhibit Sense Multiple Access with Code Division Multiple Access (ISMA/CDMA), which is described in [10].
In this scheme all separate groups send data over a group radio link to a common node, with distributed receivers, one in every group.

All data received by the central group node is broadcasted to all terminals of all groups in a common channel. In this way the hidden terminal problem is solved because the central node can be heard by every terminal. The problem with this solution is that the broadcast channel has to transport all data of all group links, and therefore becomes the systems bottle neck.

A better way is to do some copper or fibre wiring, for example between the groups and a central node in a star topology, or between the groups in a ring or a bus topology.

A star topology has the advantage of its simple communication protocol because the central node could be a simple time sliced circuit switch giving a deterministic resource allocation. The disadvantage of this topology is the dependence of the reliability of the central node. A second disadvantage is, that more wiring is necessary.

If we use a ring or a bus structure we can best apply one of the already developed LAN standards described for instance by IEEE 802. In this case several nodes are attached to the LAN, which take care of the transmissions between the groups.
Some of these LAN protocols make it possible to assign a fixed portion of the capacity to circuit switched traffic, and leave the remaining part for a statistical allocation by other traffic types. It is also possible to give a higher priority to CBO data than to DBO data on these LAN's. This makes it possible to satisfy the requirement for low transmission delay by CBO data. In chapter 7 several standards are described.
Now the subsystems of the WOCS and the desired resource allocation methods are defined and therefore the system structure can be determined.

In figure 8 the structure of the WOCS is depicted. There are several separate groups, with CBO as well as DBO terminals. Every group has its distributed part of "the mixing and routing" subsystem, which was mentioned in chapter 3. This distributed part will be called the Group Base Station (GBS). All the GBS's are mutually connected by a copper wired or glass fibre LAN.

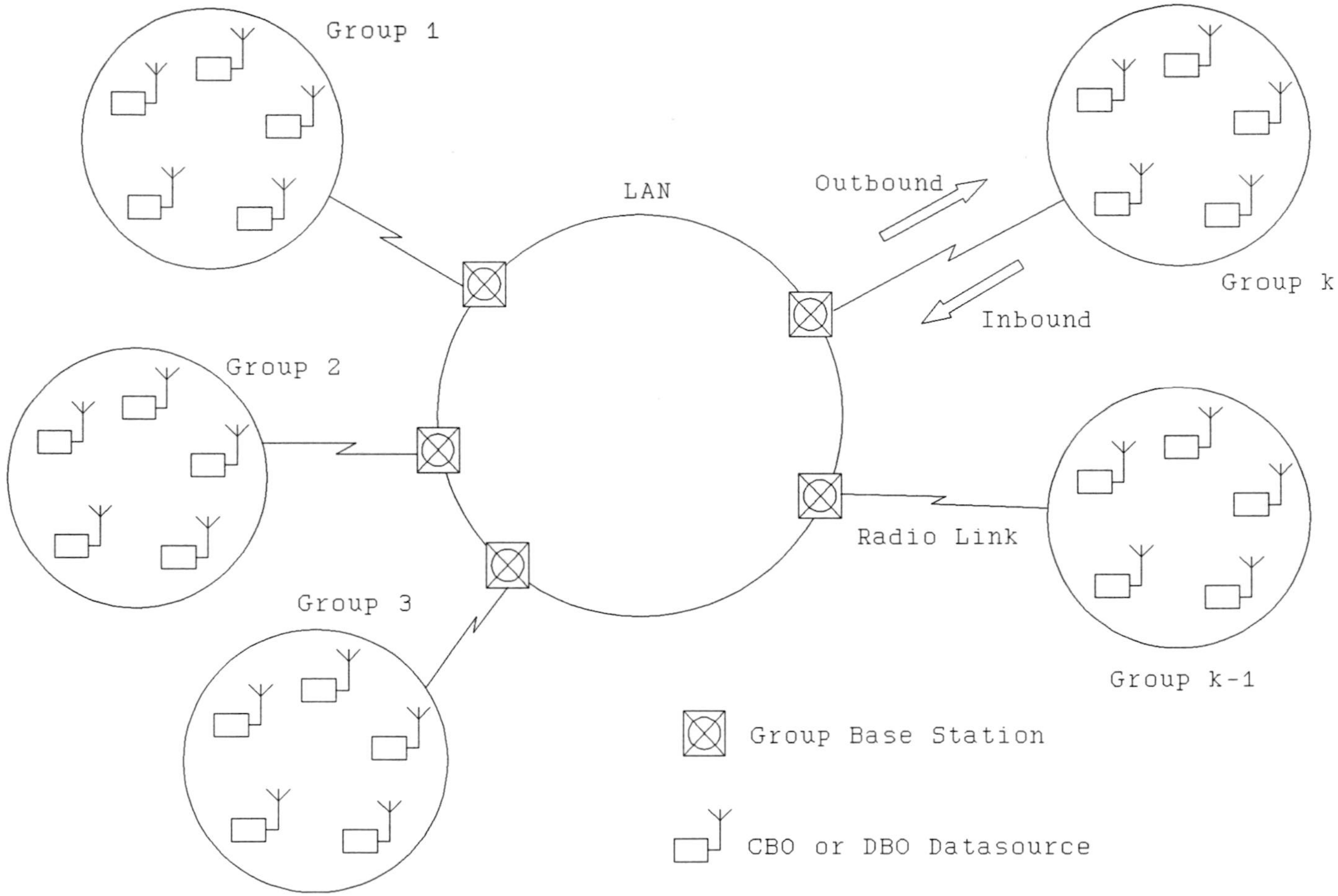

Figure 8 : Structure of the WOCS.

Each group has its own radio link. All DBO and CBO terminals and the GBS of one group have access to this group radio link. Data from the LAN towards the group is called outbound traffic and the opposite direction inbound traffic.

The protocol, which is used on the LAN will, be discussed in chapter 7.

6 THE ACCESS PROTOCOL TO THE GROUP RADIO LINK

In literature, for example in [11] – [16], a lot of articles can be found about protocols, which handle mixed voice/data traffic. Little of them use the available bandwidth in the silent periods.
One protocol, which does use this capacity is Packet Reservation Multiple Access (PRMA). This protocol is shortly described in section 6.1.
In [16] a protocol is described, which also uses the silent periods in a speech conversation. But the used method is based on based on the PRMA protocol, and therefore this protocol is not discussed here.
In section 6.2 a new protocol "Circuit Reservation Multiple Access" (CRMA) is described, which is not only applicable for speech CBO traffic, but also for other types of CBO traffic.

6.1 Packet Reservation Multiple Access

Packet Reservation Multiple Access (PMRA) is a slotted contention protocol which allows a mixture of voice packets and packets from data sources over short range duplex radio links.
In [11] a detailed description of the PRMA protocol is given. In [17] the packet loss probability is presented for the PRMA protocol.

With PRMA, slots are dynamically reserved for active voice terminals in each frame. The CBO user has to contend for reservation of the time slot by first transmitting a packet successfully. On successful transmission of a CBO packet the GBS grants reservation of the time slot in future frames to that CBO source. After the source has finished transmitting all its packets during a talkspurt, it leaves a slot blank which indicates that from the next frame. This slot is free for contention.

In case of DBO packets there is no reservation facility, and terminals have to contend for successful transmission of their packets in every frame. DBO terminals can only contend for time slots which are not reserved. The contention is done using the slotted ALOHA protocol.

During contention, if a packet stays in the terminal buffer for a very long time the oldest packet is discarded. and new packets are admitted in the buffer. DBO buffers can be longer than speech buffers.

Data to the group terminals, acknowledgements and CONTROL data, are sent in the outbound channel of the full duplex link by the GBS.

When a slot is reserved by a CBO source for future use, the GBS broadcasts a signal "reserved" to all the group users for this slot, otherwise a signal "available" is sent out for this slot.
At the end of every slot an acknowledgement is given by the receiving station.

With PRMA, most packet losses occur at the beginning of talkspurts. This front end clipping is less harmful to subjective speech quality than other types of packets.

This protocol results in a relative high correlation between the DBO arrival rate and the CBO loss probability.

6.2 Circuit Reservation Multiple Access

6.2.1 Introduction to the CRMA protocol

The PRMA gives a sufficient performance for speech traffic which can suffer a loss probability of 1% with negligible quality decrease, and up to 5 % without a major degradation in performance. For CBO data which are not allowed to have that much packet loss, another protocol, which is called "Circuit Reservation Multiple Access (CRMA), is proposed.

The CRMA protocol can be described as follows :

- The protocol uses a "half duplex" or "two way alternate" radio link. So all CBO and DBO sources and the GBS belonging to one group share a common channel.
- A CBO source first has to contend for a connection. When it is assigned a connection by the GBS, two time slots are reserved for

this source, one for the inbound, and one for the outbound packets of the duplex connection between source and destination.

- When the connection period is finished, this is signalled to the GBS, by the CBO source, and the slots are available for contention for other traffic.
- When a slot does not contain any CBO packet it may be used for DBO packets. This happens in periods of silence between the talkspurts, or when a channel is not reserved for a connection by a CBO source.
- Whether a DBO source should transmit a packet in a specific timeslot, is determined according to the slotted ALOHA protocol.
- When a DBO source wants to transmit a packet in a specific slot, it listens to the channel for a short period at the beginning of that slot. This period is long enough to assure that no CBO packet is transmitted by one of the group terminals or the GBS. When the DBO terminal does not sense a carrier of a CBO source, the slot is accessed according to the slotted ALOHA protocol.
- When a DBO packet is successfully transmitted, an acknowledgement is given by the receiving station.
- The contention for a connection by a CBO source is handled just like a DBO source. When a "request connection signal" successfully reaches the GBS, this station signals the CBO source which slot may be used for the outbound and which slot for the inbound traffic.
- The CBO packet is transmitted from the beginning of the slot to the end of the slot. For voice traffic no acknowledgment is given by the receiving station and the packets are not buffered in the transmitting station.
- For CBO traffic which requires a very low data-loss probability there are two possibilities. The first one is to apply a fault correcting code. The second is to add an acknowledgement. In latter case also a buffer in the transmitting station must be added to make retransmissions possible.
- The frame length has to be derived from the slowest CBO traffic type. This type is assigned one slot in every frame, or two in case of a duplex connection. Faster CBO traffic sources can be assigned multiple slots in every frame, to make a higher bitrate possible.

The advantages of this protocol above PRMA are.

- CBO packet loss will be much lower, because no packets have to be thrown away at the beginning of every talkspurt. With PRMA this was the case by exceeding a time delay.
- While there is no buffering a lower time delay is accomplished.
- Loss probability of CBO packets is not correlated with the arrival rate of DBO packets.
- No destination header for the CBO packets has to be added per packet, because the receiving station knows in which slot the packets for a connection are sent. Only once, when building up the connection, the destination address must be told to the GBS.
- No "reserve" and "available" signals have to be broadcasted. Frame reservation registers are not necessary in the CBO and DBO terminals.

It is clear that the CRMA exchanges a little of the link capacity, for a lower probability of loss. The reason for this is that the channel is not used, when a DBO terminal senses for an absent CBO carrier, at the beginning of a timeslot.

Because the WOCS also has to fulfil the demands of CBO traffic with a low loss probability requirement, the CRMA protocol is chosen to be used on the group radio link.

6.2.2 Accessing the radio link with CRMA

Following figure 9 a description of the access mechanism of the CRMA protocol is given. In the next sections the timing of the transmission is worked out.

A slot can contain three types of data packets.

1) CONTROL data packets
   This type of packet is generated in the management subsystem. The GBS transmits this in a fixed timeslot. All DBO and CBO terminals receive this CONTROL data.

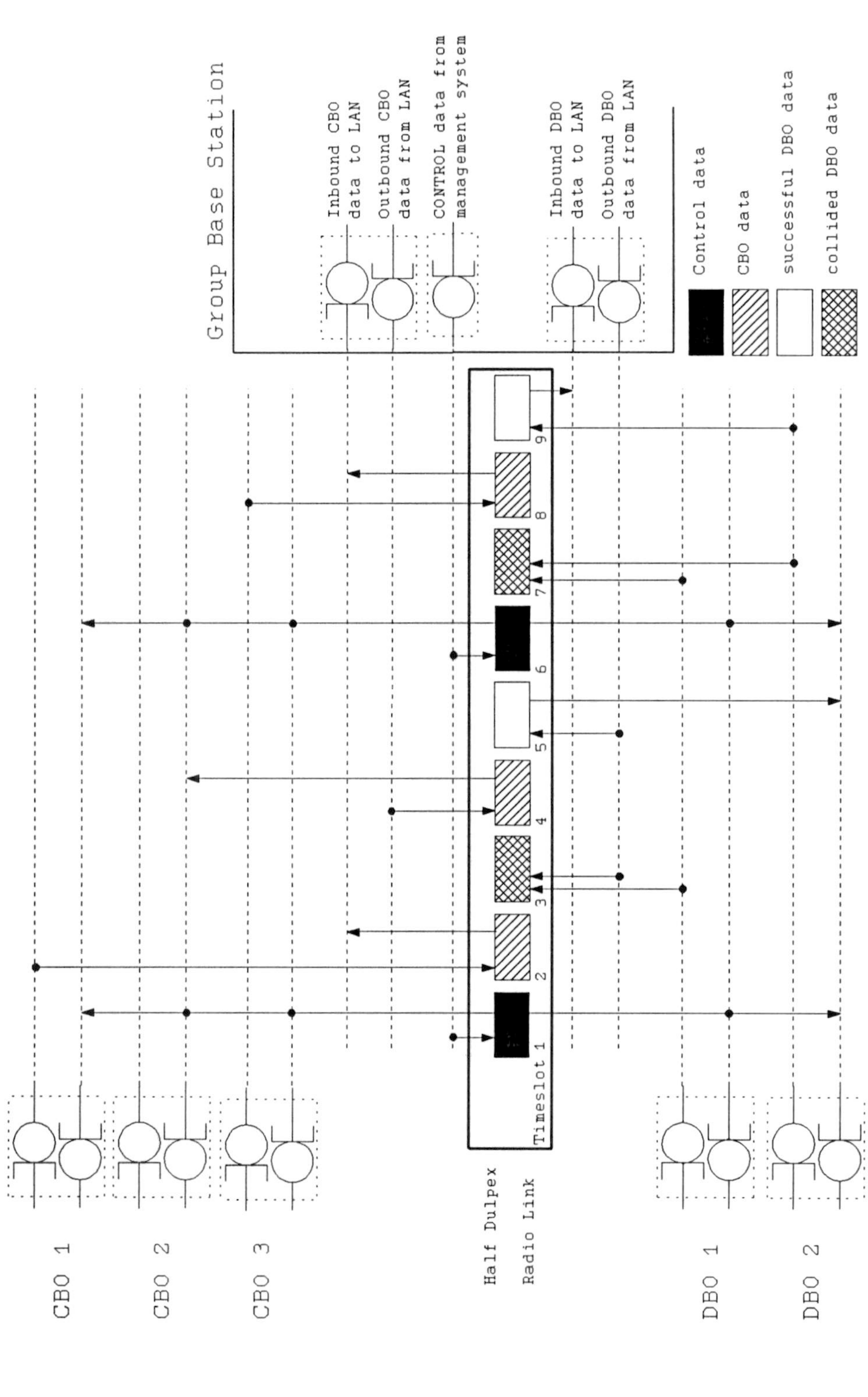

Figure 9 : Accessing the half duplex radio link with the CRMA protocol.

2) CBO data packets
   When a connection is built up by a CBO source a timeslot is reserved for this source. This source may be one of the group CBO terminals or the GBS. In case of a duplex connection, for example a telephone call, two timeslots are reserved, one for the inbound and one for the outbound data packets.
3) DBO data packets
   When a slot is not assigned for control data and not reserved or not used (for example in silent periods between talkspurts) for a CBO data packet, it is free for contention for DBO data sources. These sources may be one of the group DBO terminals or the GBS.
   The contention of the free slots for the DBO packets is done like the slotted ALOHA protocol. So if two terminals want to transmit at the same time a collision will occur. "No capture" will be assumed. So when two packets collide none of them is successfully received.

Inbound data packets are placed on the link by the group terminals and picked from the link by the GBS. The GBS will send these data packets over the LAN to the GBS of the destination group.

Outbound data packets are first picked from the LAN by the GBS and then placed in one of the link timeslots. The destination terminal will pick the packet from the link.

Control packets are placed on the radio link by the GBS and picked from the link by all CBO as well as DBO terminals.

In figure 9 there are 9 numbered timeslots. For each of them a short description will be given.

Timeslot 1: The GBS sends a control packet. All CBO and DBO terminals pick this packet from the radio link.

Timeslot 2: CBO 1 sends a packet. The GBS receives it and places it on the LAN. If the destination is one of the terminals of its own group, the GBS places the packet back on the radio link.

Timeslot 3: DBO 1 and the GBS have seen a free timeslot and both transmit a DBO packet. A collision occurs and both packets get lost.

Timeslot 4: The GBS sends a CBO packet to the CBO 2 terminal.

Timeslot 5: The GBS sends a DBO packet to DBO 2. No other terminals have sent a packet so the transmission is successful.

Timeslot 6: See timeslot 1.

Timeslot 7: See timeslot 3. Only in this case DBO 1 and DBO 2 try to access the free timeslot.

Timeslot 8: CBO 3 sends a packet to the GBS, which transmits it over the LAN to the destination.

Timeslot 9: DBO 2 successfully transmits a packet to the GBS.

6.2.3 Timing of the transmission of a CBO packet

Because a slotted protocol is used, the internal clocks of all terminals must be synchronised. The GBS has the masterclock and sends at the beginning of every CONTROL packet a synchronization signal for adjusting the internal clocks of all terminals. Due to the propagation delay the clocks of the terminals will lag with the masterclock. The furthest terminal will experience the worst case propagation delay "a". To avoid collision of bits from packets in adjacent slots, we must keep account with this synchronisation time, and introduce a gap equal to "a" between the slots.

The propagation delay is, next to this synchronisation aspect, also responsible for some time delay between the transmission and the receiving of a packet. Before starting the transmission of the first bits in a new slot, it must be certain that the last bits in the old slot have been received. This is why an extra gap, with the duration of "a" must be added between the slots.

Both above mentioned aspects result in a necessary gap of "2a" between the slots. With the CRMA protocol this gap is placed at the end of the slot. This is why a CBO source cannot transmit during the complete slot time. In figure 10 the timing diagram of a CBO packet transmission is given. This transmission may be done by one of the CBO terminals or the GBS.

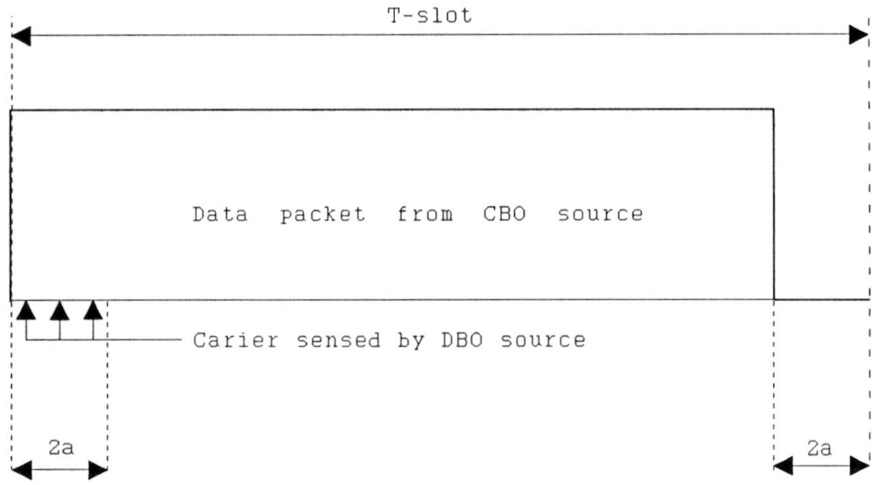

Figure 10 : Timing of a CBO packet transmission.

Directly at the beginning of the timeslot the CBO source starts the transmission. It continues the transmission almost until the end of the timeslot. Only at the end a short time, which lasts "2a" no transmission is done.

In principle no acknowledgement is given. This is why some packets may be lost because of noise.

At the beginning the channel is sensed by a DBO terminal, which wants to transmit. Because it sees a carrier it does not try to access the channel in this timeslot.

The timing of a CONTROL packet is just like that of a CBO packet.

6.2.4 Timing of the transmission of a DBO packet

In figure 11 the timing diagram for transmitting a DBO packet is shown. A terminal or the GBS, which wants to transmit a DBO packet first has to wait a short time to start transmission.

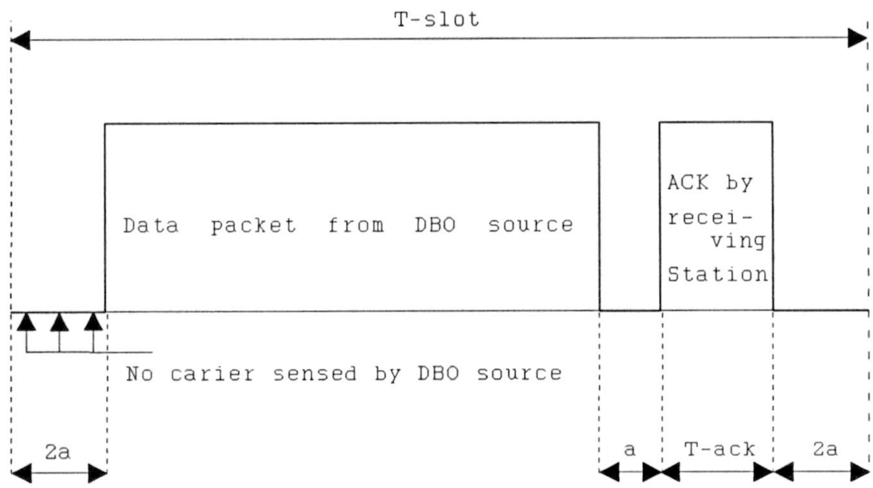

Figure 11 : Timing of a DBO packet transmission.

Due to the synchronisation lag a DBO terminal first has to wait a time "a" to be sure that a CBO terminal may have started transmission.
On top of this it also has to wait a period "a" to be certain, that a signal from the furthest station is received. This is because of the propagation delay.

This is why a DBO terminal senses the channel for a period of "2a" before transmitting, to find out if a carrier is transmitted by one of the CBO sources. If no carrier is sensed the channel is free for contention by one of the DBO sources, and the DBO terminal sends its packet.
If no other DBO source has transmitted a data packet in the same slot and the noise level is not too high, the packet will be received successfully.
The transmission just lasts that long, to make an acknowledgement in the same timeslot by the receiving station possible. Therefore it takes the propagation time "a" for the last bits of the DBO packet to reach the receiving station. In this case the synchronisation lag has no influence, because the receiving station, exactly knows when the last bits of the packet are received.
After receiving the last bits, the destination station has to check the incoming packet, and sends an acknowledgement if the transmission has

been successful. The time "T_ack" includes the processing time and the time to transmit the acknowledgement packet.

Because of the reasons mentioned in the former subsection, it is necessary to separate the slots by a silent period. Therefore the last bits of the acknowledgement packet must be sent "2a" before the slot period has finished.

A lot of measurements to indoor propagation characteristics have been done. From [18] and [19] it can be concluded that the worst case propagation delay in an indoor environment not exceeds 1 μsec. This includes a multipath time delay spread of about 400 nsec.

6.2.5 CRMA link capacity calculations

In this subsection an example of the CRMA link capacity is calculated. For this example only one CBO traffic type, i.e. speech is considered. Calculated is how much effective DBO data transport can be accomplished, giving several assumptions.

Because speech is the only traffic type, the frame-repetition frequency and the slot-length should be based on this type. A frame repetition frequency of 1/T_fr, with T_fr = 16 msec is chosen.
Speech can be coded with a bitrate of 32 kbit/s. This results in a packet size of 512 speech bits. This packet size is typical of those considered in packet voice studies.

For the calculations the various parameters are given the following values:

transmission rate	:	f_tr	=	1 Mbit/s
propagation time	:	a	=	5 μs
processing time	:	T_proc	=	7 μs
number databits CBO packet	:	# bit CBO	=	512 bit
number header bits DBO packet	:	# hdr	=	48 bit
number check bits DBO packet	:	# chk	=	16 bit
number acknowledgement bits	:	# ack	=	8 bit

number CONTROL slots per frame:	# CTR sl	=	3 sl
number CBO terminals per group:	# CBO term	=	20
number DBO terminals per group:	# DBO term	=	20
outbound traffic/CBO terminal :	outb tr/CBO term	=	0,1 erlang
inbound traffic/CBO terminal :	inb tr/CBO term	=	0,1 erlang
activity factor CBO traffic :	act fact	=	0,427

Some remarks on this data.

- Although measurements point out that the maximum propagation delay not exceeds 1μ sec, here this delay is chosen to be 5μ sec for security.
- CBO connections, which are blocked because the maximum number of assigned CBO slots have been exceeded, are assumed not to be lost, but rescheduled. Here the average traffic CBO demand is given.
- The CONTROL data is estimated to require about 10 percent of the link capacity.
- A slow speech detector is applied, which results in the given activity factor.
- For every erlang of CBO traffic two slots are required. This is necessary to accomplish the duplex connection.
- The maximum throughput for slotted ALOHA equals 1/e $\approx$ 0,368. [20]

Using this data, the following calculations can be made :

T_sl	= (# bit CBO)/f_tr + 2a	= 522 μs
# sl/fr	= integer(T_fr/T_sl)	= 30 sl/fr
tot CBO tr	= (inb + outb tr/CBO term)*(# CBO term)	= 4 erlang
# sl CBO	= tot CBO tr * 2 sl/erlang * act fact	= 3,42 sl/fr
# sl DBO	= # sl/fr − # sl CBO − # CTR sl	= 24,1 sl/fr
max # succ DBO sl	= (1/e) * # sl DBO	= 8,68 sl/fr
T_ack	= T_proc + # ack/f_tr	= 15 μs

T_data = T_sl - 5*a - T_ack = 482 μs

eff fract DBO = [T_data - (# hdr + # chk)/f_tr]/ T_sl = 0,8

max eff DBO time

= max # succ DBO sl * eff fract DBO * T_sl = 3,623 ms

transm cap DBO = (1/T_fr)*(max eff DBO time)* f_tr = 226 kbit/s

With 20 DBO terminals in every group a maximum transmission rate of 11,3 kbit/s per terminal can be achieved. This is only valid if the channel is stable, and it operates in the neighbourhood of its maximum throughput. These latter aspects are discussed in chapter 9.

In figure 12 an example of a timing diagram of one frame is given, with the assumed values for the different parameters.

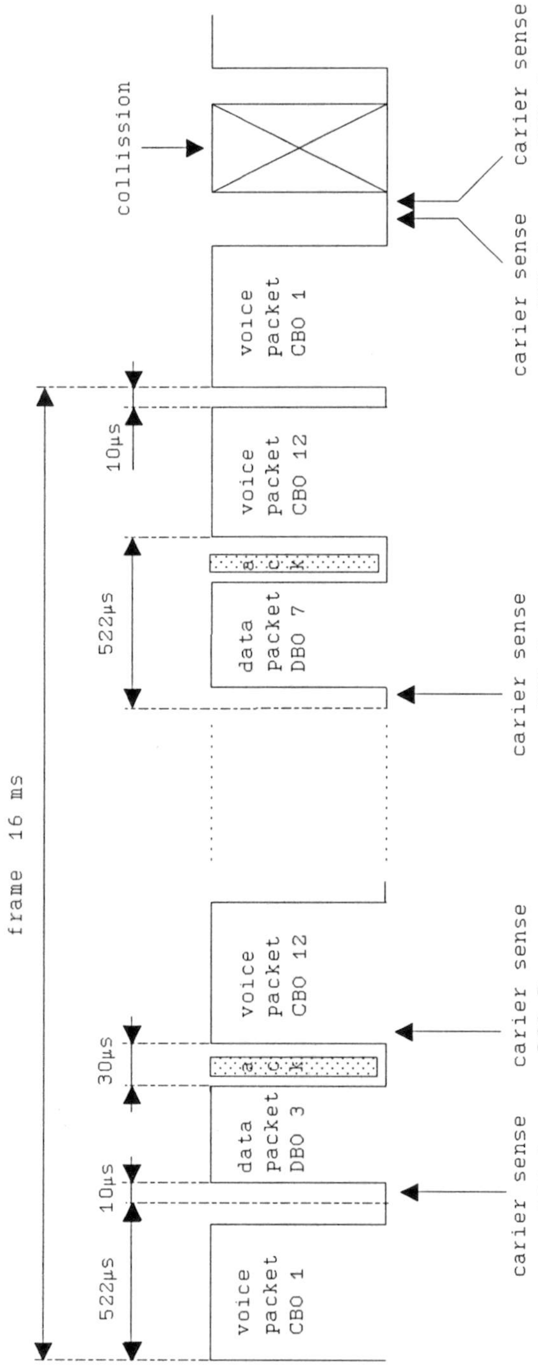

Figure 12 : Example of a CRMA frame structure with combined CBO speech and DBO data traffic.

7 THE ACCESS PROTOCOL TO THE BACKBONE NETWORK

In chapter 5 it was concluded that the best way to realise the mixed data network is to apply a ring or a bus Local Area Network. In these networks a distinction can be made in low-speed and high-speed LAN's.
A short description of three well known low-speed LAN's is given in section 7.1. A more extensive description three high-speed LAN's is given in section 7.3 to 7.5 . The final section contains an evaluation and one of the protocols is chosen.

7.1 Low-speed LAN's

In [20] an explanation of three different 802 standards is given. Also their advantages and disadvantages are summarised.

The IEEE 802.3 describes a 1-persistent Carrier Sense Multiple Access with Collision Detection (CSMA/CD) LAN. When a station wants to transmit it senses the channel. If the channel is idle it immediately starts transmission, otherwise it waits until the channel becomes idle. If a collision is detected the station immediately ceases the transmission.
This protocol gives a statistical allocated resource. It is a simple protocol, which is widely used. However according to the conclusion in chapter 4 this can only be used for the CBO traffic source when this one is intentional overdimensioned.

The IEEE 802.4 describes a token-bus system. In this system a token is passed along a logical ring, from one station to its direct neighbour. A station can only send frames if it possesses the token. Because a station is allowed to hold the token for a limited time, the token rotation time is bounded to a maximum.
An advantage of the system is that the physical order of the stations on the cable is of no importance. The system can work with priorities so it is possible to reserve a constant bandwidth for CBO traffic.

The third low-speed LAN standard is the IEEE 802.5 token-ring. In this system a token is passed from one station to another, which means its physical neighbour in the ring. Like in the former system priorities are possible giving the desired deterministic resource allocation for the CBO traffic. The biggest disadvantage is the necessity of a monitor function, which introduces a critical component.

7.2 Fibre Distributed Data Interface (FDDI)

7.2.1 Introduction to FDDI

An FDDI network provides a bitrate of 100 Mbit/s over an optical fibre medium. The FDDI protocol is based on the IEEE 802.5 token ring standard, but provides enhanced services. In [20] – [23] the protocol is discussed in detail. Here, a short description will be given.

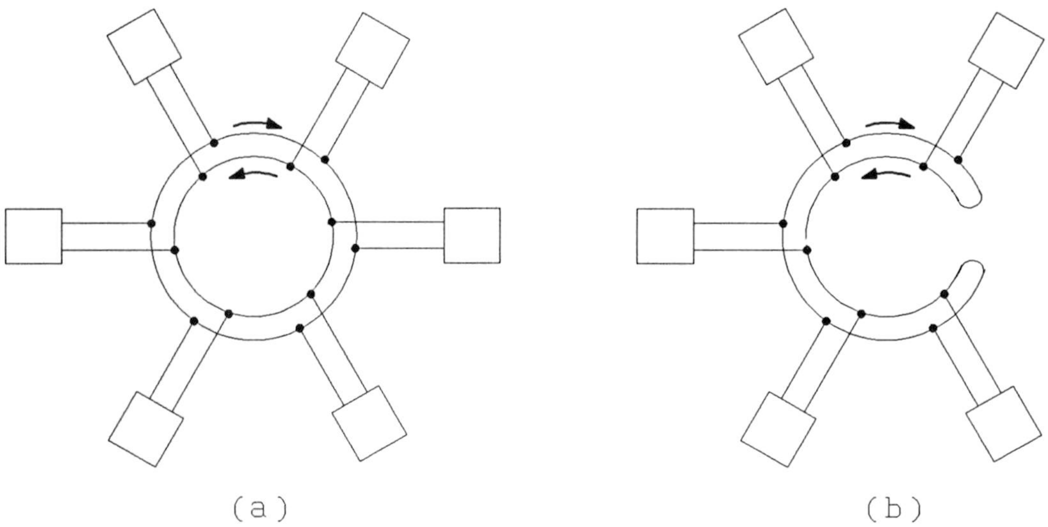

Figure 13 : (a) FDDI is built up of two rings with opposite traffic streams.
(b) In case of failure of one ring on the same point, both rings can be joined to form one long ring.

The wiring of FDDI consists of two fibre rings. One is transmitting clockwise, the other one counter clockwise. See figure 13.a. If one of the fibres breaks the other one can be used as a reserve. If both fibres break at the same point the two rings can be combined to form one ring, which is twice as long. See figure 13.b.

Within FDDI the transported information frames have no fixed length. By nature of the clocking, frames are limited to 4500 octets maximum. Multiple frames may however be transmitted on the same access opportunity.

7.2.2 Classes of stations

Two classes of stations and a concentrator are specified for use on an FDDI ring.

A class A station has two ring connections. It may be attached directly to the ring or indirectly via a concentrator. One of the connections may be in each of the counter rotating rings, or both may be in the same ring. A class A station may have optical bypass switches to remove it from both of the rings, and also healing them if the station is powered down.

A class B station may only be attached to the ring via a concentrator.

A concentrator is used to connect class B (or class A) stations into either of the two rings. It has the capability to bypass any failing class B station, thus healing the ring. It may also have optical bypass switches.

7.2.3 Basic concept of a FDDI token ring network

The basic concept of a ring is that each station repeats the frame it receives, to its downstream neighbour. If the destination address of the frame matches the stations own address the frame is copied into a local buffer for further processing. The frame is placed back on the ring and marked for successful or unsuccessful transmission. The frame propagates around the ring to the station, which placed it originally on the ring. The transmitting station determines the success of the transmission. This station is responsible for removing all the frames from the ring, which it has placed on the ring. This latter process is called stripping.

If a station has a frame to transmit it may only do so after a token has been captured. A token is a special sequence which indicates that the medium is available for use.
Priority requirements necessary to assure proper handling of frames are implemented in the rules of token capture. According to this rules, if this station is not allowed to capture the token, it must repeat this token to the next station. Having captured the token and removed it from the ring, the station is allowed to transmit one frame or diverse frames. When this is done it issues a new token as a notification that the medium is available for use by another station. This in contrast to the 802.5 token ring protocol, which allows to generate a new token only after the transmitted frame has travelled around the complete ring and comes back to the station. So several frames can propagate around the ring at the same time.

7.2.4 The Time Token Rotation protocol

FDDI uses a Timed Token Rotation (TTR) protocol to control access to the medium. Under this protocol each station measures the time, which has elapsed since a token was last received. The initialisation procedures establish the Target Token Rotation Time (TTRT) as that of the lowest bidding station.

Two classes of service are defined. The first called synchronous, allows capture of a token whenever the station has synchronous frames queued for transmission. The protocol guarantees that the maximum token round trip time remains less than 2 * TTRT. For this reason this FDDI service is well suited for the transmission of CBO traffic because guarantees are provided of the throughput and of the access delay.

The second class "asynchronous", allows only the capture of a token when the last time a token was received has not exceeded the TTRT. Whenever the actual TTR value of the station exceeds the TTRT, the token is late for roundtrip. In this case, the station is only allowed to transmit synchronous traffic. If the TTR value is less than the TTRT the station is allowed to transmit asynchronous traffic until the THT (Token Holding Timer) expires. Multiple levels of priorities for the use of asynchronous bandwidth can also be assigned.

7.2.5 FDDI-II

Beside the basic FDDI service a circuit-switched mode of operation, referred to as FDDI-II has been specified, which allocates bandwidth of the FDDI to circuit-switched data in increments of 6,144 Mbit/s isochronous channels. Up to 16 isochronous channels may be assigned using a maximum of 96,304 Mbit/s of bandwidth. Each of these isochronous channels offers a full duplex data highway which may in turn be reallocated into three 2,048 or four 1,536 Mbit/s data highways, meeting requirements of the European and North American phone system respectively. A residual token channel of 1 Mbit/s capacity remains, even when all 16 isochronous channels may be dynamically assigned and deassigned on a real time basis, with the bandwidth of any not assigned to the token channel.
FDDI-II is initialised identically to the basic FDDI and is fully interoperable with it, prior to the assignment of any isochronous channels. The presence of any non FDDI-II capable stations in a ring prevents the assignment of any isochronous channels and thus the activation of the FDDI-II mode of operation.
It is clear that this mode of operation cannot be used by the GBS's of the WOCS because they average outbound CBO traffic for every GBS is about 55 kbit/s. This figure can easily be calculated from the values given in section 6.2.5.

7.3 Distributed Queue Dual Bus (DQDB)

7.3.1 Introduction to DQDB

The IEEE Standards Committee has adopted the recommendations by the IEEE 802.6 Working Group to use the Distributed Queue Dual Bus (DQDB) architecture as the building unit for its Metropolitan Area Network. The network will cover campus-wide areas and it will ultimately integrate data, voice and video on a single high speed network.

The DQDB network consists of two highspeed unidirectional buses carrying information in opposite directions. The transmission speed of the buses will range from 44 Mbit/s to 155 Mbit/s speeds. The network nodes are distributed along the two buses attached to both of them and with the capability to transmit (resp. receive) information to (resp. from) both buses as shown in figure 14.
A detailed description of DQDB, which was originally called " The Queued Packet and Synchronous circuit eXchange (QPSX)" is given in [24] and [25].

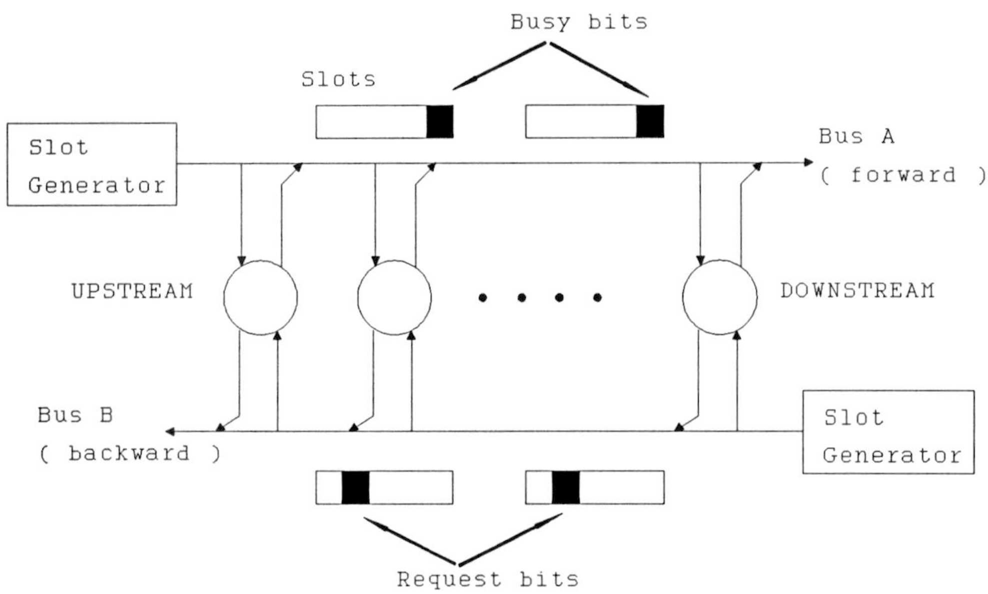

Figure 14 : The DQDB protocol

7.3.2 The medium access control protocol

The medium access control (MAC) protocol used in DQDB is an extension of a slotted bus with the greedy protocol, with the addition of a distributed reservation mechanism. According to the greedy protocol (or 1- persistent) a node is allowed to use the total bandwidth, left unused by its upstream nodes. This introduces directly the main drawback of the DQDB protocol. The protocol provides an unfair service biased in favour

of the upstream stations. To this latter point we will come back later on.
According to the DQDB MAC protocol, a node explicitly requests bandwidth from its upstream node, in contrast to the slotted bus, where no control is imposed and each node simply waits for bandwidth to become available.
Empty slots of fixed duration (the same in both buses) are generated by the Slots Generators at the leading end of each bus and filled with information by nodes tapped to the bus. Each slot is 53 octets long with 5 octets designated as the header of the slot, while the remaining 48 octets are used for information transmission. This slot format makes the DQDB network compatible with the Asynchronous Transfer Mode (ATM) architecture. ATM will be described in the next section. Messages have to be partitioned first in segments big enough to fit in a slot, before they are transmitted. The segments are reassembled to the original messages at the destination nodes.

With DQDB a node wanting to transmit a segment on one bus (say bus A), first has to queue a request to be written on the other bus (bus B). Only one outstanding request is allowed per bus node. To facilitate the discussion, nodes closer to the Slot Generator on one bus are defined to be upstream nodes. Downstream nodes are defined accordingly. A current state record is kept in every node which holds the number of segments awaiting access to the bus. When a node has a segment for transmission it uses this count to determine its position in the distributed queue.

7.3.3 The Basic Distributed Queuing Algorithm

The basic Distributed Queuing Algorithm uses two control bits, BUSY and request (REQ), to control access to the slots on the forward bus. An identical, but independent arrangement applies for access to the opposite bus.
The BUSY control bit is a marker at the head of each slot which indicates whether the slot is full and hence not available for access. The REQ control bit is the crux of the queuing mechanism and is used to signal when a segment has queued.
When a node has a segment for transmission on the forward bus it will issue a single REQ bit on the backward bus. This REQ bit serves as an

indicator to the upstream nodes that an additional segment is now queued for access.

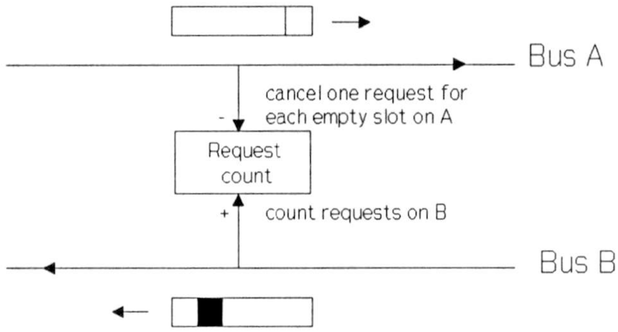

Figure 15 : Distributed queuing (Bus A). Node not queued to send.

Each node keeps track of the number of segments queued downstream from itself by counting the REQ bits as they pass on the backward bus. See figure 15. For each REQ passing on the backward bus, the request (RQ) counter is incremented. One REQ in the RQ counter is cancelled each time an empty slot passes on the forward bus. This is done since the empty segment, which passes the node will be used by one of the downstream queued segments. Hence we see that with these two actions the RQ counter keeps a precise record of the number of segments queued downstream.
When a node has a segment for access to the bus it transfers the current value of the RQ count to its second counter, the countdown (CD) counter.

This action loads the CD count with the number of downstream segments queued ahead of it. This along with the sending of the REQ for the node's segment, effectively places the segment in the distributed queue.
To ensure that the segments registered in the CD counter gain access before the newly queued segment in the given node, the CD counter is decremented for every empty slot, which passes on the forward bus. This operation is shown in figure 16. The given node can then transmit its segment in the first empty slot after the CD count reaches zero. The claiming of the first free slot ensures that no downstream segment, which queued after the given segment, can push in and access out of order.

During the time the node is waiting for access for its segment, any new REQ's received from the backward bus are added to the RQ counter, as shown in figure 16.

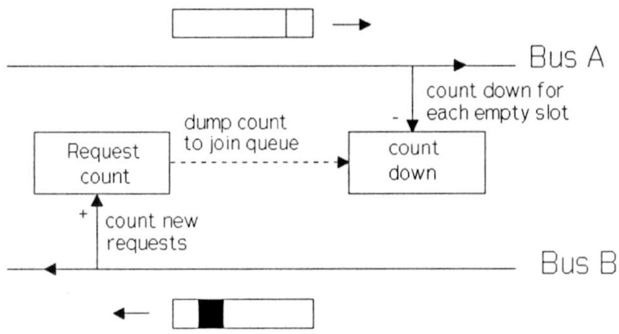

Figure 16 : Distributed queuing (Bus A). Node queued to send.

7.3.4 Priority in DQDB

The DQDB protocol also provides several levels of access priorities. For each level of priority separate distributed queues are operated. The operation of the separate queues consists of the use of a separate REQ bit on the backward bus for each level of priority, and separate RQ counters for each priority level. The counters operate much as before except that account must be taken of REQs at higher levels.
The operation of the CD counter is also slightly different. A CD count operating at a particular priority level will, in addition to counting down the passing empty segments, be incremented for REQ's received at higher priority levels. This allows the higher priority segments to claim access ahead of already queued segments.

7.3.5 Drawback of DQDB

As was mentioned in section 7.3.2 the main drawback of the DQDB protocol is its position dependent characteristics. Stations closer to the Slot Generator have a lower delay than stations further away. For this reason the protocol has been modified several times from the first description in [25].

In [26] a Bandwidth Balancing mechanism is suggested, and in [27] a Symmetric Bandwidth Balancing scheme is described to overcome the position dependant problem. Both of these mechanisms improve the fairness of the DQDB protocol but a position dependant delay still remains.

7.4 The Asynchronous Transfer Mode (ATM)

The Asynchronous Transfer Mode is the switching and multiplexing technic chosen by CCITT for the broadband access to ISDN. In contrast to the narrow band ISDN which can only support fixed rate services of 64 kbit/s, ATM offers a bitrate independent transport. In ATM a mixture of narrowband services as for example voice traffic and packet data, and broadband services as for example videoconferencing and broadcast quality video is possible.
A detailed description of ATM can be found in [28] and [29].

ATM achieves the flexible transport mechanism by multiplexing and switching of small cells. For this data from the sources are split into small cells of 53 octets including a 5 octets header.
The basic features of ATM can best be explained on the basis of the two fundamental elements of transmission, i.e.:

- the multiplexing function
- the switching function

The ATM transmission principle consists in combining these two fundamental elements. The network creates a flexible transport infrastructure, which is application independent.

7.4.1 ATM multiplex function

Successive time slots of constant length - which is a characteristic of ATM! - are occupied by information blocks, the above mentioned cells. Each cell consist of a header and an information field. The virtual channel (VC) to which the cell belongs is identified by a virtual channel identifier (VCI) contained in the header, which is assigned to sections in a connection.

This identifier is the counterpart of the time-slot number in the synchronous time division multiplex (STM). In contrast to STM, ATM allows time slots occupied by a connection, not to occur at the same distance. The distance of these time slots can depend both on the momentary availability of free time slots, and - frequently - on the requirements of the signal source of the connection. This illustrates the bit-rate independence and explains the designation "asynchronous".

7.4.2 ATM switching function

The switching function is based on the ATM multiplex principle. The cells belonging to a connection are switched from one of the input lines to one of the output lines of a switching node by evaluating the VC identifier in the header.
This involves the following steps:

- Translating the VC identifier of the input line into the VC identifier of the respective output line, determined for each call establishment control procedure.
- Storing cells provided with a new header identifier in a queue leading to the respective output line.
- Transmitting the cells in a time slot of the output line corresponding to the queue mechanism.

In comparison with the STM technique, the translation of the VC identifier corresponds to the time-slot transformation. The translation tables required for this are obtained as with STM, with "out-band" signalling at call establishment. This connection oriented mode of operation which ATM and STM have in common, together with the constant cell-length, distinguishes ATM from other well-known packet oriented techniques, eg datagrams.

7.5 Evaluation of the LAN's

From the example presented in the appendix, it can be calculated that every group is able to produces a maximum inbound traffic of about 280 kbit/s. If there are ten groups the network has to transport 2,8 Mbit/s.

This can easily be achieved with all three low speed LAN's.
The CSMA/CD network has the disadvantage of a statistical allocation of the bandwidth. So no guarantee can be given for the maximum transfer delay for DBO traffic. Several protocols, for example [30] - [32], have been proposed for a CSMA/CD to overcome this problem .
The Token ring network has the disadvantage of the critical monitor function.
The Token bus LAN seems to have little disadvantages and can easily fulfil the expected demand for transmission capacity with low delay for CBO traffic. A common disadvantage of a low speed LAN is that the capacity is not big enough to transport future broadband data services.

To make the system applicable for future use there are two possible approaches.

The first one is to make a low speed LAN for the WOCS and a separate highspeed LAN for the broadband services. Through a bridge the two networks can be coupled. The advantage of this method is, its lower price because the nodes of high speed LAN's are much more expensive than the nodes of LOW speed LAN's. The disadvantage is, the extra wiring, which is necessary, because two LAN's have to be installed. Another point is if the number of groups is much higher than ten, the capacity of the low speed LAN will soon be too small.

The second approach is to install only a high speed LAN, and connect every GBS to this LAN. File servers for instance, which require a higher capacity than the 1 Mbit/s of the radio link can directly be connected to the LAN. The disadvantage of this approach are the high costs for the GBS's. The big advantage of this approach is that the systems is likely to be suited to fulfil future demands of high capacity.
For this last reason a highspeed LAN is chosen as the backbone network for the WOCS.

FDDI has already been defined in the early 1980's. At the moment a lot of products, which satisfy the FDDI standard are available. This of course is a big advantage. The FDDI LAN could satisfies the backbone transmission requirements of WOCS, even for future growth of the system with broadband services.

The DQDB system has not fully been worked out yet. Because this system is recommended by the CCITT, it may be expected to become the standard MAN for the future.

ATM does not seem to be appropriate for the WOCS because it is more a worldwide backend than the desired backbone network. Important is the interoperability of the chosen LAN with the ATM system.
For this latter point, DQDB has an advantage over FDDI because a DQDB interface in ATM has already been planned, although it has not yet been defined.

Because DQDB is expected to be the standard MAN for the future and has an (planned) interface to ATM, this system is chosen as the backbone network for the WOCS.

8 THE GROUP BASE STATION MODEL

In figure 17 a model of the internal structure of the Group Base Station is depicted.

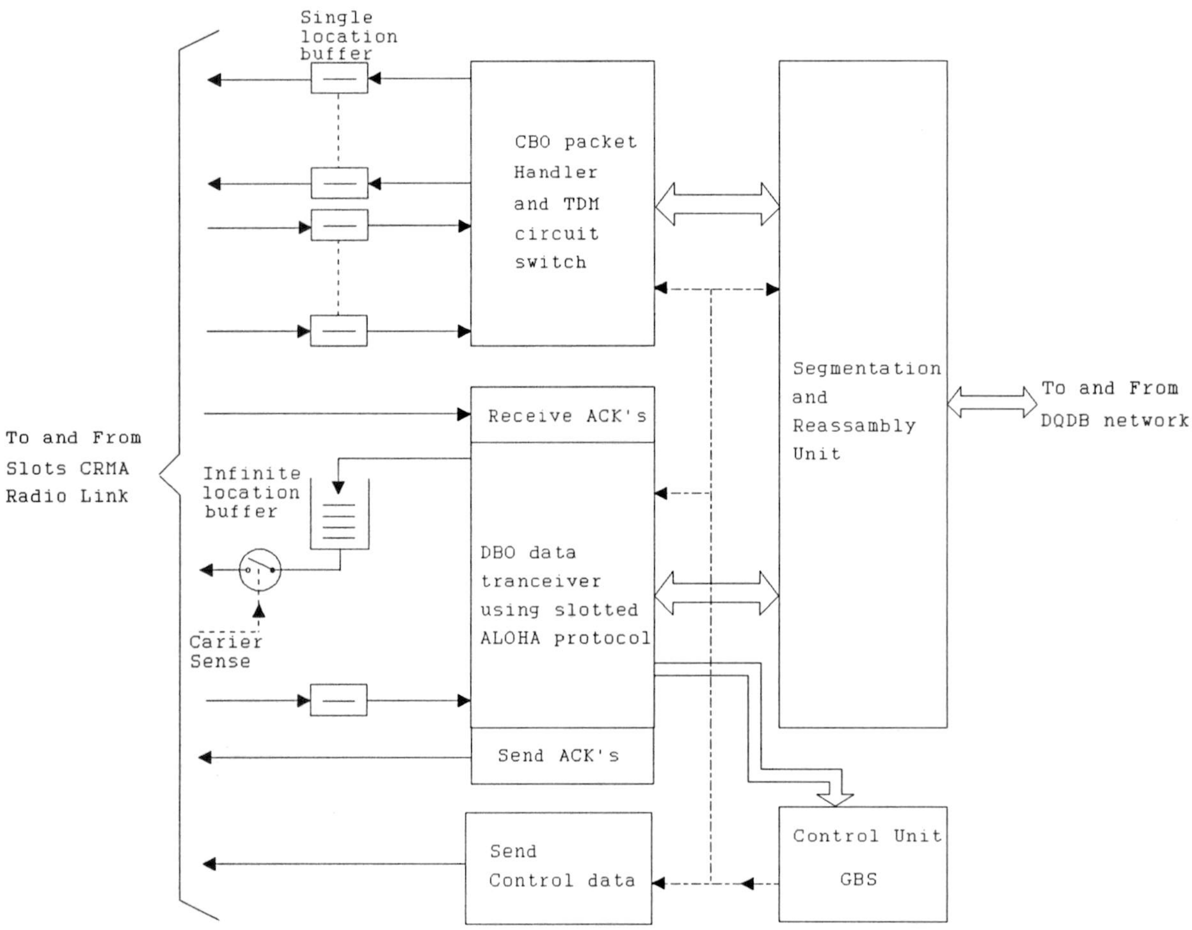

Figure 17 : Internal structure of the Group Base Station.

Before transmitting over the DQDB network, all packets have to be segmented in units of 48 octets with a header of 5 octets. When DQDB packets have been received from the network the header must be removed and the original packets have to be reassembled. All this is done by the Segmentation and Reassembly unit (SRU).

With the CRMA protocol three data types are distinguished on the radio link, the CBO, the DBO and the CONTROL data packet.

CBO packets are all transferred in a predetermined slot. CBO Packets from the SRU are disposed of their destination header and switched in the assigned timeslot by means of a TDM circuit switch. CBO packets which travel the opposite direction are picked from the radio link. Before sending to the SRU the destination header is added to every packet.
To overcome the time between sending or transmitting and processing the CBO packets they are shortly buffered in a single location buffer.

DBO packets from the SRU are stored in an infinite location buffer before transmitting. This buffer works according to the FIFO principle.
Before a DBO packet can be transmitted no carrier may have been sensed at the beginning of the chosen timeslot. Before trying to transmit another DBO packet, first a positive acknowledgement from the destination has to be received.
Incoming DBO packets from the radio link are shortly buffered, and controlled for correct receiving. If the transmission had been successful an acknowledgement is sent to the source. Hereafter the packet is transmitted to the SRU.

CONTROL packets are assembled in the Control Unit GBS (CUGBS) and then transmitted in the predetermined slots.

The "CUGBS" controls the working of all the items of the GBS.
For instance, the slots for the CBO circuits are assigned, keeping account with the maximum allowable blocking probability. It determines the packet-(re)transmitting probabilities of the DBO packets, after the load of the link has been sensed. It also assembles the CONTROL packets and transmits them in predetermined slots. Next to this the priority levels for the various DQDB packets are told to the SRU.

Terminals of the group are also able to send control info like for instance "request circuit" by a CBO terminal. This can only be done in DBO packets. This information is next to the state of the radio link transmitted to the CUGBS by the DBO data transceiver.

9 THE MANAGEMENT SUBSYSTEM

In figure 5 the management subsystem is shown as part of the complete WOCS. It is considered to control all other subsystems. It controls the access to the CRMA radio link, the working of the GBS and the access to the DQDB network.

9.1 Controlling the access to the CRMA radiolink

9.1.1 Control parameters

After defining and installing the system the number of terminals per group, the average traffic amount and the link capacity are fixed, and cannot be dynamically changed by the management subsystem.
On the other hand if we look at the CRMA protocol there are several aspects, which can be controlled to gain an optimum system output. These aspects are :

1) The maximum number of reserved slots for CBO data traffic can be limited, in favour of the available capacity for DBO data, by increasing the blocking probability.
   With a certain number of CBO terminals which each produce an average amount of traffic, and a maximum allowable blocking probability, we can calculate the demanded number of the assigned CBO slots. This can be done by using the recursive algorithm of the Engset model which is given in [3].
2) Changing the probability of transmitting new DBO packets p_o or the probability of a retransmission of a back-locked DBO packet p_r the DBO data transfer can be optimised.
   Next to the slots, which are directly assigned for the DBO data, the DBO sources may transmit in the periods of silence between the talkspurt periods of the speech traffic.
   At a specific moment the capacity for the DBO data can be considered as the sum of the directly assigned slots and the "silent" speech slots. Using the slotted ALOHA access method a maximum of 36% of this capacity can effectively be used. This maximum throughput can only be achieved in case of a stable channel, which is explained in the following subsection

9.1.2 Stability of the slotted ALOHA protocol

In [33] stability considerations are made for the slotted ALOHA protocol. A short extraction will be given here.

We consider a slotted ALOHA channel with a user population consisting of M users. Each such user can be in one of two states: blocked or thinking. In the thinking state, a user generates and transmits a new packet in a timeslot with probability σ. A packet which had a channel collision and is waiting for retransmission is said to be backlogged. From the time a user generates a packet until that packet is successfully received, the user is blocked in the sense that he cannot generate (or accept from his input source) a new packet for retransmission.

Let N^t be a random variable (called channel backlog) representing the total number of backlogged packets at time t. If S^t is the channel input rate at time t then $S^t = (M - N^t)\sigma$.

If we give the number of backlogged packets n as function of the channel input rate S there result an equilibrium contour in the (n,S) plane which is shown in figure 18. The shape of this contour can be altered by changing the retransmission probability p_r.
A possible operating point of the channel can be found by drawing the channel load line given by the equation:

$$S = (M - n)\sigma \qquad (2)$$

A possible operating point must lie on an intersecting point of the equilibrium contour and the channel load line.

In a stable channel the equilibrium point determines the steady-state throughput-delay performance of the channel over an infinite time horizon. On the other hand, an unstable channel exhibits "bistable" behaviour; the throughput-delay performance given by the channel operating point is achievable only for a finite time period before the channel drifts towards the channel saturation point.

The slotted ALOHA channel is said to be stable if its load line intersects the equilibrium contour in exactly one place. Otherwise the channel is said to be unstable.

Examples of stable and unstable channels are shown in figure 18. The arrows on the channel load line indicate the direction of drift of N^t

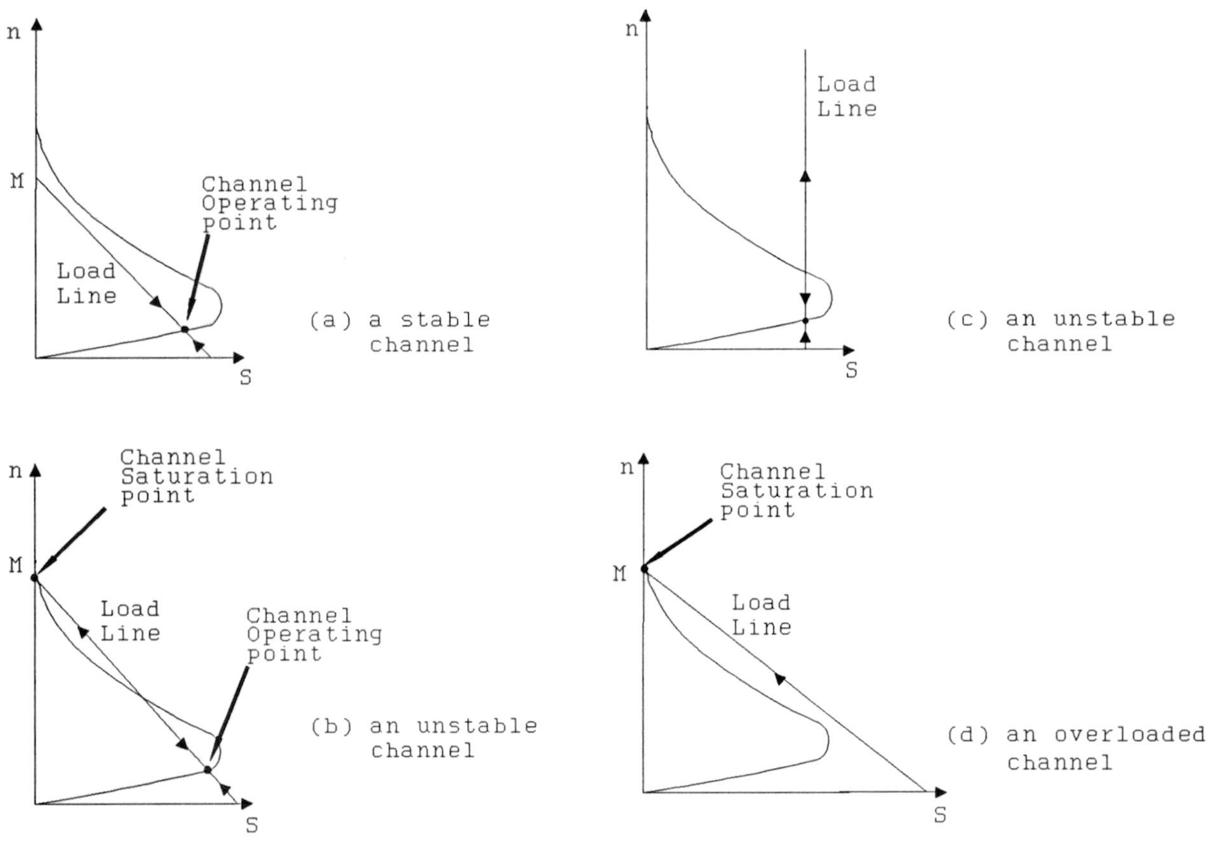

Figure 18 : Stable and unstable channels with slotted ALOHA protocol.

In figure 18.a the channel load line of a stable channel is shown. If M is finite a stable channel can always be achieved by using a sufficient small p_r. In this way the equilibrium contour is stretched out. Of course the packet delay will increase when p_r is decreased.

In figure 18.b an unstable channel is shown. The channel operating point is only a local stable point. Another equilibrium point is the channel saturation point. This point has a huge backlog and virtually zero throughput. This point is as a global stable point.

In figure 18.c the channel load line of an infinite population model is given. This is an unstable channel since $n = \infty$ is a stable equilibrium point.

The channel load line shown in figure 18.d is stable according to the stability definition. However, the globally stable equilibrium point in this case is the channel saturation point. This represents an "overloaded" channel.

In [34] several dynamic control procedures are given, which optimise the channel performance. With these procedures a stable channel with a throughput of about 36% and a relative low delay can be realised.

9.2 Controlling the access to the DQDB network

Higher loads in the DQDB network results in a higher position dependant delay. This effect also increases when the distance between the nodes is bigger. In [25] and [35] - [37] performance aspects for the DQDB can be found, under several loads and different distances between the nodes.
The WOCS is supposed to cover an area of at maximum a few kilometres. For this reason the position dependant characteristics are not very dominant. According to section 7.5, the total traffic capacity demand by the GBS's are very small in comparison with the network capacity. Thus only if equipment is directly attached to the network, which requires a large capacity, the network will suffer from the effects of the higher loads. While the characteristics of this equipment are not known, these position dependant aspects of the DQDB network will be neglected.

Because the time delay of the CBO traffic has to be as small as possible, this type of traffic must have a higher priority than the DBO traffic. This is the only control aspect that can be said about the DQDB network.

9.3 Controlling the Group Base Station

The several components of the GBS are, with the state-of-art technology of today, considered to give no restrictions on the system capacity. This means there is no internal blocking, and the internal time delay can be neglected.

9.4 Location of the management system

Because of performance and reliability considerations the management subsystem can best be employed in a distributed version. The most proper location for this is the CUGBS which is explained in the former chapter. In this element the CRMA group radio link can be controlled. By exchanging CONTROL information between the GBS's of the present groups the DQDB network can be controlled.
If one of the GBS's fails, only one group is isolated from the WOCS. The DQDB network itself is not influenced by the failure, because the failing GBS can easily be switched of the buses.

10 CONCLUSIONS AND RECOMMENDATIONS

A global study of a Wireless Office Communication System (WOCS) is given in this report.

Groups of users can transport various traffic types over a half duplex radio link to an interface on a backbone network. Each group is built up of a mixture of users with a constant and variable bandwidth demand. Users with different bitrates can efficiently be serviced, with a low loss probability.

The backbone network is a high speed Distributed Queue Dual Bus (DQDB) metropolitan area network, and makes communication between users of different groups possible. On top of this, the network can deliver a transport service for highspeed equipment, which is directly attached to its buses.

All users of a group and the interface to the network, which is called the Group Base Station (GBS), have access to the half duplex radio link. The access to this link is done according to the new proposed Circuit Reservation Multiple Access (CRMA) protocol. This is a slotted protocol in which users with a constant bandwidth demand or Continuous Bitstream Oriented (CBO) users, are assigned one or more slots for the duration of the connection. Users with a variable bandwidth demand are called Discontinuous Bitstream Oriented (DBO) users. They have to contend for slots not assigned to CBO users, or left unused by the CBO users in periods of silence, according to the slotted ALOHA protocol.

To be able to realise the WOCS, all its subsystems have to be subject of further investigation.

A lot of research is done worldwide to the DQDB network. Recommended is to keep up with the developments about this subject.

For the physical and signal characteristics of the receiver/transmitter on the radio link, standard equipment and access methods are proposed.

The CRMA protocol has not been applied or published yet. This is why a thorough research of this protocol is proposed. Recommended items for investigation about this protocol are:

- performance analysis
- spectrum efficiency
- influence of physical characteristics of the transport medium
- stability analysis
- dynamic load control

When all foregoing items have been worked out, a more detailed design of the GBS can be made. This includes the distributed management element, which is placed in this GBS.

Finally the integration of all above mentioned subsystems is necessary to finish the detailed design of the WOCS.

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